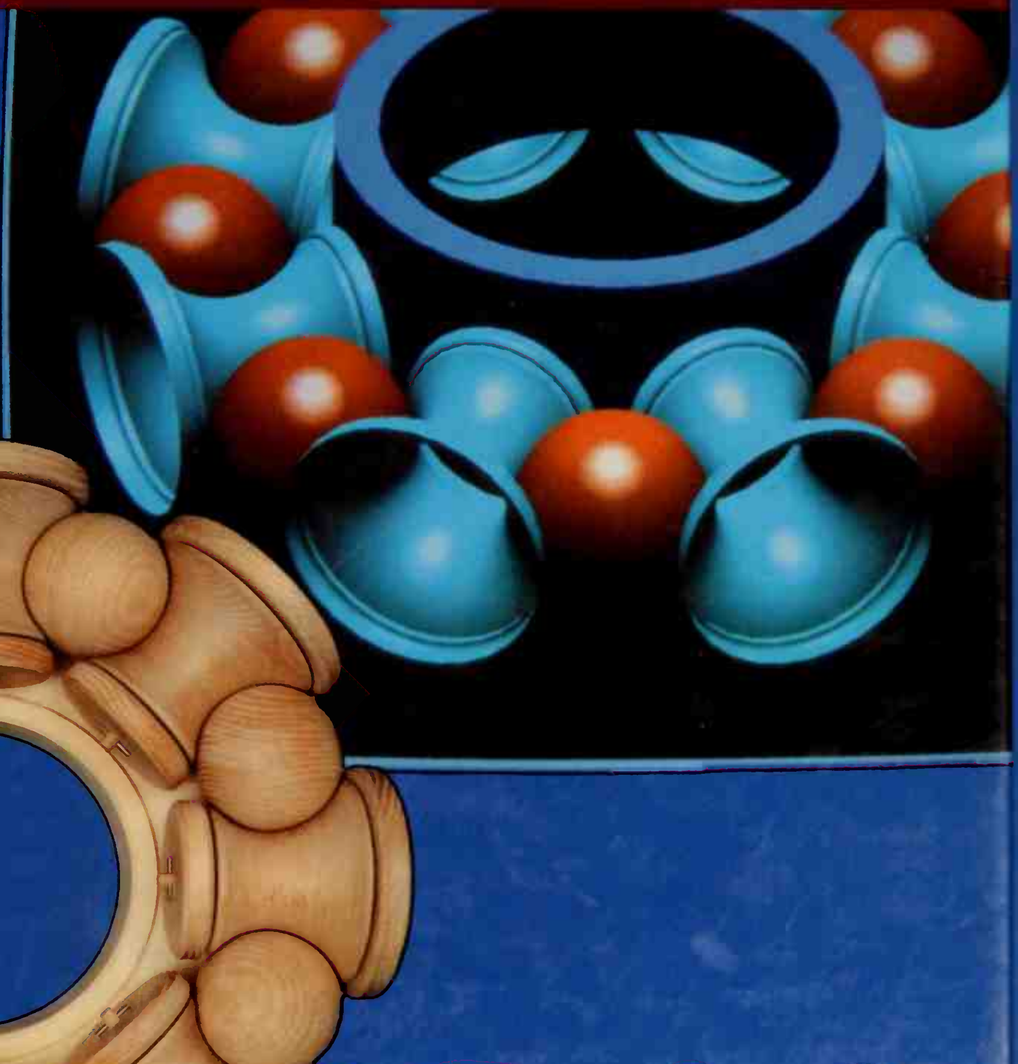
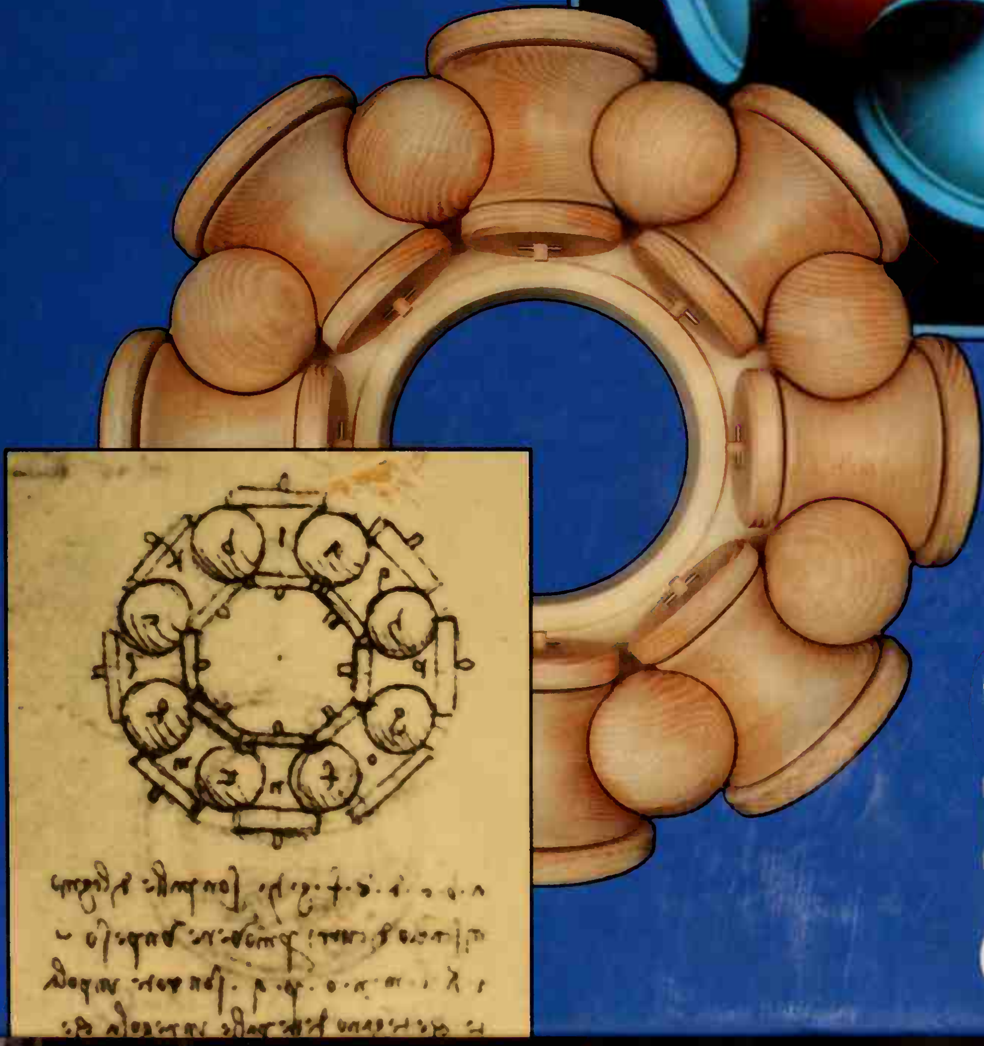
TECHNICAL DRAWING

FUNDAMENTALS · CAD · DESIGN

Second Edition





Goetsch
Nelson
Chalk

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Second Edition

David L. Goetsch
John A. Nelson
William S. Chalk

Delmar Publishers Inc.®

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DEDICATION

From David L. Goetsch . . . .
. . . . To Savannah Day, Toby, Dustin, and Clifford Jay

From John A. Nelson . . . .
. . . . To my wife, Joyce

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Ball-bearing model based on a drawing by Leonardo da Vinci. Photo: Brian Merrett. Collection of The Montreal Museum of Fine Arts.

Detail from Leonardo da Vinci Madrid MS I, f.20v, courtesy of Biblioteca Nacional, Madrid.

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Preface

Purposes *Technical Drawing* is intended for use in such courses as basic and advanced technical drawing, basic and advanced drafting, engineering graphics, descriptive geometry, mechanical drafting, machine drafting, tool and die design and drafting, and manufacturing drafting. It is appropriate for those courses offered in comprehensive high schools, area vocational schools, technical schools, community colleges, trade and technical schools, and at the freshman and sophomore levels in universities.

Prerequisites There are no prerequisites. The text begins at the most basic level and moves step-by-step to the advanced levels. It is as well suited for students who have had no previous experience with technical drawing as it is for students with a great deal of prior experience.

Innovations An advantage of the text is that it has evolved during a time when the world of technical drawing and design is undergoing a period of major transition from manual to automated techniques. Computer-aided drafting (CAD) is slowly but steadily gaining a foothold. This transitional period will last at least until the turn of the century, with CAD gaining greater acceptance every year.

This transition has created a need for a major text that deals with both traditional knowledge and skills and CAD-related knowledge and skills. *Technical Drawing* fills this need. Even when the world of technical drawing and design has become fully automated, drafters and designers will still need to know the traditional basics and technical drawing fundamentals. These basic factors will not change. Therefore, the traditional fundamentals are treated in depth in this text.

What is changing, and will continue to change, is the way that drafters and designers prepare technical drawings. For this reason, CAD is also treated in depth, and many of the drawings and illustrations were prepared on various CAD systems. Along with this treatment, *Technical Drawing* offers students and teachers a special blend of the manual and automated knowledge and techniques that are needed now through the turn of the century and even beyond.

Another advantage of the text is that it was written after the latest update of the most frequently used drafting standard—ANSI Y14.5. This standard was updated with major revisions in 1982, and is now ANSI Y14.5M—1982. Consequently, all dimensioning and tolerancing material in *Technical Drawing* is based on this most recent edition of the standard.

New Features in the 2nd Edition

- Four new chapters, including *Pipe Drafting*, *Electronic Drafting* and *Charts and Graphs*.
- Brand new *design chapter* introduces students to the unique "design process" they will need to succeed in industry.
- Completely new chapters in *geometric dimensioning and tolerancing* and *dimensioning and notation* have been commented upon as "the best presentation of dimensioning information in *any* currently available text."
- Over 400 new drawing problems, most of which are classified in the "challenging to very difficult" range, have been classroom tested.
- Rewritten, in-depth *Descriptive Geometry* chapter will give students a solid foundation in this subject.
- CAD chapters are fully updated to reflect the very latest in microCAD technology and are based on AutoCAD®, VersaCAD®, and CADKEY® systems.
- Much new art is CAD-generated to familiarize your students with the style of machine-drawn art.
- Computer Integrated Manufacturing (CIM) information is fully integrated into the *Shop Processes* chapter.
- Technical screening done on existing art and problems to set a high standard for the 2nd Edition.

Tested and Proven Features

- Step-by-step explanations of drawing procedures and techniques.
- Written in language your students will understand; technical terms are defined as they are used.
- Unique blue and red color format depicts isometric views more clearly than "flat" black-and-white drawings; shaded effect is an excellent "depth" projector.
- Text and illustrations are located in *direct* relationship to each other.
- CAD techniques are integrated thoughout the text as well as in two fully dedicated chapters.
- "Real-world" techniques and drawings are highlighted throughout the text.
- Although the emphasis is on mechanical drafting, other pertinent drafting subjects are included for a comprehensive, well-rounded approach to technical drawing.

The Package

- Comprehensive *Textbook*.
- Comprehensive, up-to-date manual *Workbook*.
- All new *multi-function Workbook* with drawing problems that can be done manually or with CAD, via AutoCAD®, VersaCAD®, CADKEY®, or MicroStation®.
- *Instructor's Guide* with overhead transparency masters and complete course syllabus.
- *Solutions Manual* with solutions for selected problems from both the textbook and the manual workbook.

Acknowledgments The authors would like to acknowledge the efforts of many people without whose assistance this project would not have been completed. Special acknowledgment is made to Edward G. Hoffman, author of Chapter 20, "Shop Processes"; and Robert D. Smith, author of Appendix A, "Mechanical Drafting Mathematics." We thank Ray Adams, Dana Welch, Susan Wilkinson, and Ron Ryals for their assistance with illustrations. We thank Deborah M. Goetsch for her assistance with photography and typing. We thank Joyce Nelson for her assistance with typing.

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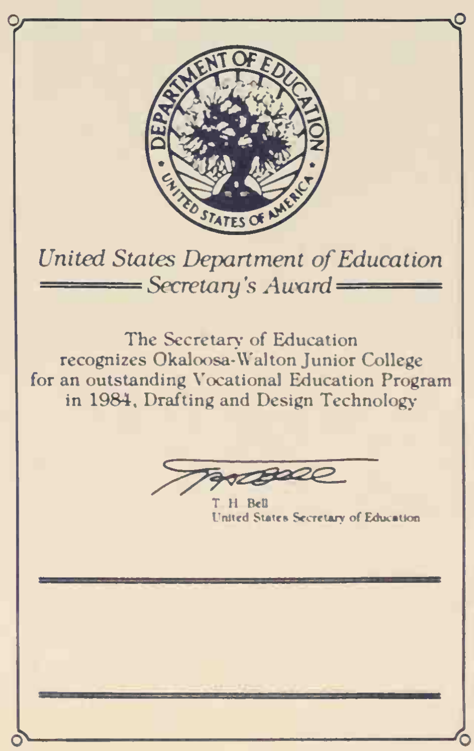

tered education full time after a successful career in design and drafting in the private sector where he spent more than eight years as a Senior Drafter and Designer for a subsidiary of Westinghouse Corporation. This is his 12th book.

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John A. Nelson

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Always interested in the practical applications of education, Professor Chalk has conducted a number of nation-wide design workshops for industry. He is a recipient of Western Electric's "Outstanding Instructor of the Year" award for 1968. In addition, Bill was the associate editor of *Design Graphics Journal* in 1967.

Professor Chalk holds a Master's degree in Mechanical Engineering from the University of Washington and has participated in design training workshops at Dartmouth College and Stanford University. He is the co-author of an engineering graphics text and workbook and is the author of an ASEE paper titled "A Realistic Approach to Tracking Engineering Design" (ASEE, Nov. 1984).

Professor Chalk's valuable contributions to *Technical Drawing*, 2nd Edition, include the new chapters "The Design Process" and "Charts and Graphs."

William S. Chalk

TECHNICAL DRAWING

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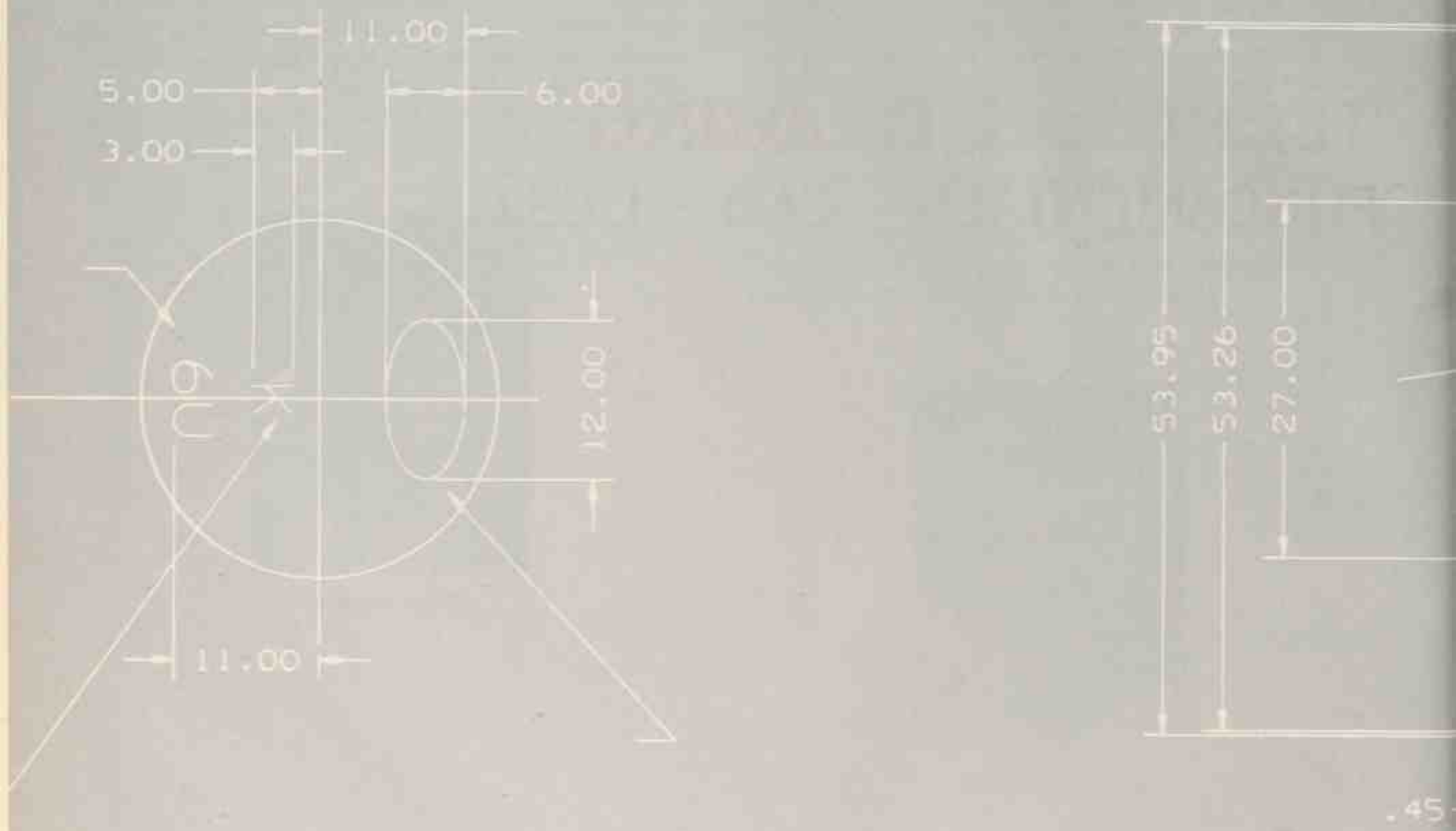
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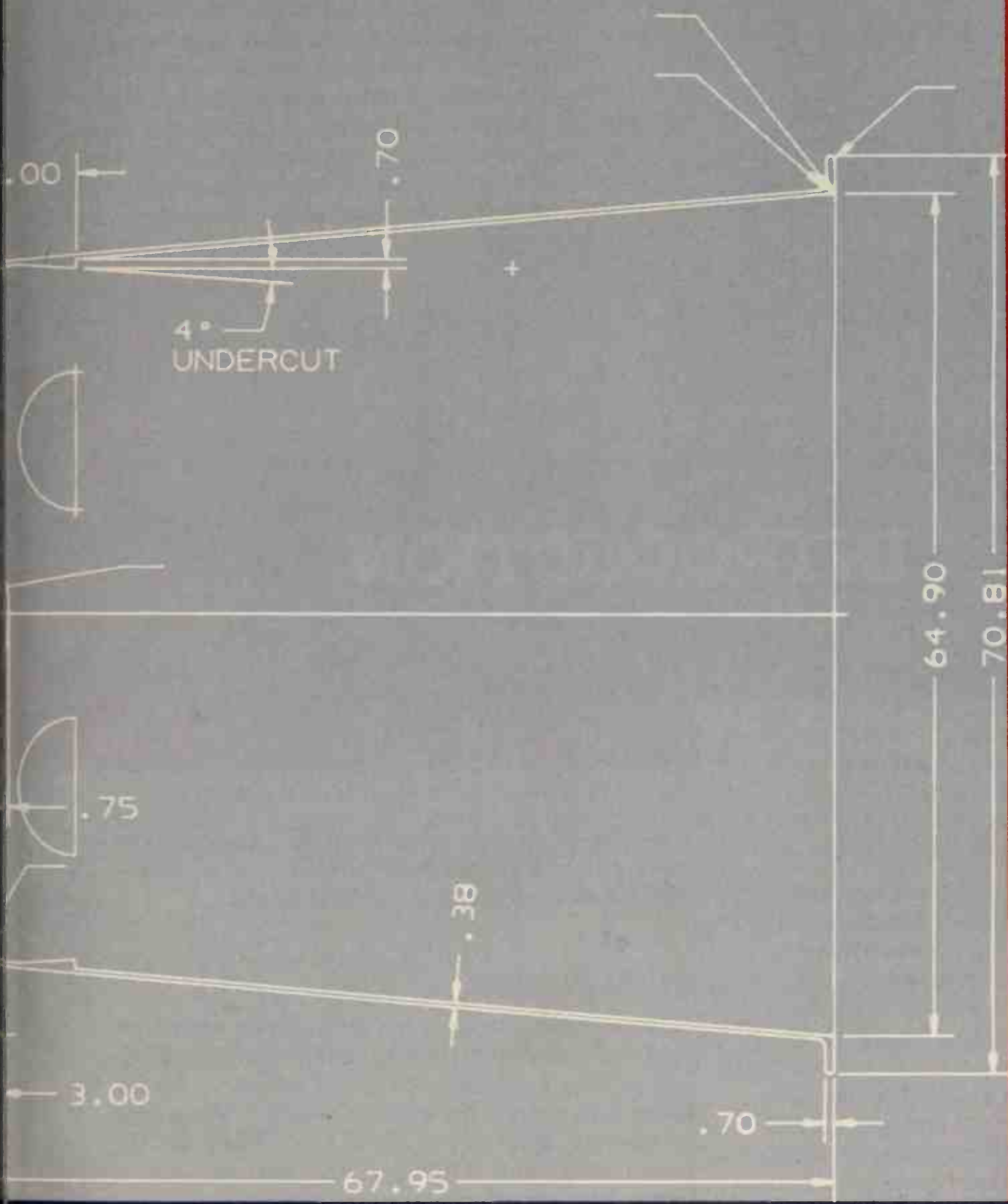
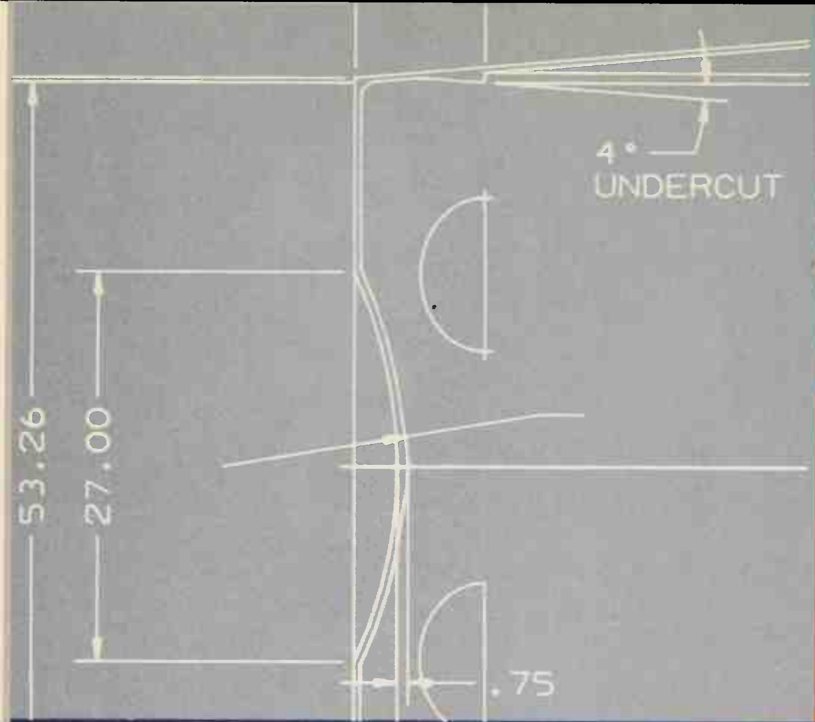
SECTION ONE

BASICS





This introduction to Technical Drawing and Design presents the concept of technical drawing and traces its evolution from primitive manual techniques to modern computer-aided drafting (CAD) techniques. Major topics covered include: drawings described; types of drawings; types of technical drawings, their purpose, applications, and regulation; and a checklist of what students of technical drawing and drafting should learn.

INTRODUCTION

Drawings Described

A *drawing* is a graphic representation of an idea, a concept or an entity which actually or potentially exists in life. The drawing itself is 1) a way of communicating all necessary information about an abstraction, such as an idea or a concept; or 2) a graphic representation of some real entity, such as a machine part, a house, or a tool, for example.

Drawing is one of the oldest forms of communication, dating back even farther than verbal communication. Cave dwellers painted drawings on the walls of their caves thousands of years before paper was invented. These crude drawings served as a means of communicating long before verbal communications had developed beyond the grunting stage. In later years, Egyptian hieroglyphics were a more advanced form of communicating through drawings.

The old adage "one picture is worth a thousand words" is still the basis of the need for technical drawings.

Types of Drawings

There are two basic types of drawings: artistic and technical. Some experts believe there are actually three types: the two mentioned and another type which combines these two. The third type is usually referred to as an illustration or rendering.

Artistic Drawings

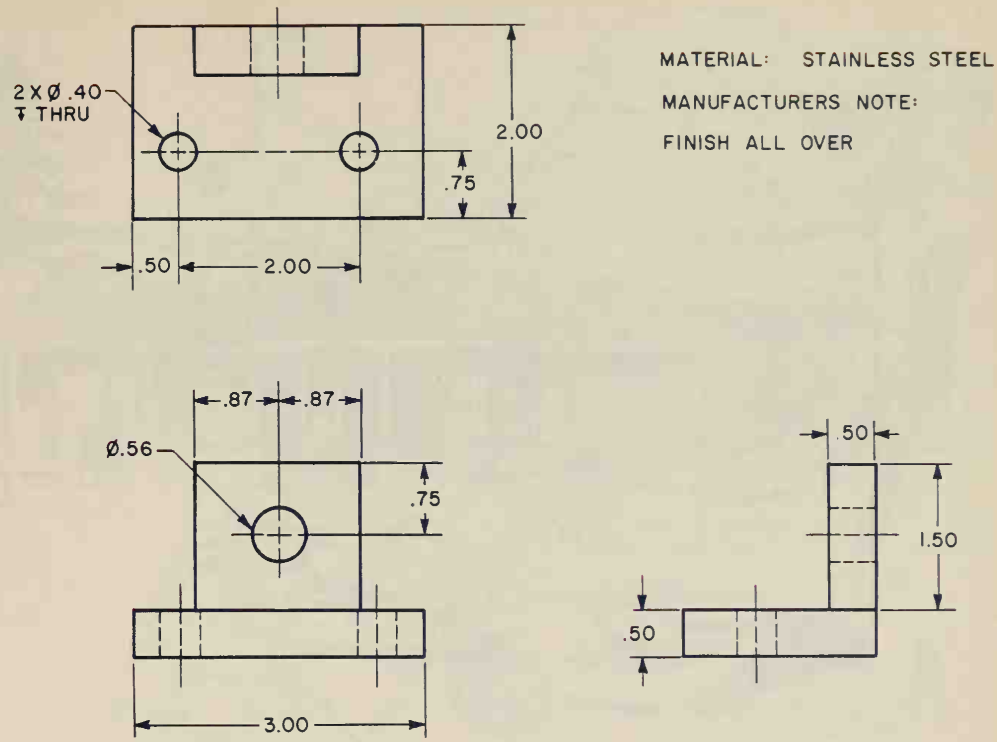
Artistic drawings range in scope from the most simple line drawings to the most famous paintings. Regardless of their complexity or status, artistic drawings are used to express the feelings, beliefs, philosophies or abstract ideas of the artist. This is why the lay person often finds it difficult to understand what is being communicated by a work of art.

In order to understand an artistic drawing, it is sometimes necessary to first understand the artist. Artists often take a subtle or abstract approach in communicating through their drawings. This gives rise to the various interpretations often associated with artistic drawings.

Technical Drawings

The technical drawing, on the other hand, is not subtle or abstract. It does not require an understanding of its creator; only an understanding of technical

Figure I-1 Technical drawing (mechanical)



drawings. A *technical drawing* is a means of clearly and concisely communicating all of the information necessary to transform an idea or a concept into reality. Therefore, a technical drawing often contains more than just a graphic representation of its subject. It aiso contains dimensions, notes, and specifications.

The mark of a good technical drawing is that it contains all of the information needed by individuals for converting the idea or concept into reality. The conversion process may involve manufacturing, assembly, construction, or fabrication. Regardless of the process involved, a good technical drawing allows the conversion process to proceed without having to ask designers or drafters for additional information or clarification.

Figures I-1 and I-2 contain samples of technical mechanical drawings which are used as guides by the people involved in various phases of manufactur-

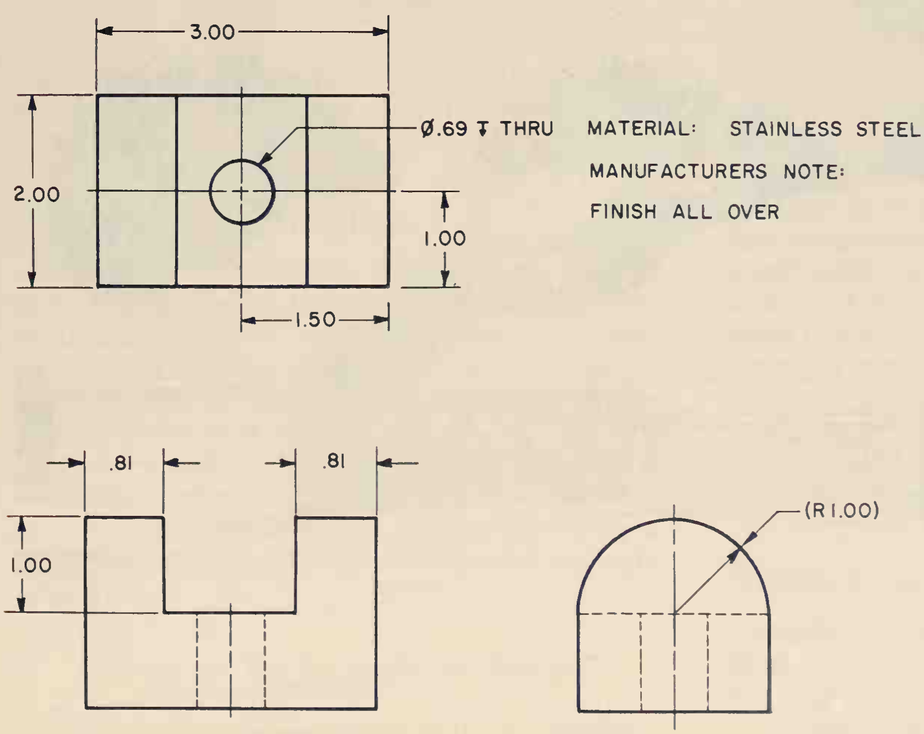


Figure I-2 Technical drawing (mechanical)

Figure I-3 Rendering

Figure I-4 Rendering

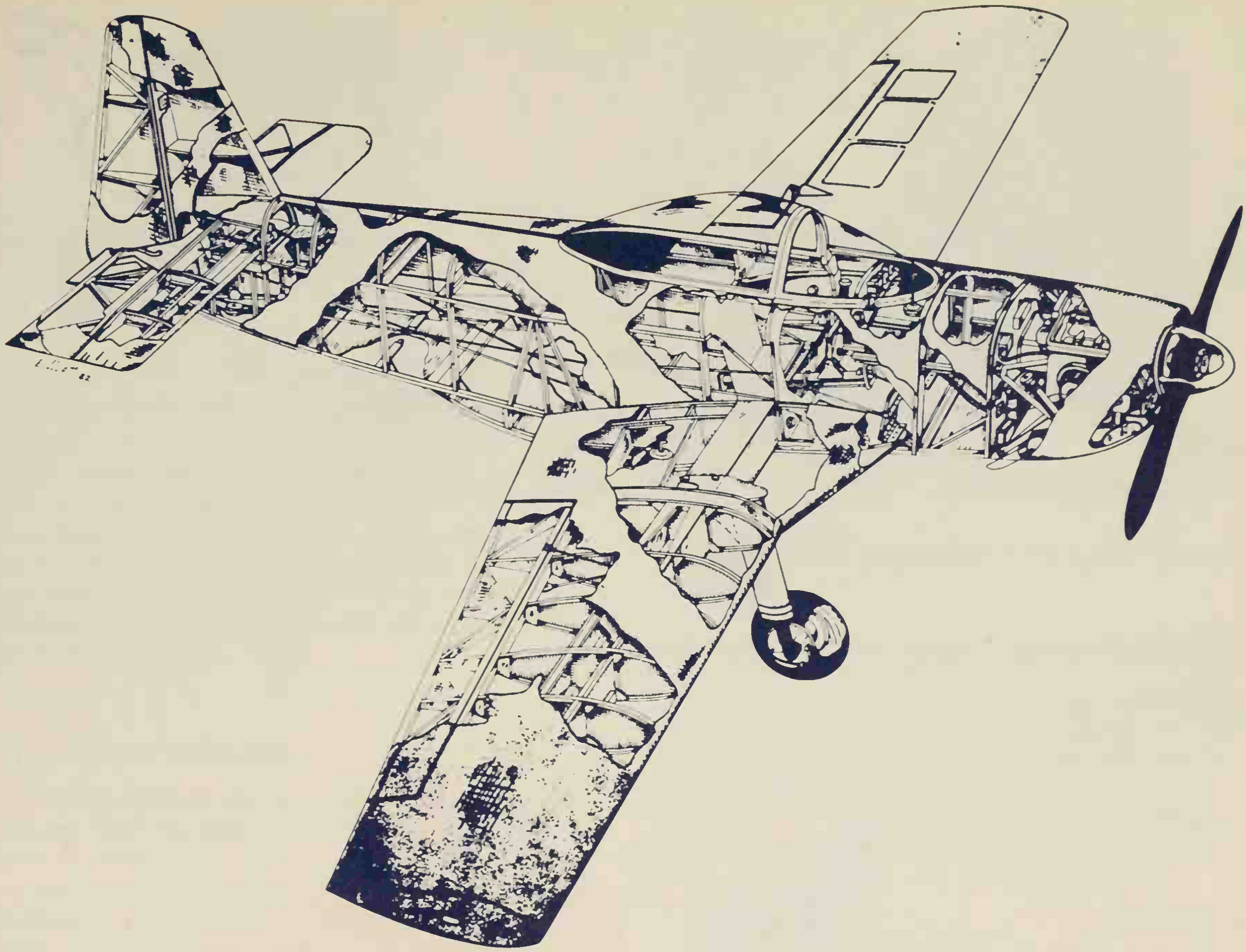


Figure I-5 Mechanical illustration (*Courtesy Ken Elliott*)

ing the represented parts. Notice that the drawings contain a graphic representation of the part, dimensions, material specifications, and notes.

Illustrations or Renderings

Illustrations or renderings are sometimes referred to as a third type of drawing because they are not completely technical, neither are they completely artistic; they combine elements of both, as shown in Figures I-3, I-4, I-5, and I-6. They are technical in that they are drawn with mechanical instruments or on a computer-aided drafting system, and they contain some degree of technical information. However, they are also artistic in that they attempt to convey a mood, an attitude, a status or other abstract, nontechnical feelings.

Types of Technical Drawings

Technical drawings are based on the fundamental principles of projection. A *projection* is a drawing or representation of an entity on an imaginary plane or planes. This projection plane serves the same purpose in technical drawing as is served by the movie screen in a theater.

As can be seen in Figure I-7, a projection involves four components: 1) the actual object that the drawing or projection represents, 2) the eye of the viewer looking at the object, 3) the imaginary projection plane (the viewer's drawing paper or the graphics display in a computer-aided drafting system), and 4) imaginary lines of sight called *projectors*.

Two broad types of projection, both with several subclassifications, are parallel projection and perspective (converging) projection.

Parallel Projection

Parallel projection is subdivided into the following three categories: orthographic, oblique, and axonometric projections.

Orthographic projections are drawn as multiview drawings which show flat representations of principal views

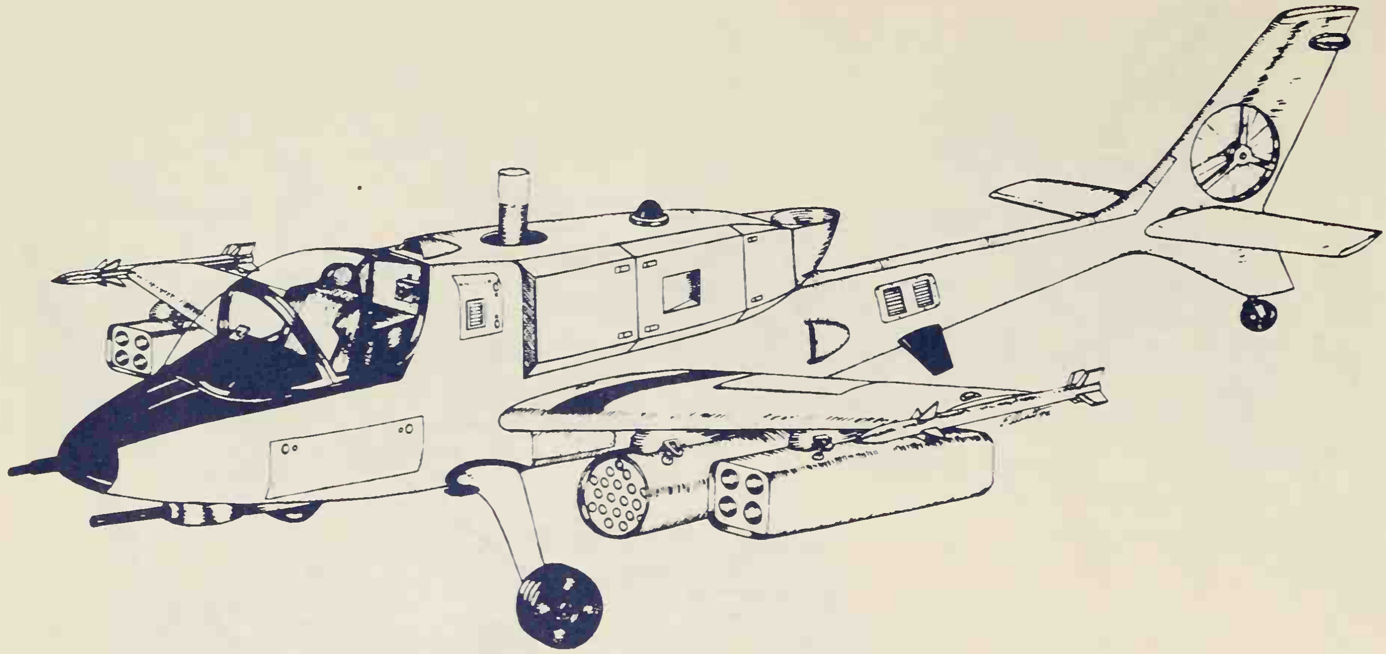


Figure I-6 Mechanical illustration (*Courtesy Ken Elliott*)

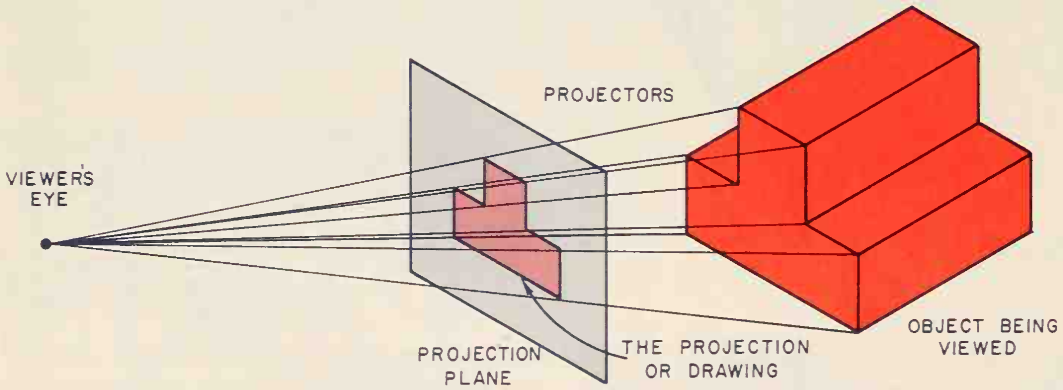


Figure I-7 The projection plane

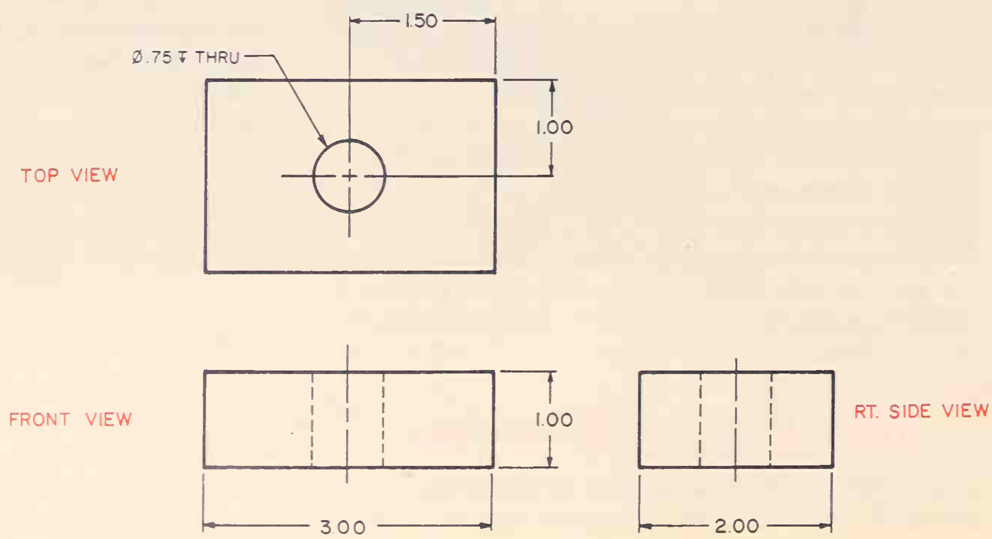


Figure I-8 Orthographic multiview drawing

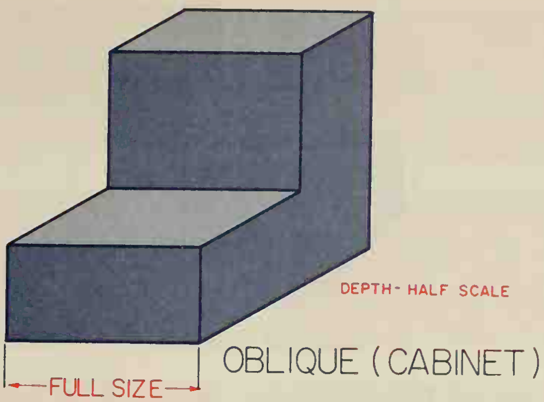


Figure 1-9 Oblique projection (cabinet)

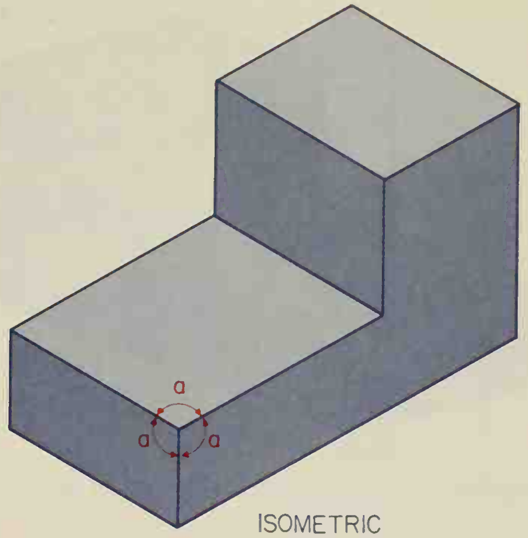


Figure 1-10 Axonometric projection (isometric)

of the subject, Figure 1-8. *Oblique projections* actually show the depth of the subject, and are of two varieties: *cabinet* (half scale) or *cavalier* (full scale) projections, Figures 1-9 and 1-10. *Axonometric projections* are three-dimensional drawings, and are of three different varieties: isometric, dimetric, and trimetric, Figures 1-11, 1-12, and 1-13.

Perspective Projection

Perspective projections are drawings which attempt to replicate what the human eye actually sees when it views an object. That is why the projectors in a perspective drawing converge. There are three types of perspective projections: one-point, two-point, and three-point projections, Figures 1-14, 1-15, and 1-16.

Purpose of Technical Drawings

To appreciate the need for technical drawings, one must understand the design process. The design process is an orderly, systematic procedure used in accomplishing a needed design.

Any product that is to be manufactured, fabricated, assembled, constructed, built or subjected to any other type of conversion process must first be designed. For example, a house must be designed before it can be built. An automobile must be designed before it can be manufactured. A printed circuit board must be designed before it can be fabricated.

The Design Process

The *design process* is an organized, step-by-step procedure in which mathematical and scientific principles, coupled with experience, are brought to bear in order to solve a problem or meet a need. The design process has five steps. Traditionally, these steps have been 1) identification of the problem or a need,

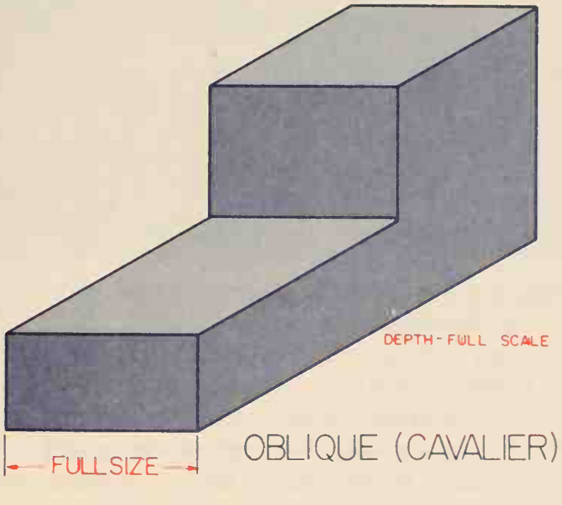


Figure 1-11 Oblique projection (cavalier)

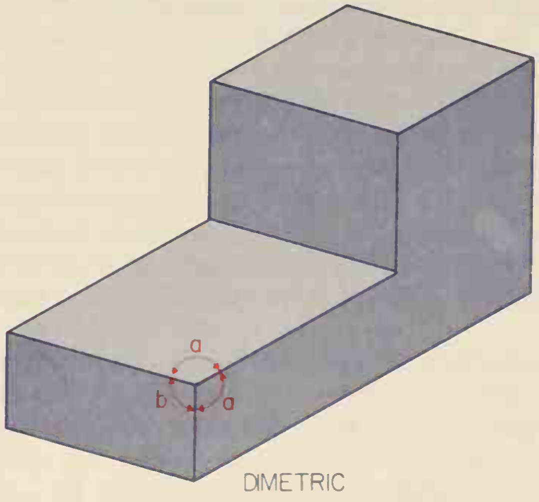


Figure 1-12 Axonometric projection (dimetric)

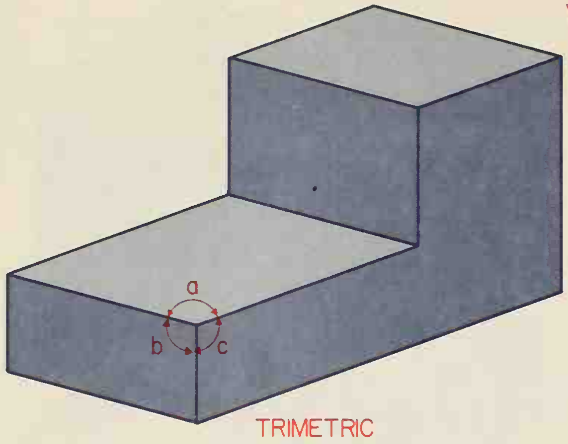


Figure I-13 Axonometric projection (trimetric)

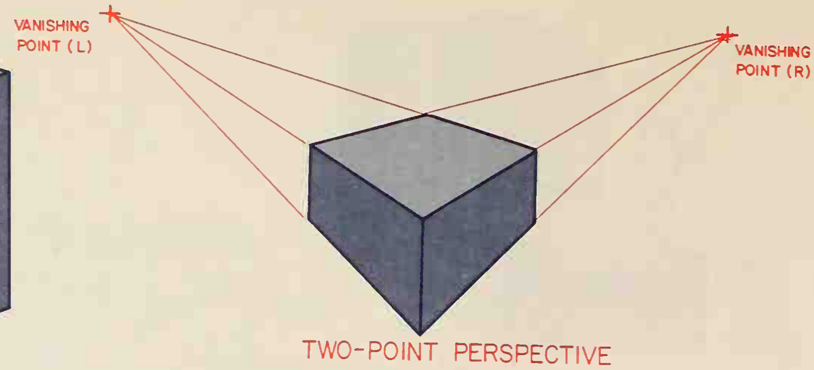


Figure I-15 Two-point perspective projection

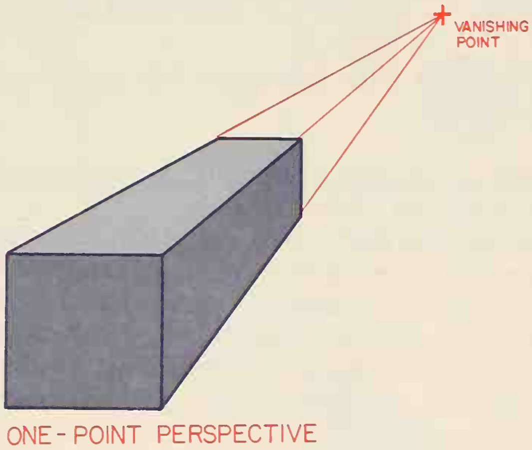


Figure I-14 One-point perspective projection

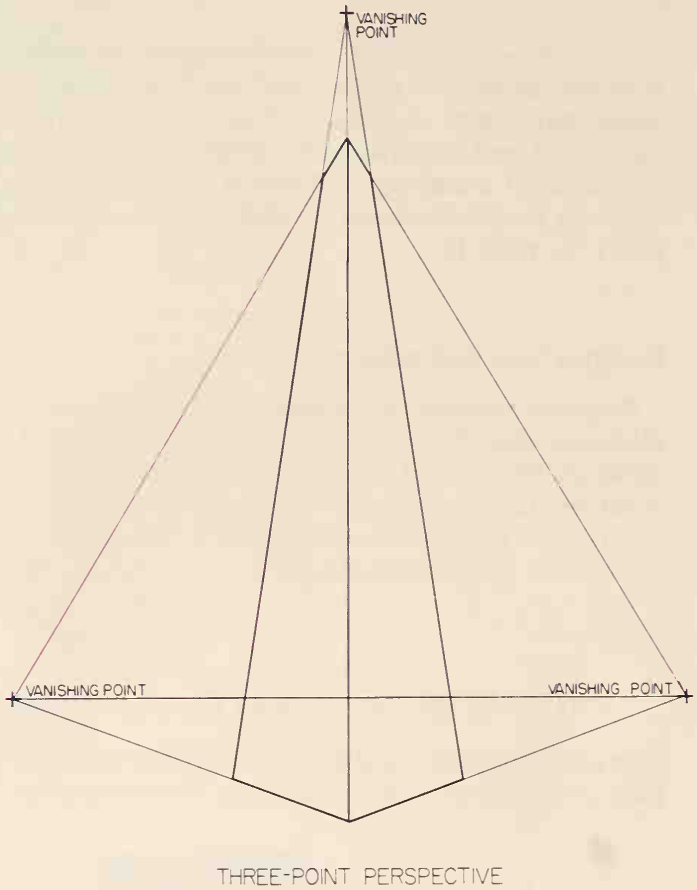


Figure I-16 Three-point perspective projection

2) development of initial ideas for solving the problem, 3) selection of a proposed solution, 4) development and testing of models or prototypes, and 5) developing working drawings, Figure I-17.

The age of computers has altered the design process slightly for those companies which have converted to computer-aided design and drafting. For these companies, the expensive, time-consuming fourth step in the design process — the making and testing of actual models or prototypes — has been substantially altered, Figure I-18. This fourth step has been replaced with three-dimensional computer models which can be quickly and easily produced on a CAD system using the data base built-up during the first three phases of the design process, Figure I-19.

Whether in the traditional design process or the more modern computer version, in either case, working drawings are an integral part of the design process from start to finish.

The purpose of technical drawings is to document the design process. Creating technical drawings to support the design process is called *drafting*. People who do drafting are known as *drafters* or *drafting technicians*. The words "draftsman" or "draughtsman" are no longer used.

In the first step of the design process, technical drawings are used to help clarify the problem or the need. The drawings may be old ones on file or they may be new ones created for the purpose of clarification. In the second step, technical drawings — often in the form of sketches or preliminary drawings — are used to document the various ideas and concepts formed. In the third step, technical drawings — again, usually preliminary drawings — are used to communicate the purposed solution.

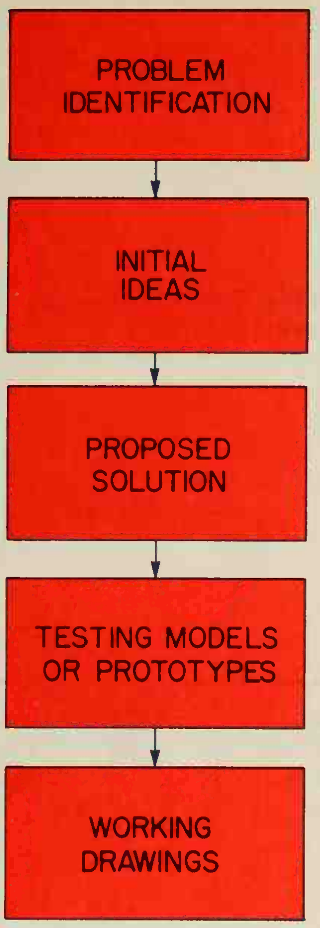


Figure 1-17 The design process (manual)

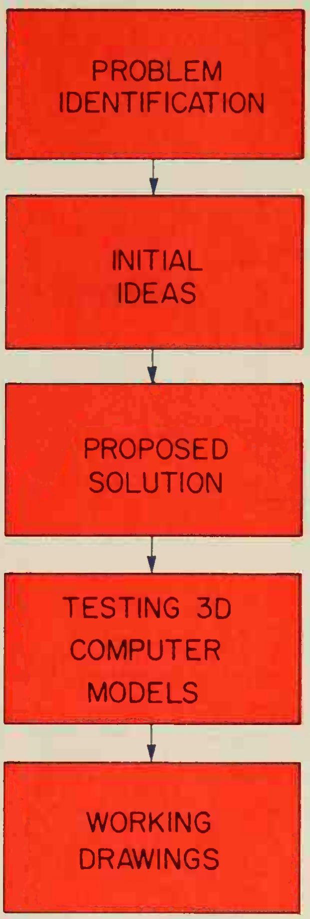


Figure 1-18 The design process (CAD)

Figure 1-19 Three-dimensional computer model (*Courtesy Terak Corporation*)

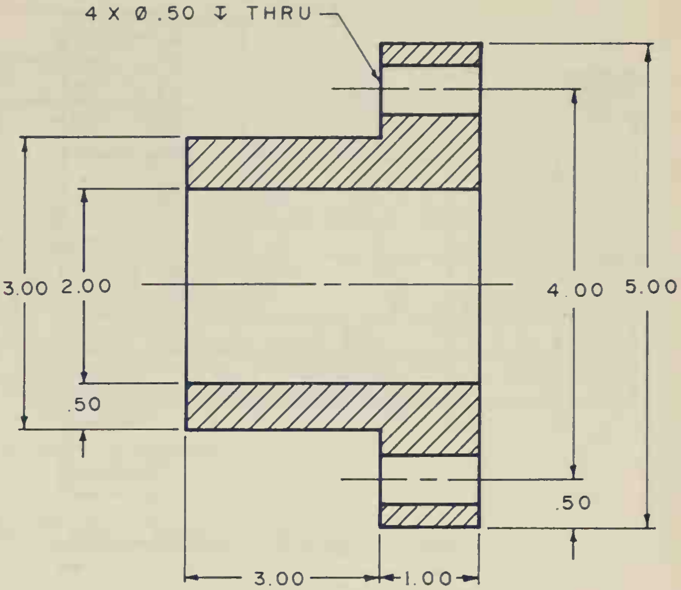


Figure 1-20 Simple mechanical drawing (manual)

If the traditional fourth step in the design process s being used, preliminary drawings and sketches from he first three steps will be used as guides in constructing models or prototypes for testing. If the more modern fourth step is being used, the data base built-up during documentation of the first three steps can be used in developing three-dimensional computer models. In both cases, the final step is the development of complete working drawings for guiding individuals involved in the conversion process. Figure 1-20 is a working drawing documenting the design of a simple mechanical part. The drawing was produced manually. Figure 1-21 is a similar drawing produced on a CAD system.

Applications of Technical Drawings

Technical drawings are used in many different applications. They are needed in any setting which involves design, and in any subsequent form of conversion process. The most common applications of technical drawings can be found in the fields of manufacturing, engineering, architecture and construction, and all of their various related fields.

Architects use technical drawings to document their designs of residential, commercial, and industrial buildings, Figures 1-22 and 1-23. Structural, electrical, and mechanical (heating, ventilating, air conditioning (HVAC) and plumbing) engineers who work with architects also use technical drawings to document those aspects of the design for which they are responsible, Figures 1-24, 1-25, and 1-26.

Surveyors and civil engineers use technical drawings to document such work as the layout of a new subdivision, or the marking-off of the boundaries for a piece of property, Figure 1-27. Contractors and construction personnel use technical drawings as their blueprints in converting architectural and engineering designs into reality, Figures 1-28 and 1-29.

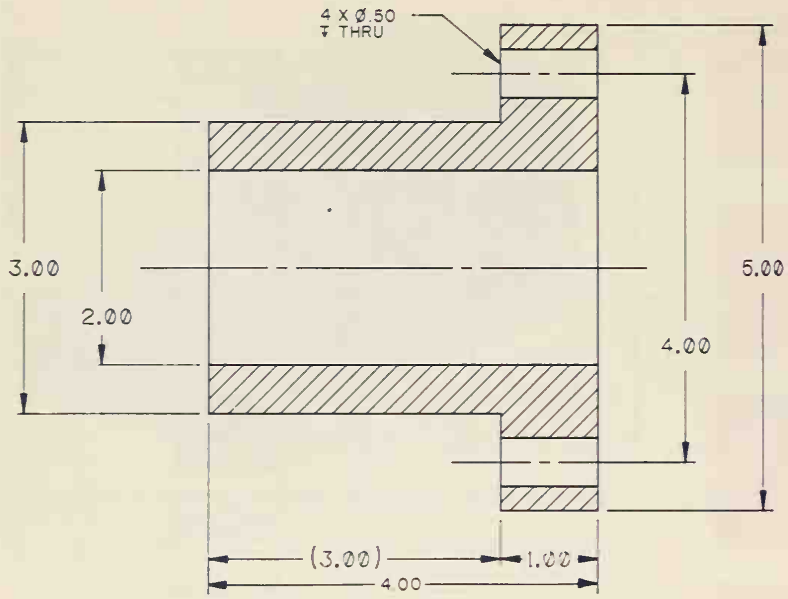


Figure 1-21 Simple mechanical drawing (CAD)

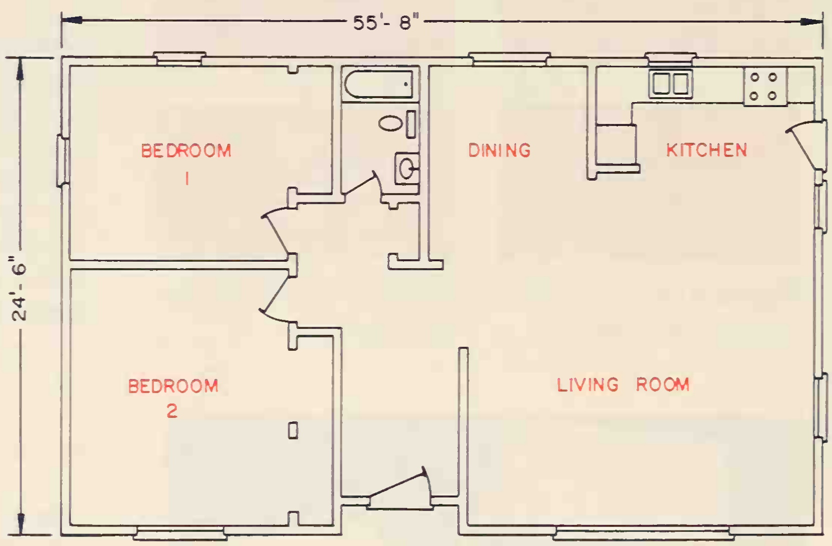


Figure 1-22 Technical drawing (architectural)

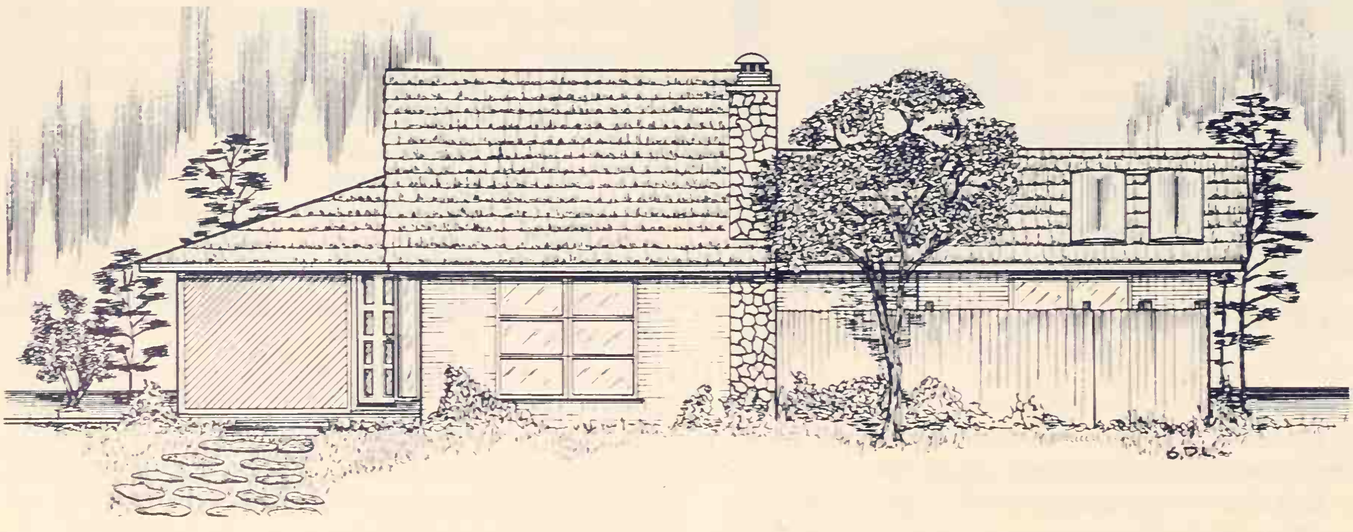


Figure 1-23 Technical drawing (architectural)

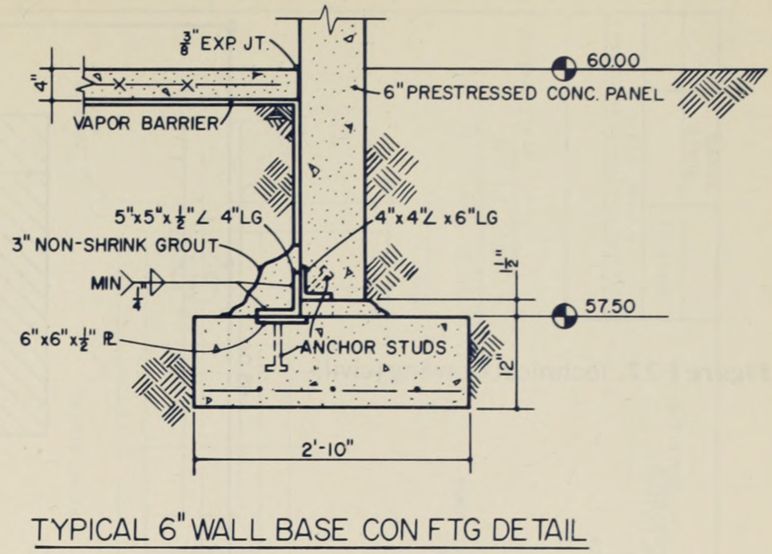


Figure I-24 Technical drawing (structural)

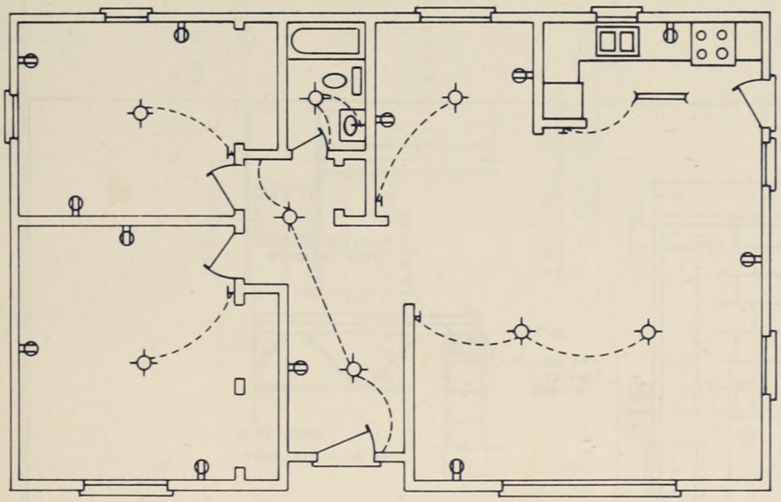


Figure I-25 Technical drawing (electrical)

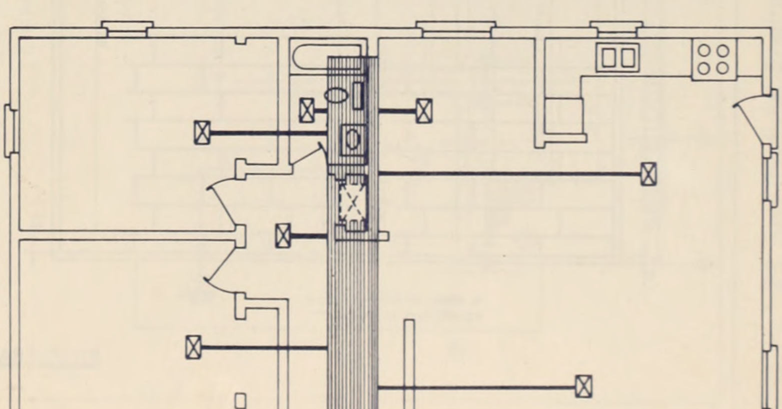


Figure I-26 Technical drawing (HVAC)

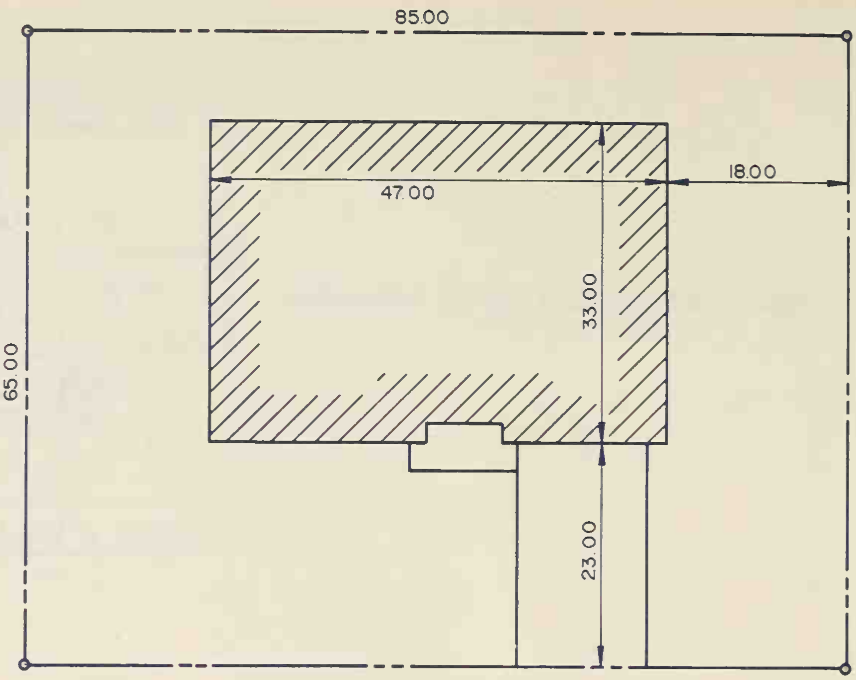


Figure 1-27 Technical drawing (civil)

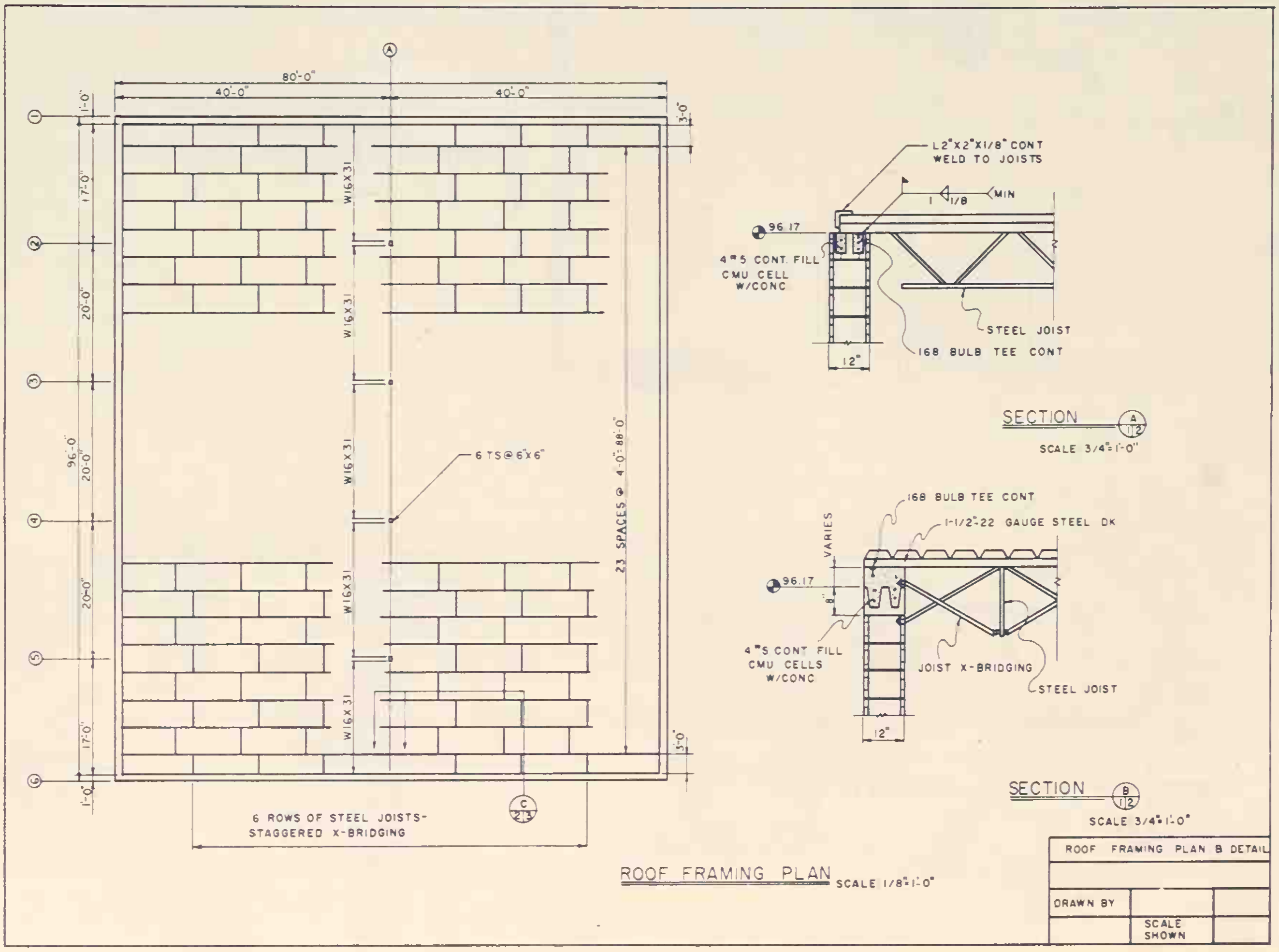


Figure 1-28 Architectural/Engineering drawing

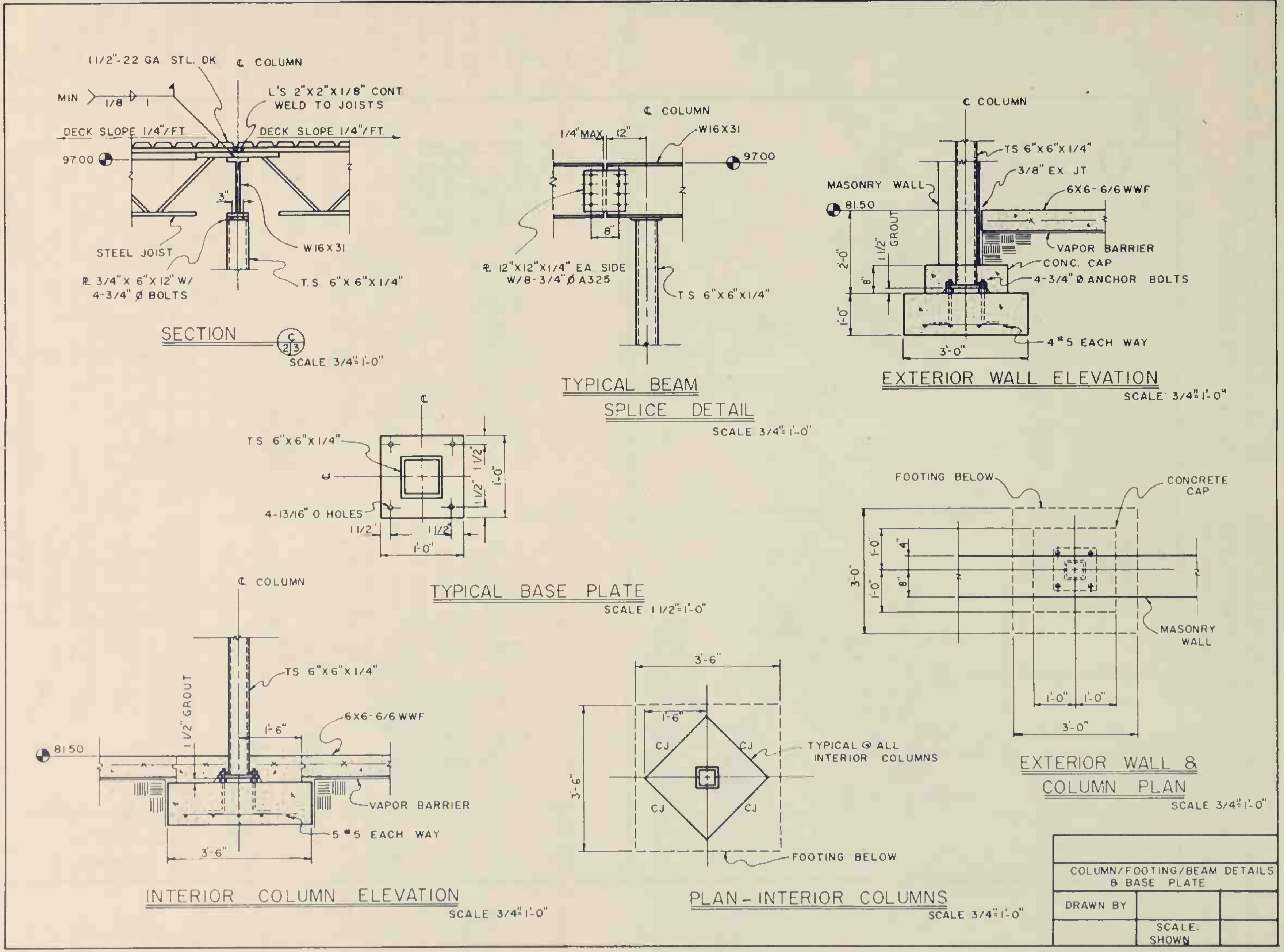
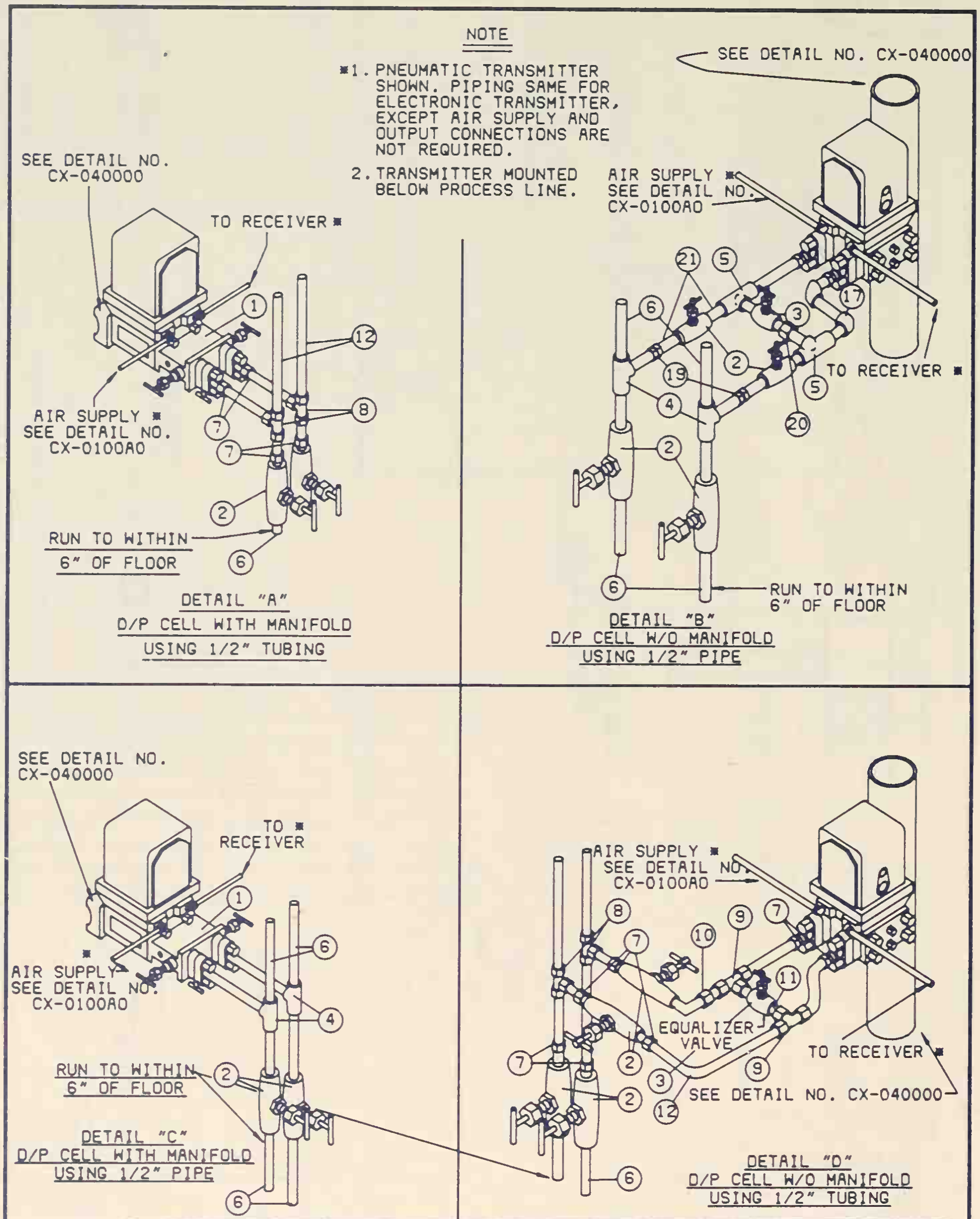


Figure 1-29 Architectural/Engineering drawing

Technical drawings are equally important to engineers, designers, and various other individuals working in the manufacturing industry. Manufacturing engineers use technical drawings to document their designs. Technical drawings guide the collective efforts of individuals who are concerned with the same common goal, Figures I-30 and I-31.



ITEM	DESCRIPTION	SPEC	ITEM	DESCRIPTION	SPEC	ITEM	DESCRIPTION	SPEC
1	3-VALVE MANIFOLD		8	1/2"T. TEE		20	1/4" UNION	
2	1/2" VALVE		9	1/2"T. X 1/4"P. TEE		21	1/2" NIPPLE	
3	1/4" VALVE		10	1/2"T. X 1/2"P. ELBOW				
4	1/2" TEE		11	1/4" PIPE				
5	1/2" X 1/4" TEE		12	1/2" TUBING				
6	1/2" PIPE		19	1/2" UNION				
7	1/2"T. X 1/2"P. CONN.		17	1/2" 90° ELBOW				

THE RUST ENGINEERING COMPANY | INSTRUMENTATION INSTALLATION DETAIL — D/P CELL TRANSMITTERS FOR LIQUID AND STEAM SERVICE | DRAWN / CHECKED / APPROVED | REVISION / DATE / DETAIL NUMBER: CF-040001

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Figure I-30 Isometric mechanical drawing (*Courtesy The Rust Engineering Company*)

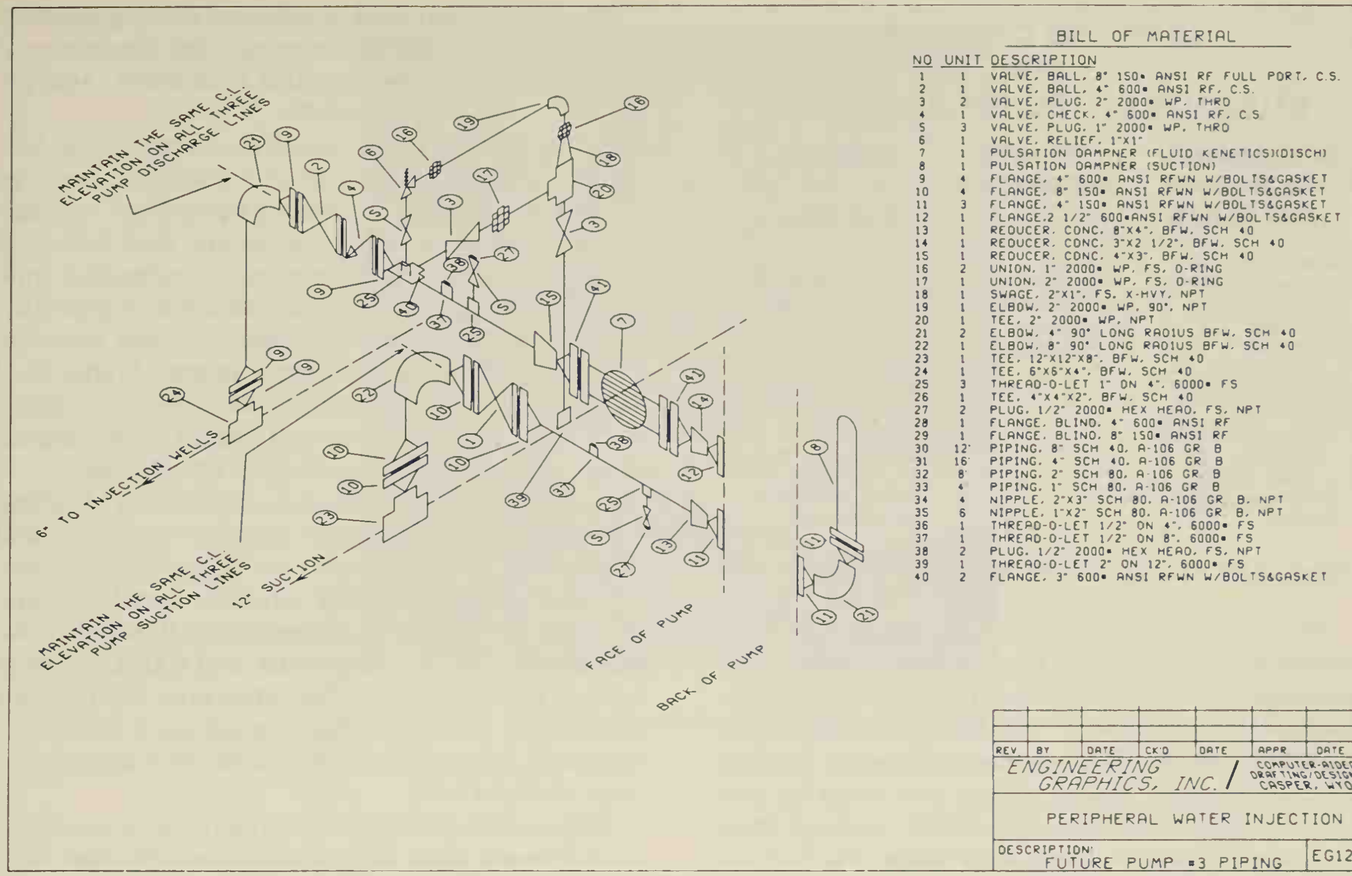


Figure 1-31 Isometric piping schematic (*Engineering Graphics, Inc.*)

Regulation of Technical Drawings

Technical drawing practices must be regulated because of the diversity of their applications. Just as the English language must have certain standard rules of grammar, the graphic language must have certain rules of practice. This is the only way to ensure that all people attempting to communicate using the graphic language are speaking the same language.

Standards of Practice

A number of different agencies have developed standards of practice for technical drawing. The most widely used standards of practice for technical drawing and drafting are those of the U.S. Department of Defense (DOD), the U.S. Military (MIL), and the American National Standards Institute (ANSI).

The American National Standards Institute does not limit its activities to the standardization of technical drawing and drafting practices. In fact, this is just one of the many fields for which ANSI maintains a continuously updated set of standards.

Standards of interest to drafters, designers, checkers, engineers, and architects are contained in the "Y" series of ANSI standards. Figure 1-32 contains a list of ANSI standards frequently used in technical drawing and drafting specifications.

What Students of Technical Drawing and Drafting Should Learn

Many people in the world of work use technical drawings in various forms. Engineers, designers, checkers, drafters, and a long list of related occupations use technical drawings as an integral part of their jobs. Some of these people must be able to actually make drawings; others are only required to be able to read and interpret drawings; some must be able to do both.

SIZE AND FORMAT	Y14.1
LINE CONVENTIONS AND LETTERING	Y14.2
PROJECTIONS	Y14.3
PICTORIAL DRAWING	Y14.4
DIMENSIONING AND TOLERANCING	Y14.5M
SCREW THREADS	Y14.6
GEARS, SPLINES AND SERRATIONS	Y14.7
GEAR DRAWING STANDARDS	Y14.7.1
MECHANICAL ASSEMBLIES	Y14.14

Figure 1-32 Sample list of drafting standards

LEARNING CHECKLIST FOR STUDENTS OF TECHNICAL DRAWING

FUNDAMENTAL KNOWLEDGE AND SKILLS	RELATED KNOWLEDGE	ADVANCED KNOWLEDGE AND SKILLS
DRAFTING EQUIPMENT	MATH	DEVELOPMENT
FUNDAMENTAL DRAFTING TECHNIQUES	WELDING	GEOMETRIC DIMENSIONING AND TOLERANCING
SKETCHING	SHOP PROCESSES	THREADS AND FASTENERS
GEOMETRIC CONSTRUCTION	MEDIA AND REPRODUCTION	SPRINGS
MULTIVIEW DRAWING		CAMS
SECTION VIEWS		GEARS
GRAPHICAL DESCRIPTIVE GEOMETRY		MACHINE DESIGN DRAWING
AUXILIARY VIEWS		PICTORIAL DRAFTING
GENERAL DIMENSIONING		DRAFTING SHORT-CUTS
NOTATION		CAD TECHNOLOGY
		CAD OPERATION

Figure 1-33 Checklist for students of technical drawing

What students of technical drawing and drafting should learn depends on how they will use technical drawings in their jobs. Will they make them? Will they read and interpret them? This textbook is written for students in the fields of engineering, design, drafting, and architecture, among others, who must be able to make, read, and interpret technical drawings. These students should develop a wide range of knowledge and skills, Figure 1-33.

The learning required of technical drawing students can be divided into three categories: fundamental knowledge and skills, related knowledge, and advanced knowledge and skills.

In the "fundamentals" category, students of technical drawing and drafting should develop knowledge and skills in the areas of drafting equipment; such fundamental drafting techniques as line work, lettering, scale use, and sketching; geometric construction; multiview drawing; sectional views; descriptive geometry; auxiliary views; general dimensioning; and notation.

In the "related knowledge" category, students of technical drawing and drafting should develop a broad knowledge base in the areas of related math, welding, shop processes, and media and reproduction.

In the "advanced" category, students of technical drawing and drafting should develop knowledge and skills in the areas of development, geometric dimensioning and tolerancing, threads and fasteners, springs, cams, gears, machine design drawing, pictorial drafting, drafting shortcuts, and CAD/CAM technology and operations. The latter area represents a significant change in techniques used to create, maintain, update, and store technical drawings, Figures 1-34 and 1-35.

Figures 1-36 through 1-40 contain examples of several different kinds of technical drawings taken from the "real world" of drafting.

Figure 1-34 Modern CAD technology (*Courtesy* CADKEY)

Figure 1-35 Modern CAD system (*Courtesy Autodesk, Inc.*)

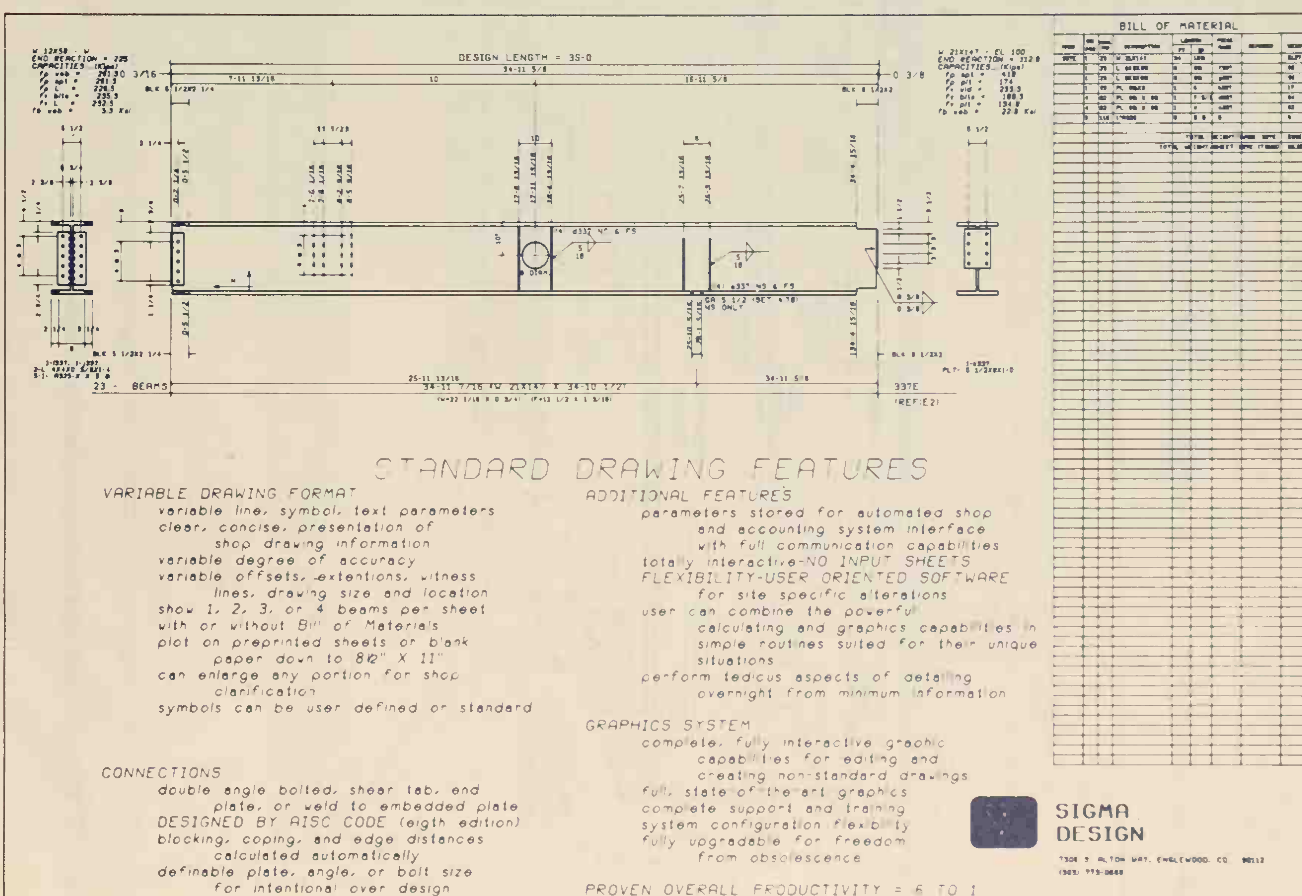


Figure 1-36 Structural steel drawing (*Courtesy Sigma Design*)

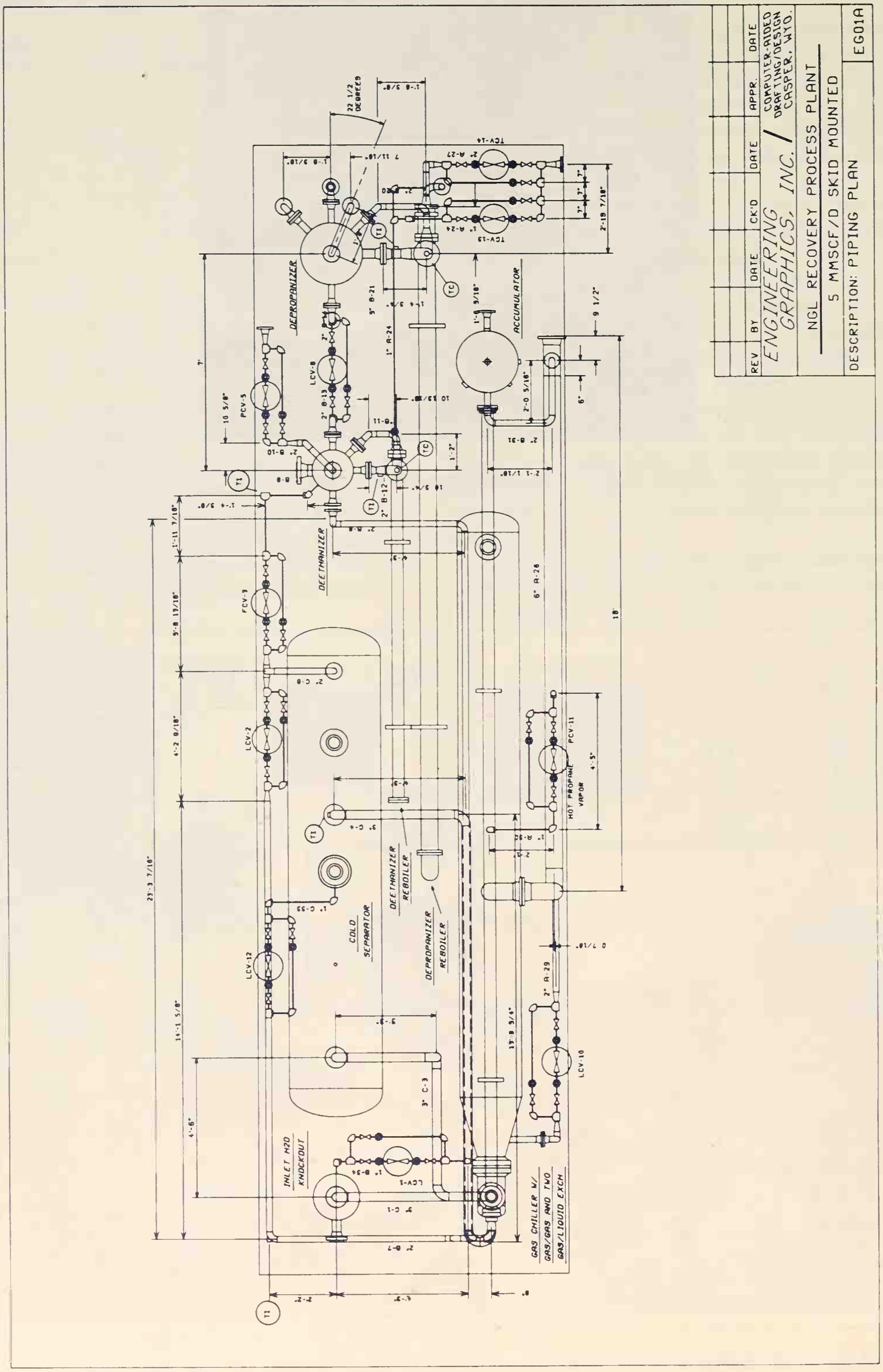


Figure I-37 Piping drawing (*Courtesy Engineering Graphics, Inc.*)

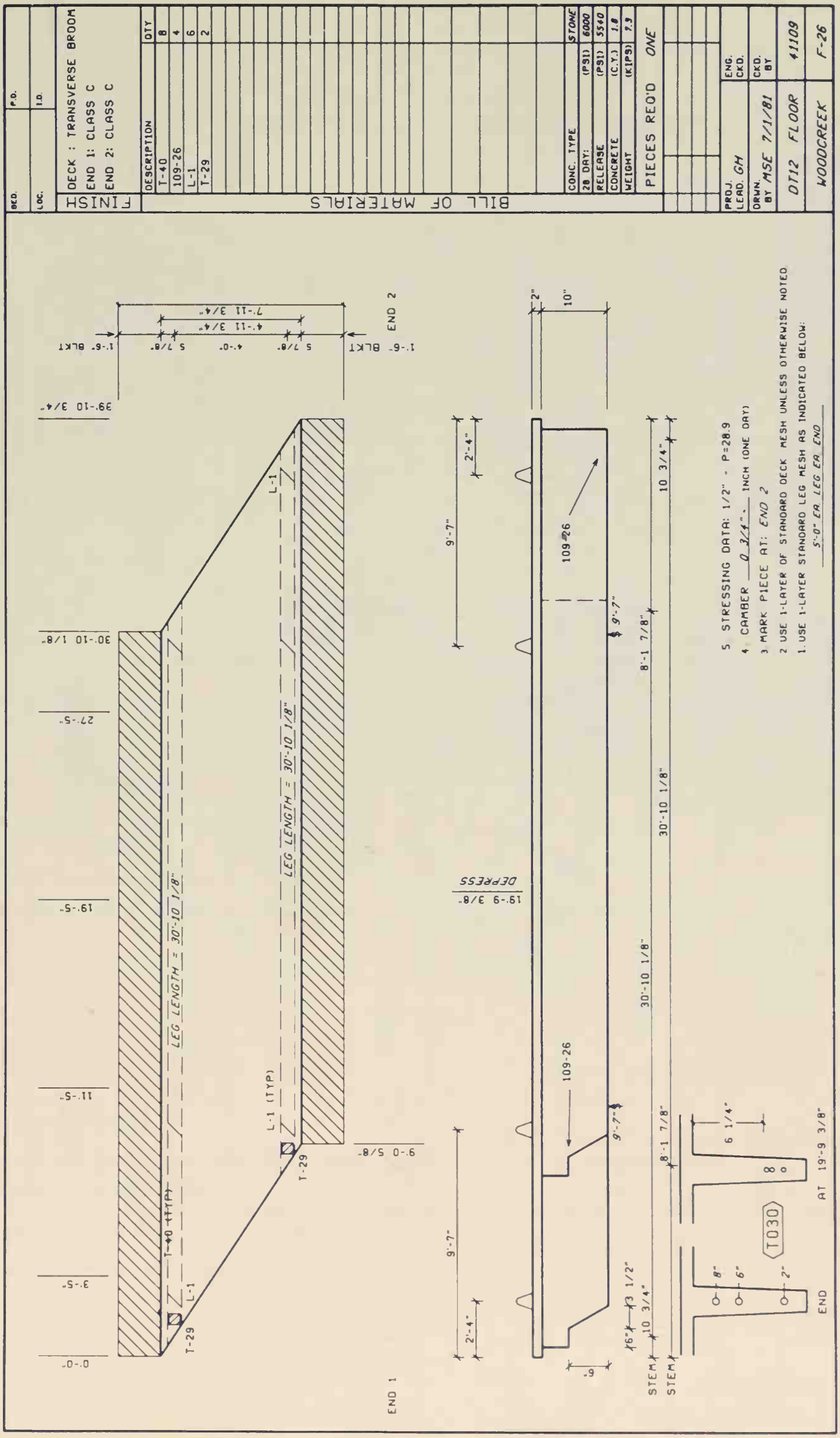


Figure I-38 Prestressed concrete drawing (Courtesy *Sigma Design*)

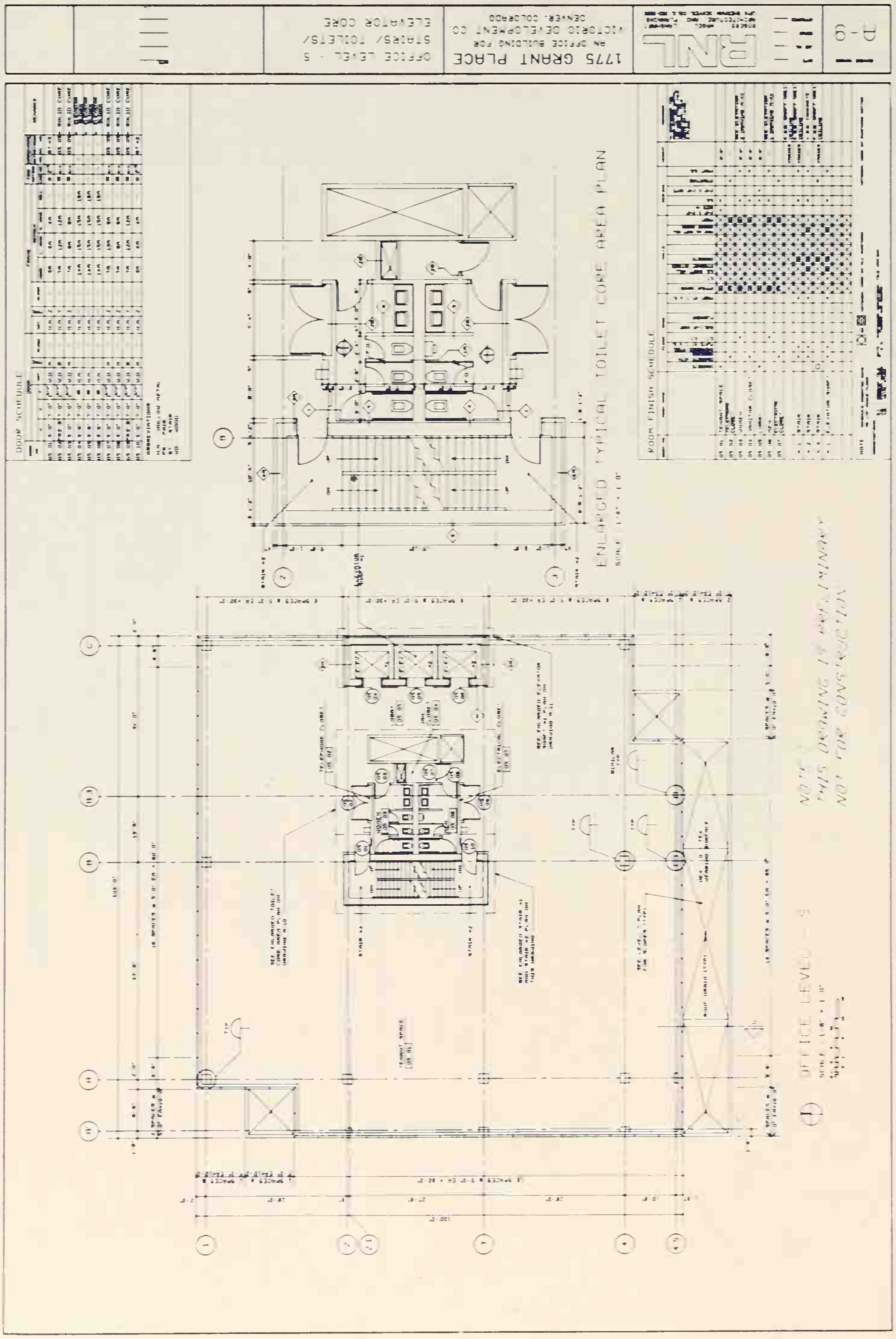


Figure 1-39 Architectural drawing (*Courtesy Sigma Design*)

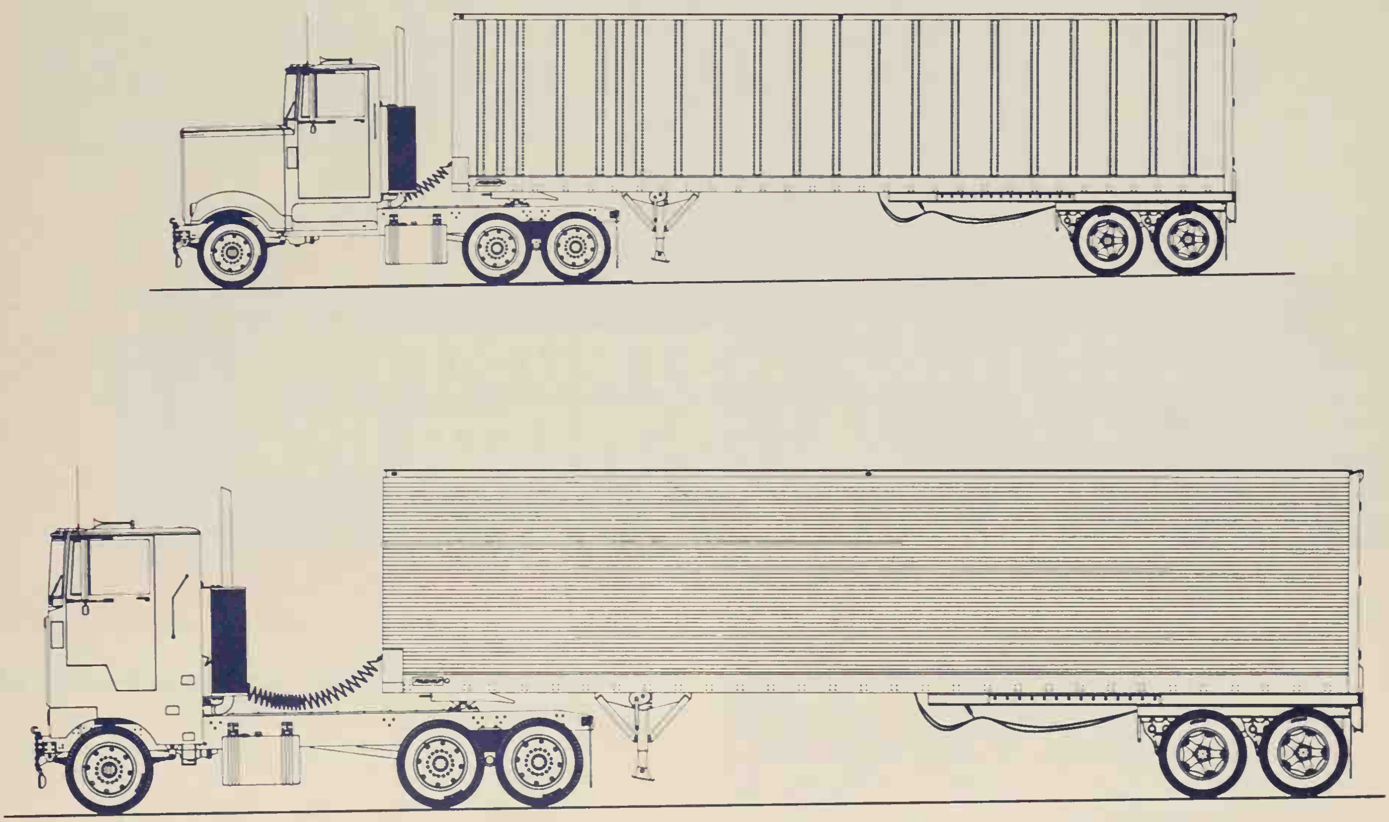
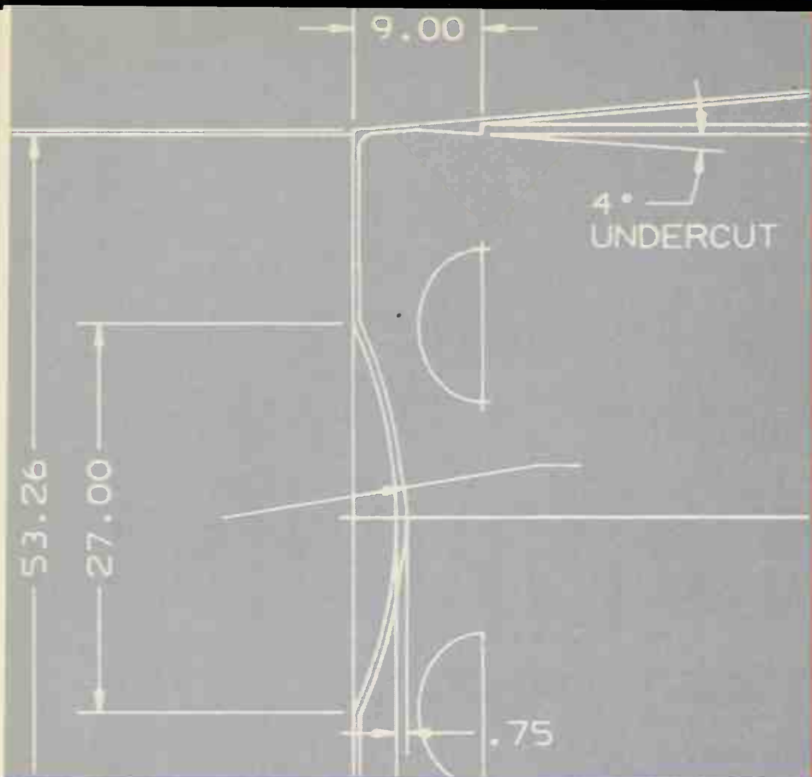


Figure 1-40 Mechanical pictorial drawing (*Courtesy Fruehauf Corporation*)

Review

1. What is a drawing?
2. What old adage explains the basis of the need for technical drawings?
3. What are the two basic types of drawings?
4. Explain the major difference between the two basic types of drawings.
5. What are the four components of a projection?
6. Name the three subdivisions of parallel projection.
7. Name the three types of axonometric projection.
8. Name the three types of perspective projection.
9. What are the five steps in the design process?
10. Name four fields in which technical drawings are used extensively.
11. Explain how technical drawings differ from artistic drawings.
12. Name three organizations that regulate technical drawing practices.



CHAPTER 1

This chapter discusses in detail the use of conventional drafting instruments and equipment, including their proper care; touches on CAD/CAM equipment, which is described more fully in Section 3; line-making methods; drafting media; copying equipment; measuring devices; scales; and many other basic drafting requirements and techniques.

DRAFTING INSTRUMENTS AND THEIR USE

Conventional and CAD/CAM Drafting Equipment

In drafting, no lines are made freehand. Each and every line is drawn using some kind of a drafting tool. It is up to the drafter to own a complete set of standard drafting tools in order to be fully functional.

When purchasing conventional drafting equipment, care must be taken to obtain quality equipment from a reliable dealer. It is advisable to consult with an experienced drafter, a drafting instructor, or a reputable dealer. The following is a list of the minimum required drafting equipment. Special templates and special equipment must be added to this list, depending upon the field of drafting and, in some cases, the actual product manufactured by the company. Each of the following pieces of equipment is illustrated in this chapter.

- Drawing board – 24" x 36" (60 cm x 90 cm) minimum size
- T-square (parallel straightedge or drafting machine) to suit board
- 45° triangle – 8" (20 cm) size
- 30°-60° triangle – 8" (20 cm) size
- Triangular scale (depending upon the field of drafting)
- Center wheel bow compass – 6" (15 cm) with extension bar)
- Drop bow compass (recommended)
- Irregular curves (two or three different configurations)
- Dividers – 6" (15 cm)
- Drafting brush
- Mechanical drafting pencils with lead
- Protractor or adjustable triangle
- Erasing shield
- Eraser
- Lead pointer with steel cutting wheel (pencil)
- Lead sandpaper or flat file (for compass lead)
- Circle template
- Ellipse template
- Drafting tape or drafting dots
- Calculator
- Dry cleaning pad (optional)

The following is a list of the required inking supplies.

- Technical pen #2 1/2 (for lettering scriber)
- Technical pen #1 (for lettering scriber)
- Technical pen #0 (for lettering scriber)

Figure 1-1 A computer-aided design system (*Courtesy Autodesk, Inc.*)

Figure 1-2 Drawing table and reference desk (*Courtesy Keuffel & Esser Co.*)

- India ink – black
- Pen cleaning solvent
- Lettering scriber
- Lettering template #100
- Lettering template #175
- Lettering template #290
- Compass adaptor for pen

Note that some specialized or expensive equipment is often furnished by the company.

CAD/CAM equipment is another drafting tool and is covered more fully in Chapters 10 and 11 in Section 3 of this text. For a very basic description, refer to Figure 1-1. The photo shows the following equipment, from left to right:

Printer – The printer is an output device used for producing printouts of alphanumeric data.

Workstation – (Text display, trackball, auxiliary keyboard, push-button menu board).

a. *The text display*
   An output device for displaying user prompts which tell the user what to do and how to do it.
b. *The trackball*
   A baseball-shaped input device used for creating horizontal, vertical, and diagonal lines, and for positioning the cursor.
c. *Auxiliary keyboard*
   An input device for entering commands, text, annotation, and dimensions.
d. *Push-button menu board*
   An input device for entering commands from a menu, and calling up stored data.

Graphics display – An ouput device for displaying drawings and other graphic data as they are being worked on.

Figure 1-3 Small drawing table (*Courtesy Stacor Corp.*)

Digitizing table with puck – An input device used for entering graphic data into the system. Graphic data is converted to digital data (digitized) and entered into the system as X-Y coordinates.

Conventional Drafting Requisites

Drawing Table

Drawing tables are available in a variety of styles. Most are adjustable up and down, and can tilt to almost any angle from vertical 90° to horizontal, Figures 1-2 and 1-3.

Drawing Surface

The drawing surface, whether it is a drawing tabletop or drawing board, must be flat, smooth and large enough to accommodate the drawing and some drafting equipment. If a T-square is used on a drawing board, at least one edge of the board must be absolutely true. Most quality drafting boards have a metal edge to ensure against warpage and against which to hold the T-square securely.

Standard drafting boards range in size from small, 12" x 17" (30 cm x 43 cm), to large, 31" x 42" (78 cm x 105 cm). Standard drafting tabletops range in size from 31" x 42" (78 cm x 105 cm) to 37½" x 60" (94 cm x 150 cm).

Lighting It is important that the drawing surface be fully lighted without any shadows, Figure 1-4.

Top Cover The drafting board should have a top cover which protects the board surface and provides a perfect drawing surface A good top cover actually seals over holes made by compass points, and it is easily cleaned, Figure 1-5.

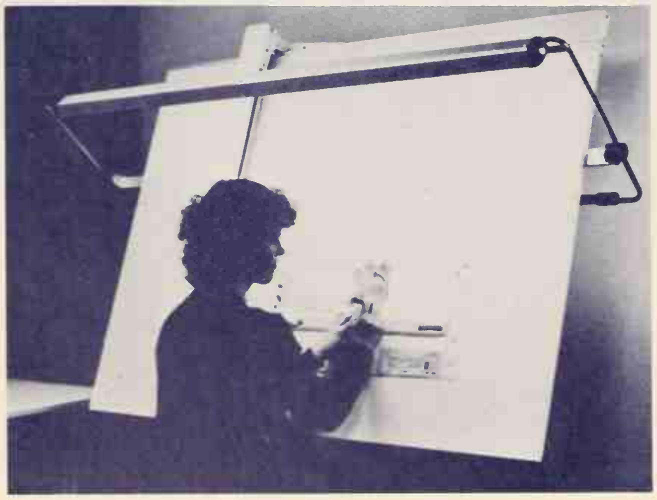


Figure 1-4 Fluorescent lamp for drawing surface (*Courtesy Waldmann Lighting Co.*)

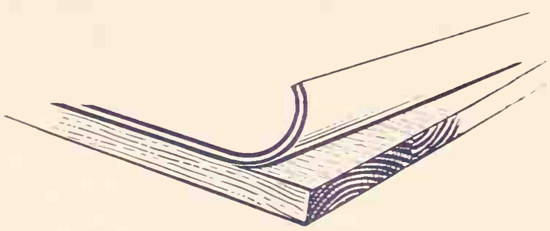


Figure 1-5 Drafting board top cover (*Courtesy Modern School Supplies, Inc.*)

Efficiency

To be fully efficient at drafting, all equipment must be clean, correctly adjusted and/or sharpened, and stored in a convenient location, ready for use at all times. It is good drafting practice to store each piece of equipment in a specific location and return it to its location after use. An organizer, such as the one shown in Figure 1-6, aids in keeping all equipment in its place.

Left-handed Drafters

Most drafting equipment is designed for the right-handed drafter, although left-handed types of drafting machines can be purchased. The T-square is simply placed on the right side of the drafting board by left-handed drafters, but everything else is right handed. The left-handed drafter has to adapt. The lettering scriber is especially difficult to manipulate.

T-Square

While T-squares are not used today in industry, they do provide a parallel straightedge for the beginning drafter. The T-square is used to draw horizontal lines. Draw lines only against the upper edge of the blade. Make sure the head is held securely against the left

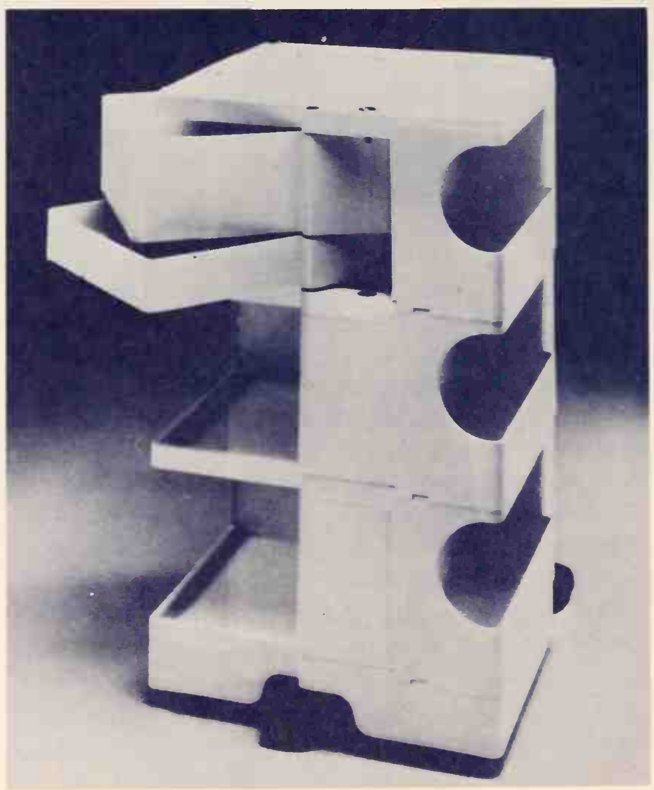


Figure 1-6 Equipment organizer (*Courtesy Stacor Corp.*)

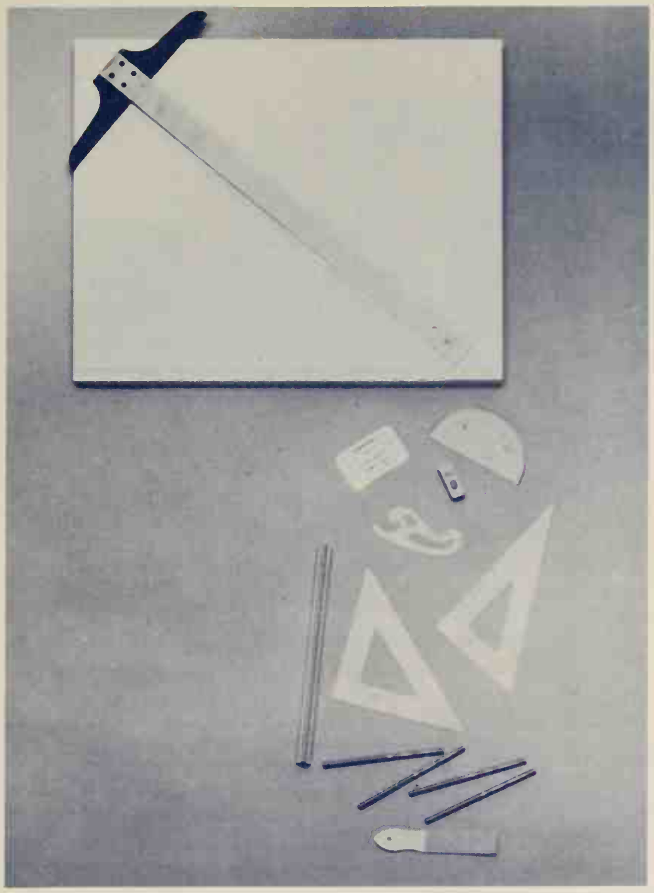


Figure 1-7 T-square in use (*Courtesy Teledyne Post*)

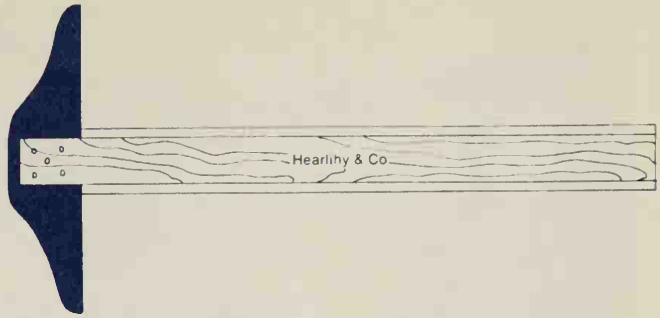


Figure 1-8 Parts of the T-square (*Courtesy Hearlihy and Co.*)

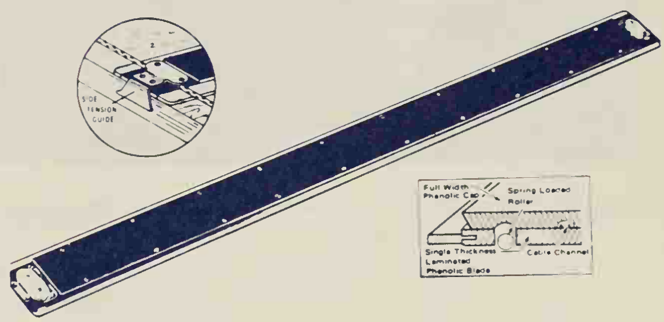


Figure 1-9 Parallel straightedge (*Courtesy Modern School Supplies, Inc.*)

edge of the drawing board to guarantee parallel lines, Figure 1-7.

The T-square is composed of two parts: the head and the blade, Figure 1-8. The two parts are fastened together at an exact right angle. The blade must be straight and free of any nicks or imperfections. A transparent acrylic edge is recommended since this allows the drafter to see the drawing underneath the edge. T-squares can be purchased with adjustable heads for drawing specific angles.

Parallel Straightedge

The parallel straightedge is always parallel, regardless of where it is placed upon the drawing surface. Parallel control is accomplished by a system of cords and pulleys, Figure 1-9. The parallel straightedge replaced the T-square in industry, and is still used somewhat today. Most straightedges come with a transparent acrylic edge, and some have rollers for a smooth gliding action. Some have a locking brake that permits the straightedge to be locked in any position.

Drafting Machines

A drafting machine is a device that attaches to the drafting table and replaces both the T-square and the parallel straightedge. There are two basic kinds of drafting machines. One is the arm type, Figure 1-10, and the other, the newer, is the track type, Figure 1-11. On both types, a round head holds two straightedges at right angles to each other. The head can be rotated to set the straightedges at any angle. Most machines are available with interchangeable straightedges marked with different scales along their edges.

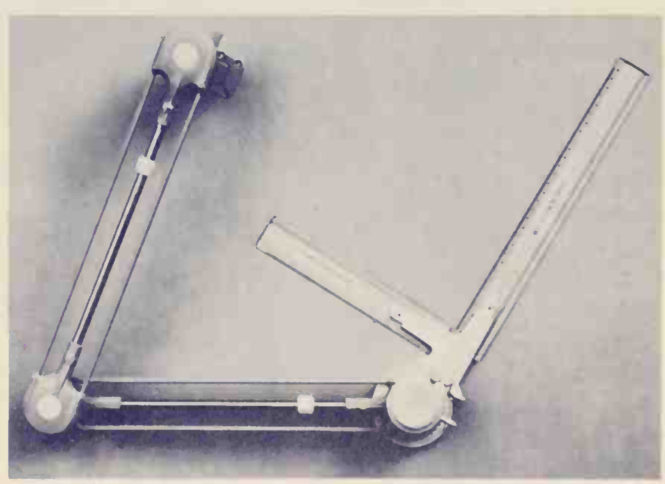


Figure 1-10 Arm-type drafting machine (*Courtesy Teledyne Post*)

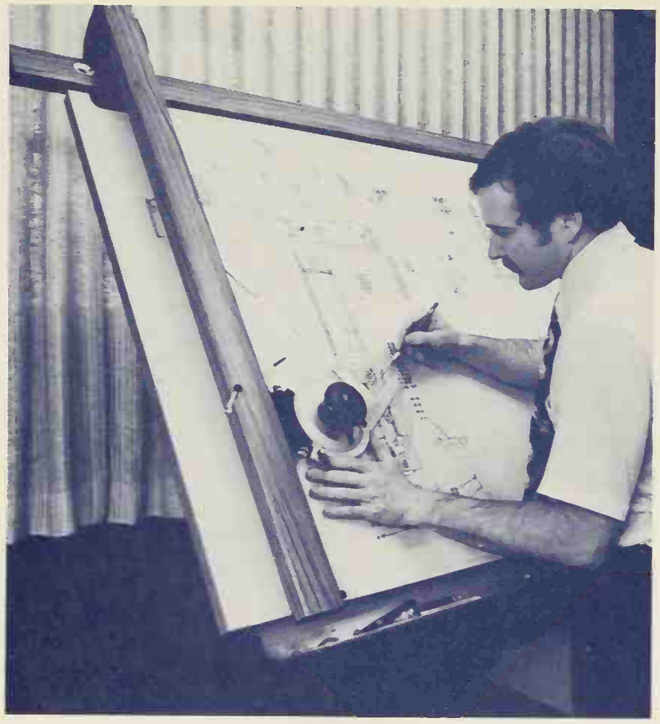


Figure 1-11 Track-type drafting machine (*Courtesy Vemco, Inc.*)

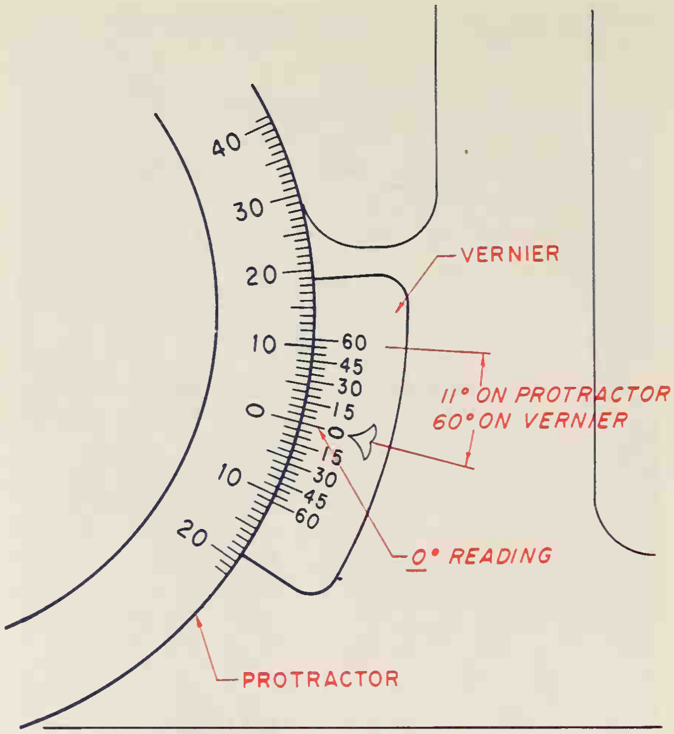


Figure 1-12 Protractor with vernier

Drafting machines replace straightedges, scales, triangles, and protractors. They increase accuracy and greatly reduce drafting time. A drafting machine is one of the few tools that can be purchased either as a right-handed or a left-handed instrument.

Most drafting machines have a protractor and a vernier which permit readings to 5 minutes of an arc, Figure 1-12. Notice that zero on the protractor is in line with the zero on the vernier. The venier is graduated in 5-minute increments from zero to 60 minutes. To read the vernier, first read the protractor, Figure 1-13. In this example, the zero on the vernier points between 18° and 19°. On the vernier, notice that the only line that lines up with a line on the protractor is the 45; thus,this is read as 18°-45'. Some drafting machine heads simplify this process by adding a digital readout, see Figure 1-14.

Drafting machine straightedges come in sizes of 9" (23 cm), 12" (30 cm) and 18" (45 cm), graduated or ungraduated, in both transparent plastic and aluminum scale, Figure 1-15.

A drafting machine, although a precision instrument, should be checked for accuracy at least once a week. The instructions for checking and adjusting a drafting machine are included with the manufacturer's information.

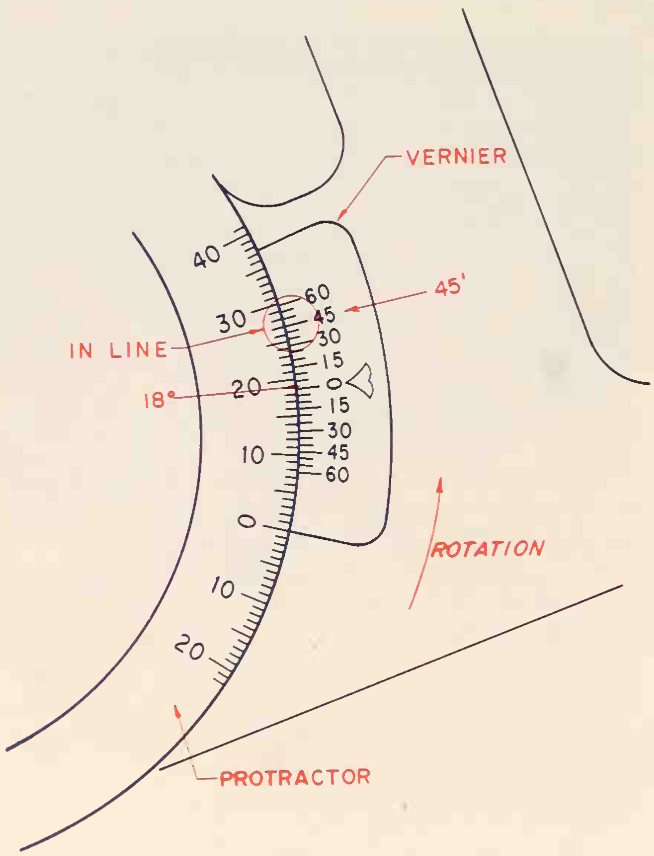


Figure 1-13 Reading the vernier

Figure 1-14 Drafting machine head with digital readout (*Courtesy Consul & Mutoh, Ltd.*)

Drawing Sets

Typical drawing sets include compasses, dividers, and a ruling pen, Figure 1-16. Many sets include a variety of tools not normally used by the drafter. It is recommended that only those tools actually needed be purchased.

Compasses

There are two main types of compasses: the friction-joint type, and the spring-bow type. The friction-joint type is still widely used for lightly laying out pencil drawings which will be inked. The disadvantage of this type of compass is that the setting may slip when strong pressure is applied to the lead.

The spring-bow type of compass, Figure 1-17, is best for pencil drawings and tracings as it retains its

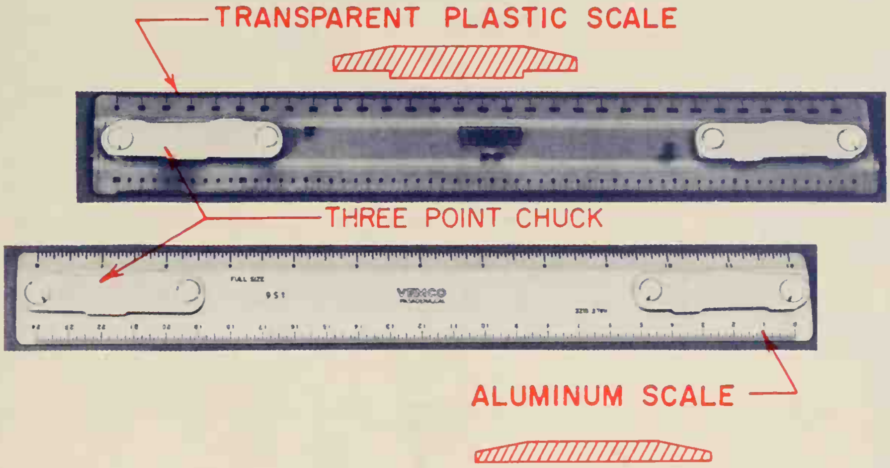


Figure 1-15 Transparent and metal drafting machine straightedges with scale (*Courtesy Vemco, Inc.*)

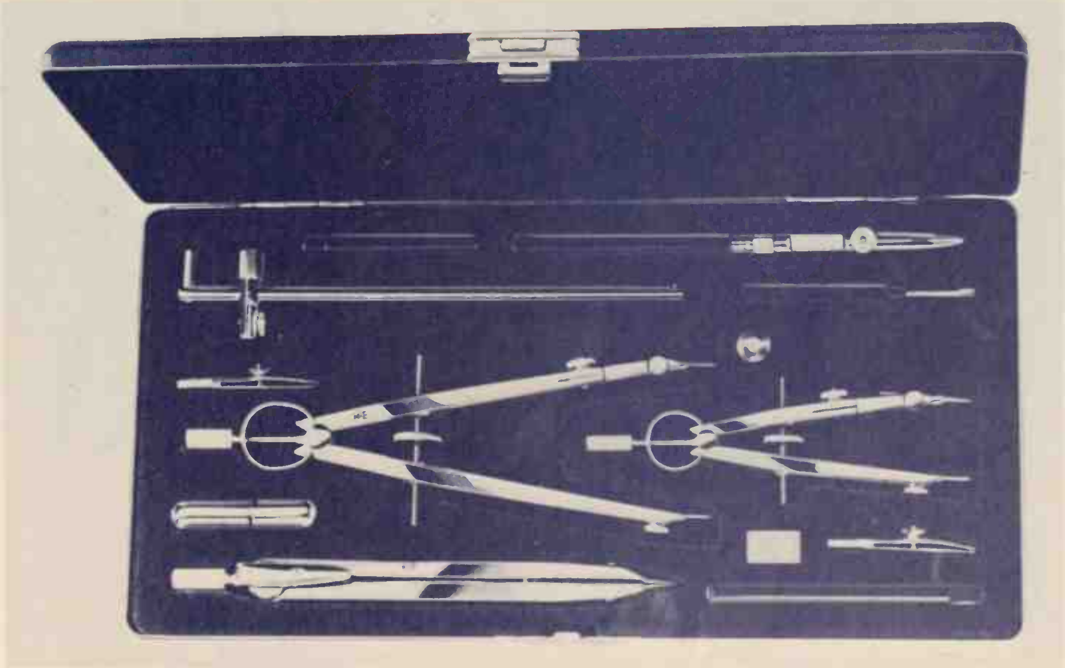


Figure 1-16 Complete drafting set (*Courtesy Keuffel & Esser Co.*)

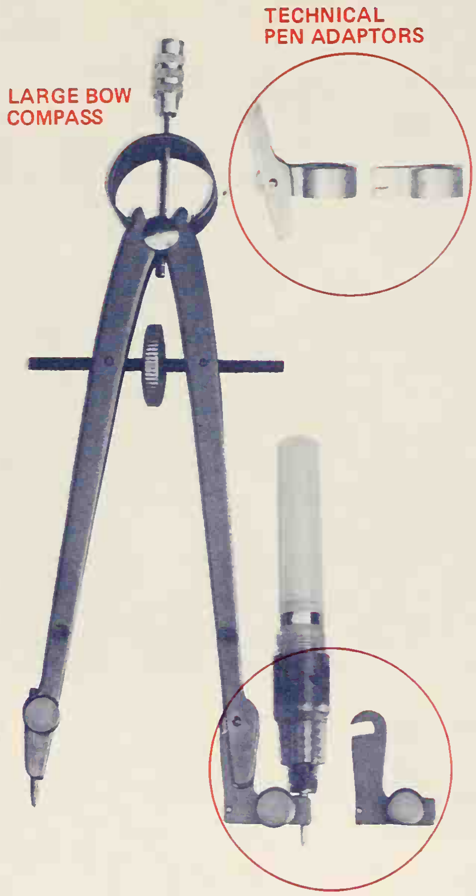


Figure 1-17 Spring bow compass with pen adaptor (*Courtesy Vemco, Inc.*)

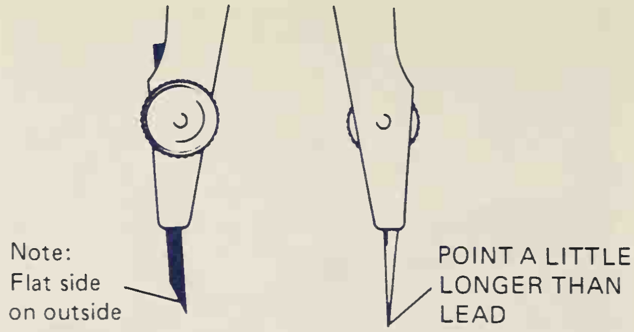


Figure 1-18 Bow compass lead and metal points

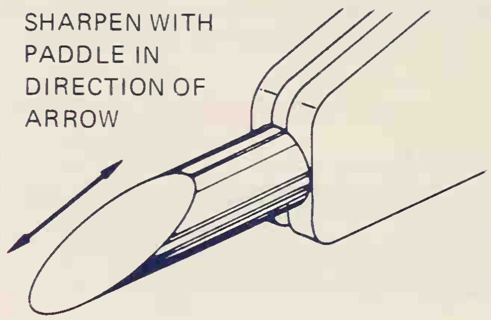


Figure 1-19 Bow compass lead point shape (*Courtesy Drafting for Trades and Industry, Basic Skills, Nelson, Delmar Publishers Inc.*)

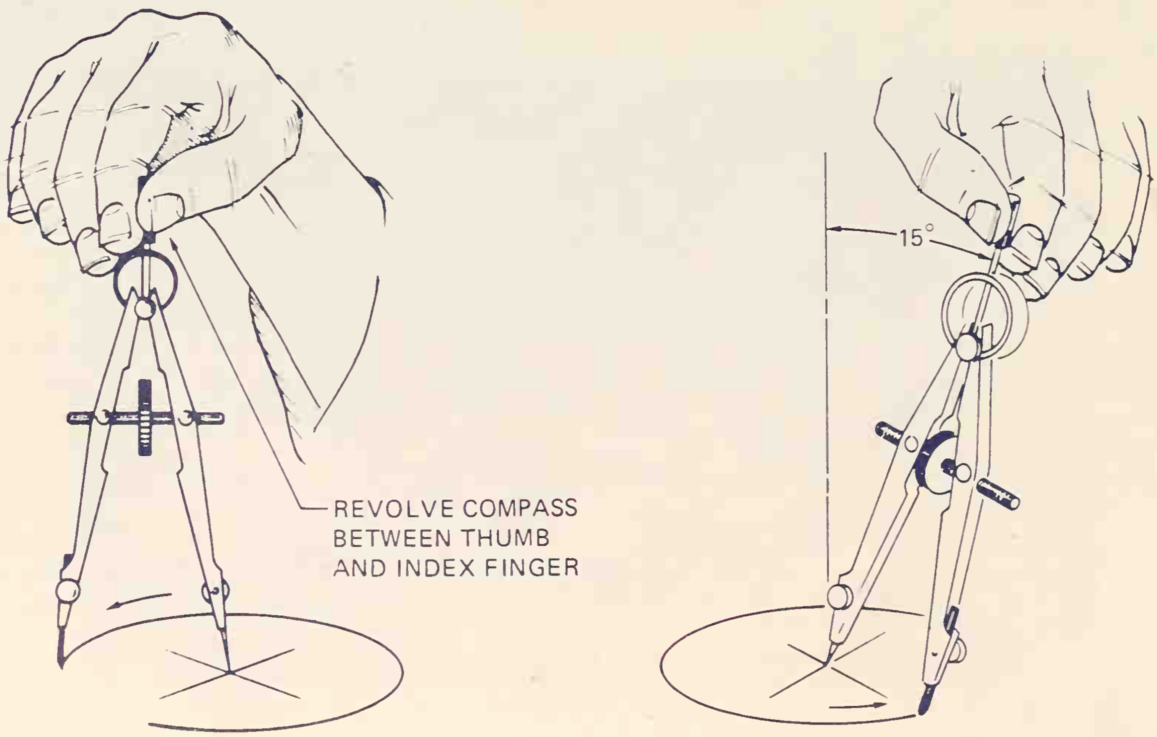


Figure 1-20 Drawing a circle with a bow compass

setting even when strong pressure is applied to obtain dark lines. The spring, located at the top of the compass, holds the legs securely against the adjusting screw. The adjusting screw is used to make fine adjustments.

Compass leads should extend approximately 3/8" (0.9 cm). The metal point of the compass extends slightly more than the lead to compensate for the distance the point penetrates the paper, Figure 1-18. The lead is sharpened with a sandpaper paddle to produce clean, sharp lines. The flat side of the lead faces *outward* in order to produce circles of very small diameter, Figure 1-19. Sharpen with paddle in direction of arrow, as shown, in order to keep the lead sharp longer.

To draw a circle with the bow compass, the compass is revolved between the thumb and the index finger, Figure 1-20. Pressure is applied downward on the metal point to prevent the compass from jumping out of the center hole.

Drop Bow Compass The drop bow compass, Figure 1-21, is used for circles of .03" (0.08 cm) to .50" (1.3 cm) diameter. The compass is adjusted to the required radius. The center point is located on the circle or arc swing point and held in place with the index finger. Rotate the knurled head of the compass between the thumb and second finger.

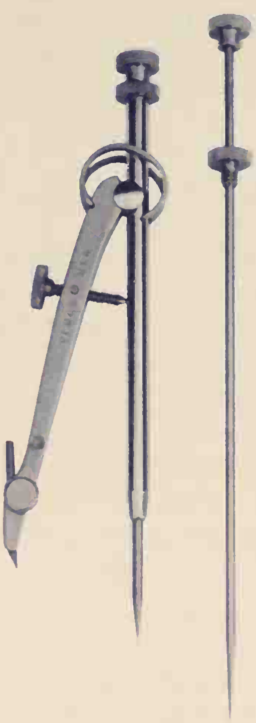


Figure 1-21 Drop bow compass (*Courtesy Vemco, Inc.*)

Bow Compass with Lead Clutch In order to eliminate the process of sharpening compass leads, some drafters use a compass with a lead clutch of 0.5-mm lead, Figure 1-22. This compass saves time, and ends messy lead sharpening. Special compasses are designed only for inking, Figures 1-23 and 1-24. An adaptor to attach to a standard compass to draw ink lines is illustrated in Figure 1-25.

Figure 1-22 Bow compass with special lead clutch (*Courtesy B. Carter Lykins*)

Figure 1-23 Inking bow compass (*Courtesy Koh-I-Noor Rapidograph*)

Figure 1-24 Inking drop bow compass (*Courtesy Koh-I-Noor Rapidograph*)

Figure 1-25 Standard compass ink adaptor (*Courtesy Koh-I-Noor Rapidograph*)

Beam Compass A beam compass, Figure 1-26, is used to draw large circles or arcs. Fine line adjustments can be obtained and locked in place. Beam compasses come in sizes from 13" (33 cm) bars and upwards.

Figure 1-26 Beam compass (*Courtesy Vemco, Inc.*)

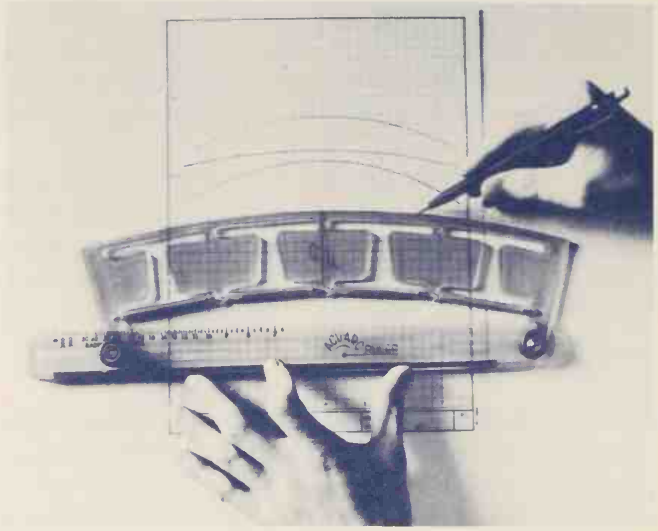


Figure 1-27 Adjustable curve (*Courtesy Hoyle Products, Inc.*)

Adjustable Curve An adjustable curve, Figure 1-27, has a locking knob, and is used to draw any radius from 6.75" to 200" (17 cm to 500 cm). This tool takes over where the ordinary compass leaves off, and eliminates the beam compass.

Divider

A divider is similar to a compass except that it has a metal point on each leg. It is used to lay off distances and to transfer measurements, Figure 1-28.

Proportional Dividers Proportional dividers are used to enlarge or reduce an object in scale. This tool has a sliding, adjustable pivot which varies the proportions of the tips of each leg, Figure 1-29.

Triangle

Two standard triangles are used by drafters. One is a 30-60-degree triangle, usually written as 30°-60° triangle. The other is a 45-degree triangle, written as 45° triangle. The 45° triangle consists of two 45-degree angles, and one 90-degree angle, Figure 1-30A. The

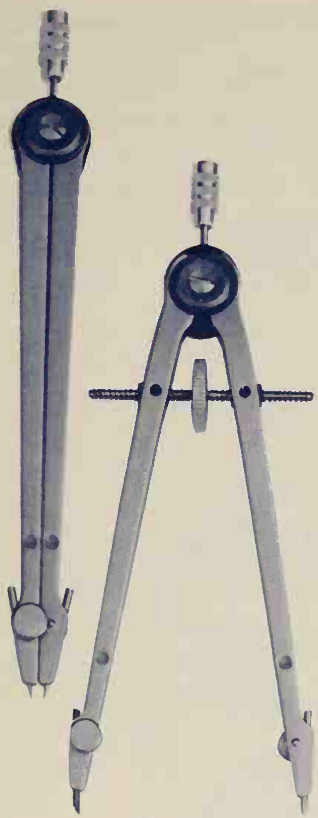


Figure 1-28 Divider (*Courtesy Vemco, Inc.*)

Figure 1-29 Proportional dividers (*Courtesy Modern School Supplies, Inc.*)

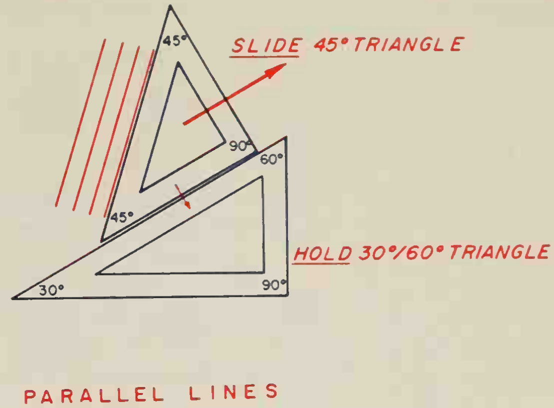


Figure 1-31 Drawing parallel angular lines

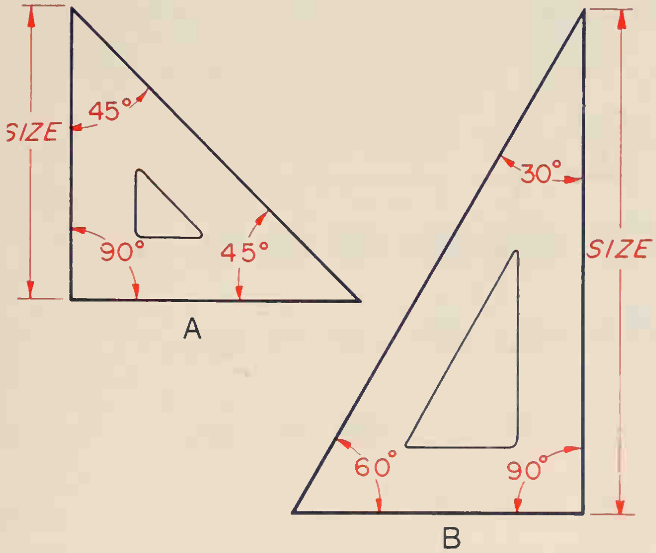


Figure 1-30 (A) 45° triangle, and (B) 30°-60° triangle

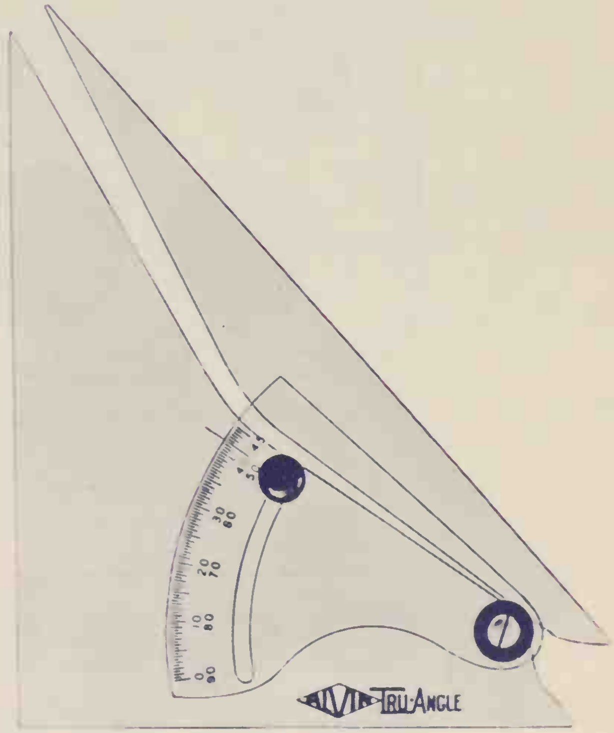


Figure 1-32 Adjustable triangle (*Courtesy Modern School Supplies, Inc.*)

30°-60° triangle contains a 30-degree angle, a 60-degree angle, and a 90-degree angle, Figure 1-30B.

Triangles are made of plastic and come in a variety of sizes other than those mentioned. When laying out lines, triangles are placed firmly against the upper edge of the straightedge. Pencils are placed against the left edge of the triangle and lines drawn upwards, away from the straightedge. Parallel angular lines are made by moving the triangle to the right after each new line has been drawn, Figure 1-31.

Adjustable Triangle An adjustable triangle may take the place of both the 30°-60° and 45° triangles, Figure 1-32. It is recommended, however, that this tool be used only for drawing angles that cannot be made with the two standard triangles. The adjustable triangle is set by eye and thus is not as accurate as the solid triangle.

Template

A template is a thin, flat piece of plastic containing various cutout shapes, Figures 1-33, 1-34, and 1-35. It is designed to speed the work of the drafter and to make the finished drawing more accurate. Templates are available for drawing circles, ellipses, plumbing fixtures, bolts and nuts, screw threads, electronic symbols, springs, gears, and structural metals, to name just a few uses.

Templates come in many sizes to fit the scale being used on the drawing. A template should be used wherever possible to increase accuracy and speed. It is preferable to purchase templates that are stamped and not molded, as molded templates become brittle in time and break.

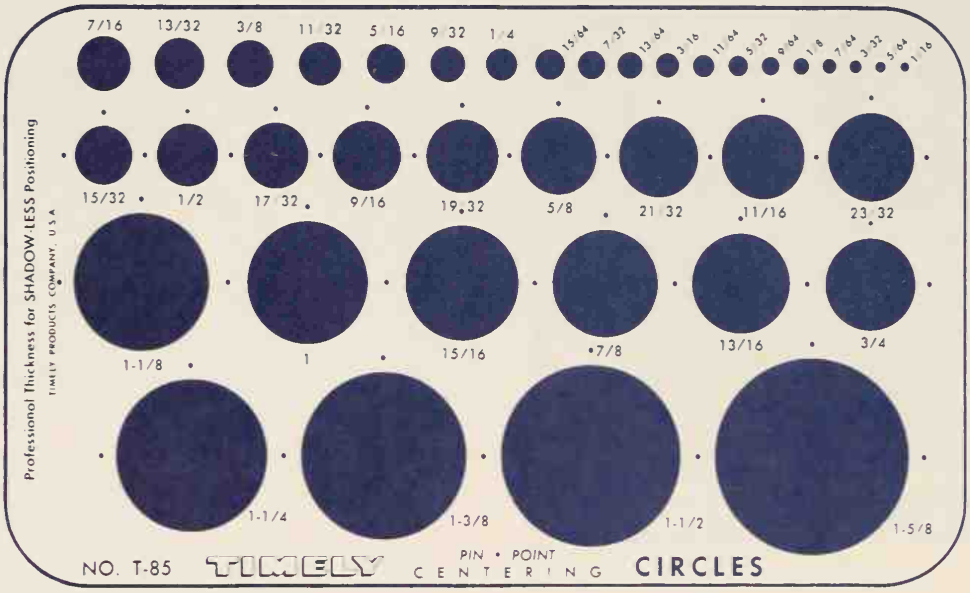


Figure 1-33 Circle template (*Courtesy Timely Products Co.*)

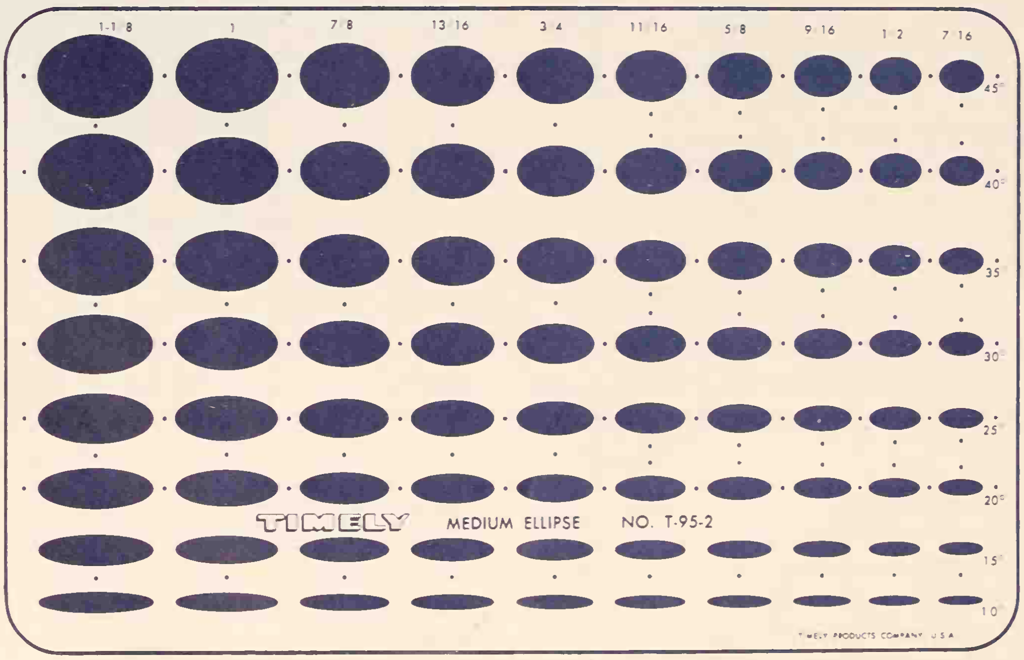


Figure 1-34 Ellipse template (*Courtesy Timely Products Co.*)

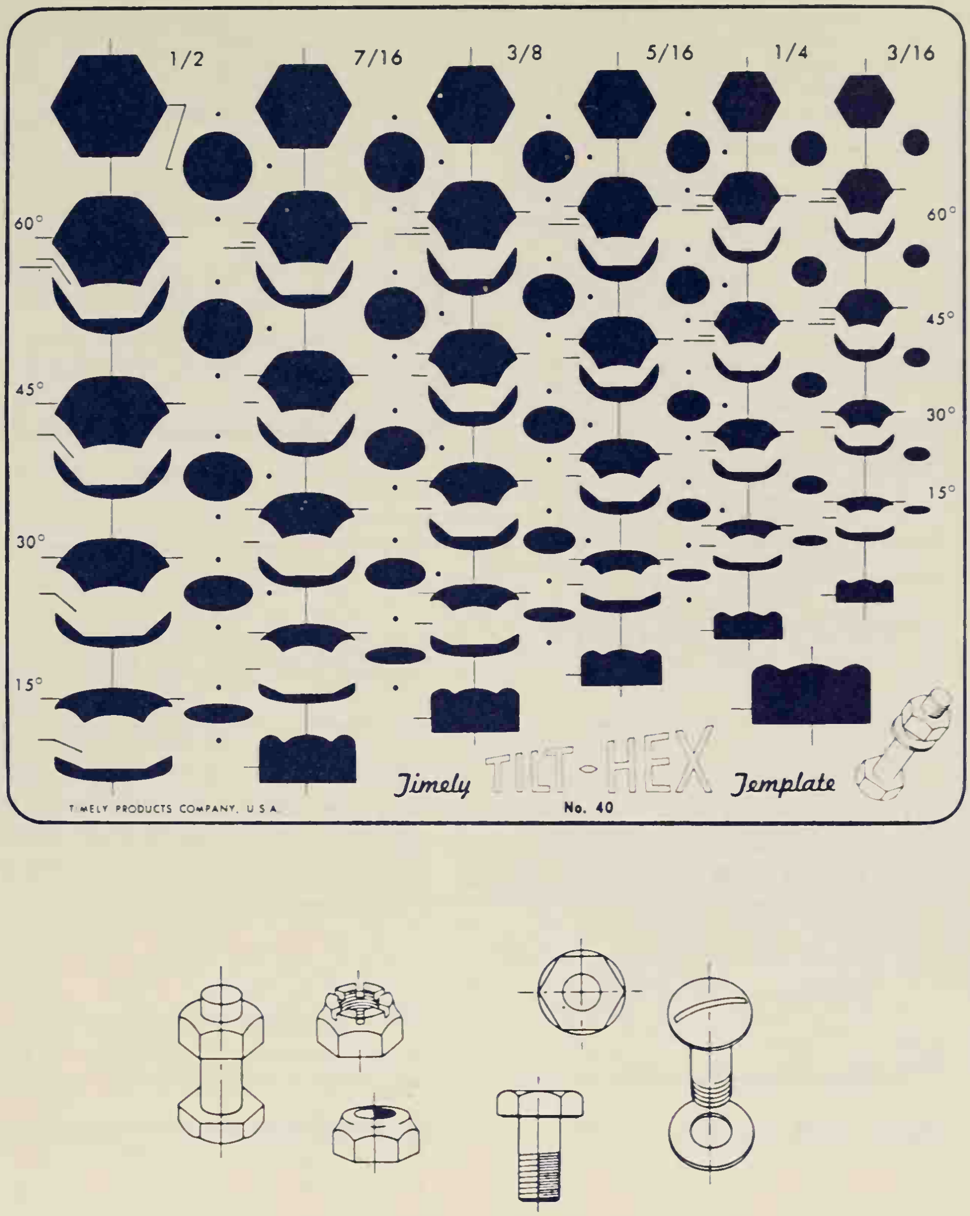


Figure 1-35 Bolt and nut template (*Courtesy Timely Products Co.*)

French Curves

French curves are thin, plastic tools that come in an assortment of curved surfaces, Figure 1-36. They are used to produce curved lines that cannot be made with a compass. Such lines are referred to as *irregular curves*. Most good French curves are actually segments of such geometric curves as ellipses, parabolas, hyperbolas, and the like.

Using a French Curve To use a French curve, the irregular curve must be defined by a series of dots. *Lightly* connect straight lines to get a general idea of where the curved line is going. If the line makes an abrupt turn, a line *lightly* sketched in place of the straight lines may be more useful. Starting from one side or the other, line up the French curve along as many points as possible and draw a dark line connecting these points, Figure 1-37. Readjust and align the French curve along all additional points, and continue drawing the curved line. Proceed in this manner until the line is completed.

Adjustable Curve Adjustable curves form smooth curves. Figure 1-38 shows a flexible steel measuring tape that measures the perimeter of the curve to be drawn. The curve is held by friction between many layers of interlocking channels.

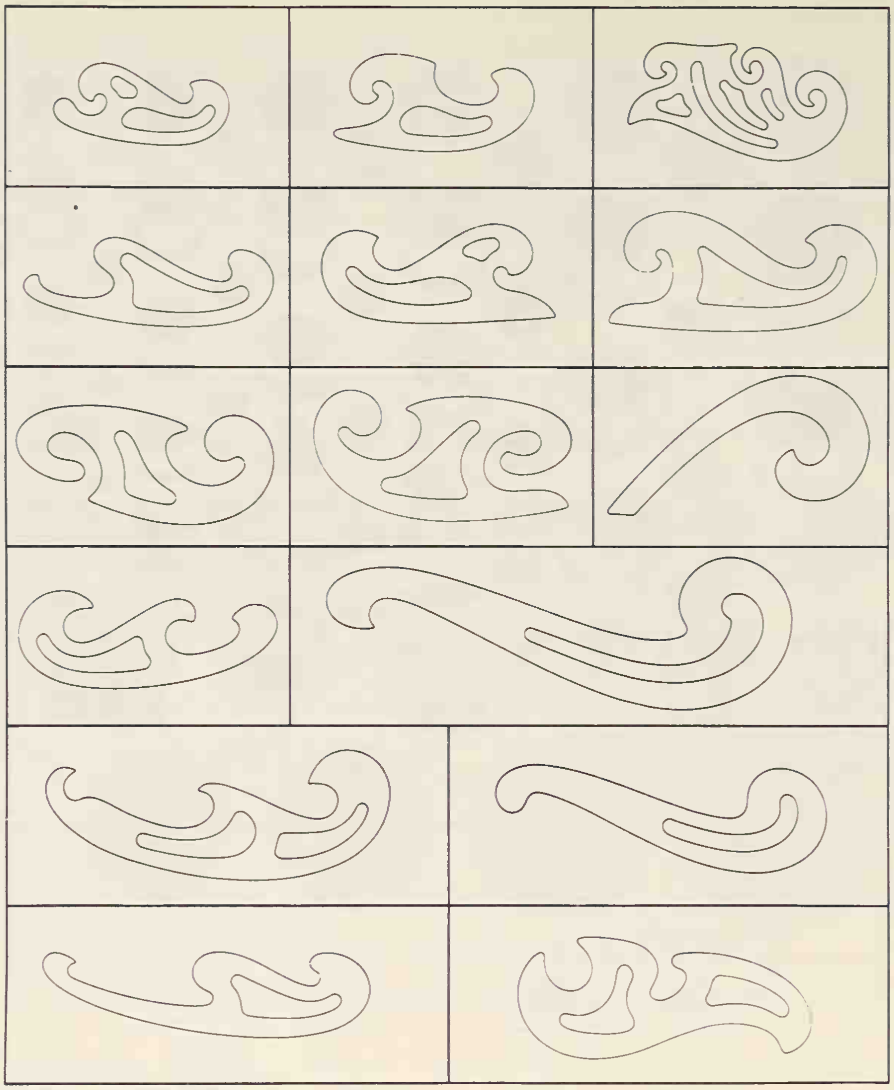


Figure 1-36 Assortment of French curves (*Courtesy Modern School Supplies, Inc.*)

Figure 1-37 Drawing an irregular curve (*Courtesy Koh-I-Noor Rapidograph*)

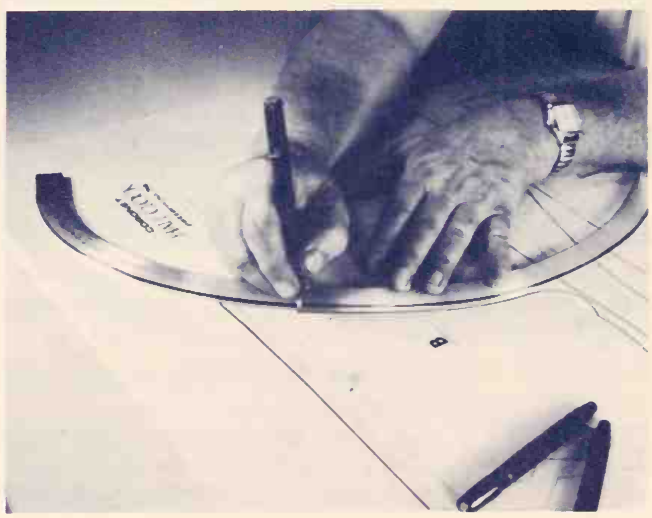


Figure 1-38 Using an adjustable curve (*Courtesy Hoyle Products, Inc.*)

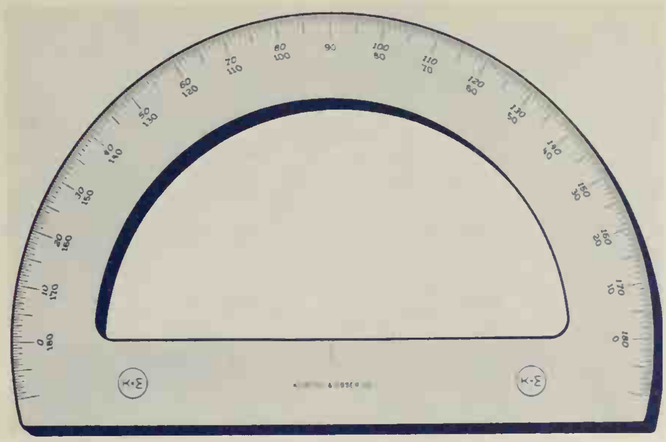


Figure 1-39 Protractor (*Courtesy Keuffel & Esser Co.*)

Protractor

A protractor is used to measure and lay out angles, Figure 1-39. It can be used in place of a drafting machine or an adjustable triangle.

To use the protractor, place the center point (located at the lower edge of the protractor) on the corner point of the angle. Align the base of the protractor along one side of the angle. The degrees are read along the semicircular edge.

Pencils and Leads

Lead for a mechanical drafting pencil comes in 18 degrees of hardness, ranging from 9H, which is very hard, to 7B, which is very soft, Figure 1-40. For drafting purposes, the scale of hardness is as follows: 4H lead is recommended for layout work, and 2H lead is recommended for all other lines. Experiment with various leads to determine which ones give the best line thickness. This varies depending upon the pressure applied to the point while drawing lines. Figure 1-41 shows leads for a mechanical drafting pencil.

Regular pencils are sharpened with a pencil sharpener. It is important that enough wood is removed to ensure that the lead, not the wood, of the pencil comes in contact with the straightedge or triangle edges.

Lead Holders and Leads

Lead holders hold sticks of lead, Figure 1-42. The leads designed for lead holders come in the same range of hardness as those for regular mechanical pencils, and are used for the same purposes. The main advantage is that they are more convenient to use. Leads are usually sharpened in a lead pointer. Electric lead pointers are fully automatic. A slight

TASK	LEAD
CONSTRUCTION LINES	3H, 2H
GUIDE LINES	3H, 2H
LETTERING	H, F, HB
DIMENSION LINES	2H, H
LEADERLINES	2H, H
HIDDEN LINES	2H, H
CROSSHATCHING LINES	2H, H
CENTERLINES	2H, H
PHANTOM LINES	2H, H
STITCH LINES	2H, H
LONG BREAK LINES	2H, H
VISIBLE LINES	H, F, HB
CUTTING PLANE LINES	H, F, HB
EXTENSION LINES	2H, H
FREEHAND BREAK LINES	H, F, HB

Figure 1-40 Grades of lead (top) and lead-lines chart (bottom)

Figure 1-41 Drafting lead (*Courtesy Staedtler Mars*)

Figure 1-42 Lead holder (*Courtesy Teledyne Post*)

Figure 1-43 lead pointer (*Courtesy Koh-I-Noor Rapidograph, Inc.*)

downward pressure of the lead starts the motor action, Figure 1-43. This machine produces a perfectly tapered point, and eliminates all loose clinging graphite.

Sandpaper Paddle A sandpaper paddle consists of several layers of sandpaper attached to a small wooden holder, Figure 1-44. The sandpaper is used to sharpen compass leads only. Do not sharpen leads over a drawing as the graphite will smear the drawing surface.

Erasers

Various kinds of erasers are available to a drafter. One of the most commonly used is a soft, white block-type eraser, Figure 1-45. Figure 1-46 shows a pencil-type eraser with an adjustable clutch. By developing good drawing habits, erasing can be kept to a minimum.

Figure 1-44 Sandpaper paddle (*Courtesy Keuffel & Esser Co.*)

Figure 1-45 Block-type eraser (*Courtesy Staedtler Mars*)

Figure 1-46 Pencil-type eraser with clutch (*Courtesy Staedtler Mars*)

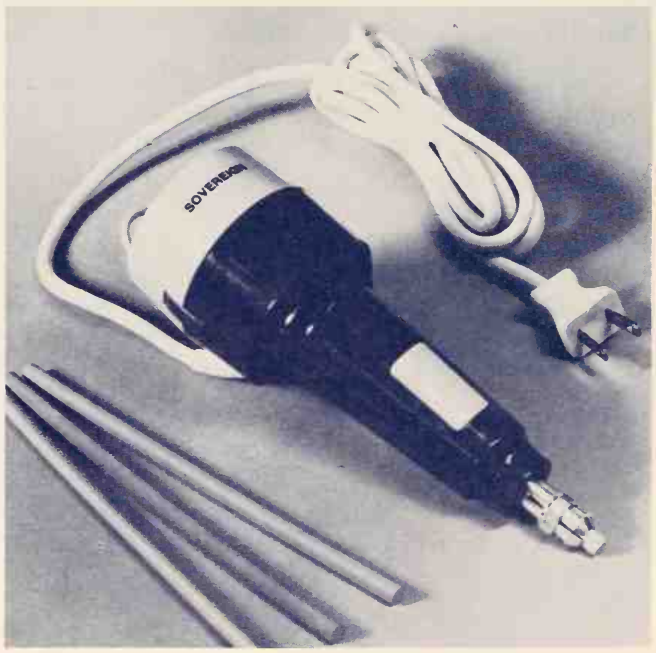


Figure 1-47 Electric eraser with slip clutch (*Courtesy Rotex Co.*)

Electric Eraser An electric eraser speeds up corrections. Some models take a 7" (17.5 cm) long eraser strip. The model illustrated in Figure 1-47 has a slip clutch to hold the eraser strip in place.

Figure 1-48 Rechargeable electric eraser (*Courtesy Rotex Co.*)

Figure 1-49 Erasing shield (*Courtesy Staedtler Mars*)

A cordless erasing machine can be used with or without the standard electric cord, and uses rechargeable NiCad batteries, Figure 1-48. As the eraser is placed in the stand, the batteries are recharged.

Electric erasers do save time, but care must be taken not to burn through the drawing paper. This can be avoided by using an erasing shield and placing a thick sheet of paper beneath the drawing to cushion it.

Erasing Shield An erasing shield restricts the erasing area so that correctly drawn lines will not be disturbed during the erasing procedure. It is made from a thin, flat piece of metal with variously sized cutouts, Figure 1-49. The shield is used by placing it over the line to be erased and erasing through the cutout.

Figure 1-50 Drafting brush (*Courtesy Hearlihy & Co.*)

Drafting Brush

The drafting brush is used to remove loose graphite and eraser crumbs from the drawing surface, Figure 1-50. Do not brush off a drawing surface by hand as this tends to smudge the drawing. Drafting brushes come in various sizes from 10½" to 14" (26 cm to 35 cm). The bristles can be either horsehair or nylon, and they can be cleaned with warm, soapy water.

Dry Cleaning Powder

Cleaning powder is used to help keep drawings clean, to avoid smearing, and to speed up the drafting process. Cleaning powder comes in a can or as pads, Figure 1-51, and is sprinkled over the drawing before starting. It is imperative that all cleaning powder is removed before placing the original drawing into a whiteprinter as the powder tends to stick to the roller. If good drafting habits are followed, the dry cleaning powder is not necessary.

Scales

Various kinds of scales are used by drafters, Figure 1-52. A number of different scales are included on each instrument. Scales save the drafter the work of computing new measurements every time a drawing is made larger or smaller than the original.

Scales come open divided and full divided. A *full-divided scale* is one in which the units of measurement are subdivided throughout the length of the scale. An *open-divided scale* has its first unit of measurement subdivided, but the remaining units are open or free from subdivision.

Mechanical Engineer's Scale

Mechanical engineer's scales are divided into inches and parts to the inch. To lay out a full-size measurement, use the scale marked 16. This scale has each inch divided into 16 equal parts or divisions of 1/16 inch. It is used by placing the 0 on the

Figure 1-51 Dry cleaning powder (*Courtesy* Hearlihy & Co.)

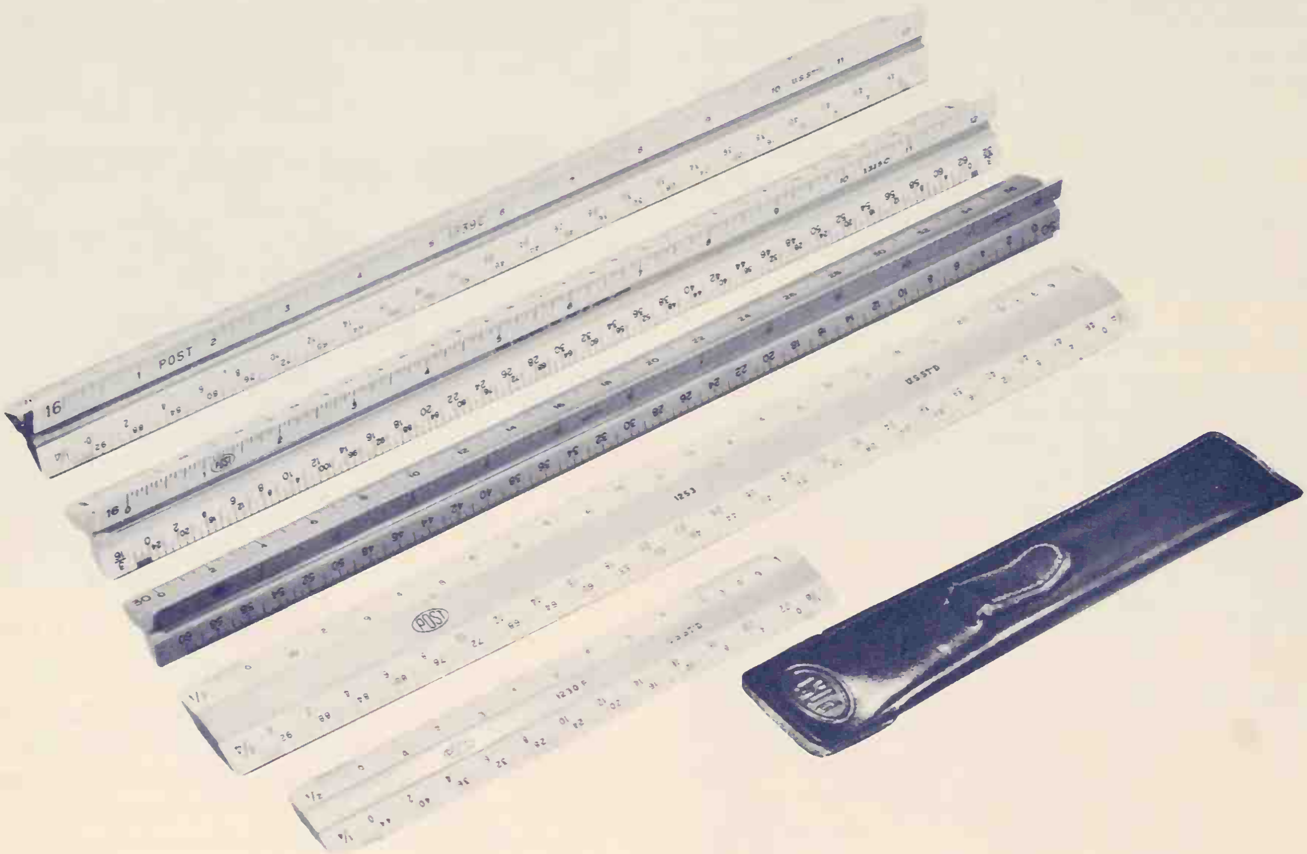


Figure 1-52 A variety of drafting scales (*Courtesy Teledyne Post*)

point where measurement begins, and stepping off the desired length, Figure 1-53.

To reduce a drawing 50 percent, use the scale marked 1/2. The large 0 at the end of the first subdivided measurement lines up with the other unit measurements that are part of the same scale. The large numbers crossed out in Figure 1-54 go with the 1/4 scale starting at the other end. These numbers are ignored while using the 1/2 scale. To lay out

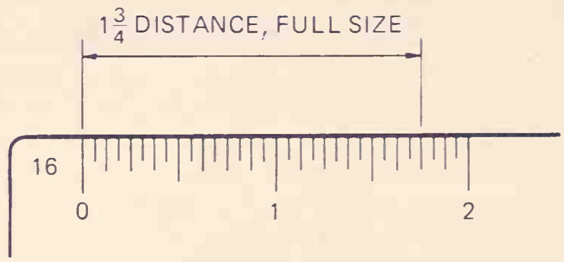


Figure 1-53 Regular full-size scale

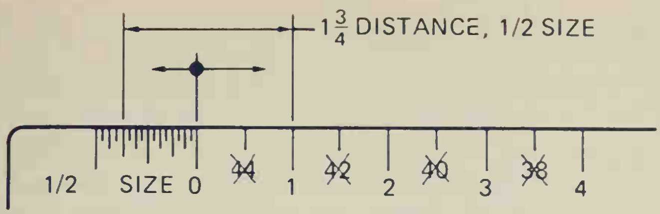


Figure 1-54 Half-size scale

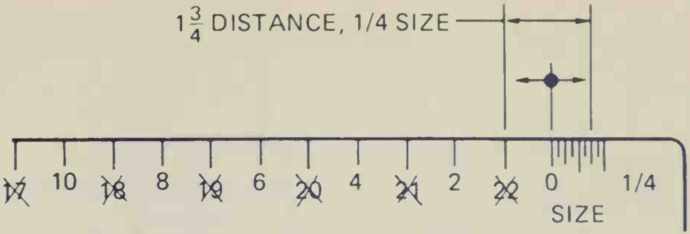


Figure 1-55 Quarter-size scale

1 3/4 inches at the 1/2 scale, read full inches to the right of 0 and fractions to the left of 0.

The 1/4 scale is used in the same manner as the 1/2 scale. However, measurements of full inches are made to the left of 0 and fractions to the right, because the 1/4 scale is located at the opposite end of the 1/2 scale, Figure 1-55.

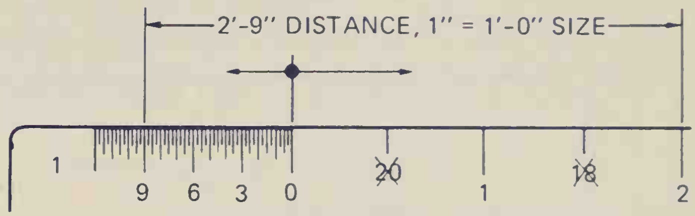


Figure 1-56 Architectural scale (full size)

Architect's Scale

The architect's scale is used primarily for drawing large buildings and structures. The full-size scale is used frequently for drawing smaller objects. Because of this, the architect's scale is generally used for all types of measurements. It is designed to measure in feet, inches, and fractions of an inch. Measure full feet to the right of 0; inches and fractions of an inch to the left of 0. The numbers crossed out in Figure 1-56 correspond to the 1/2 scale. They can be used, however, as 6 inches as each falls halfway between full-foot divisions. Measurements from 0 are made in the opposite direction of the full scale, because the 1/2 scale is located at the opposite end of the scale, Figure 1-57.

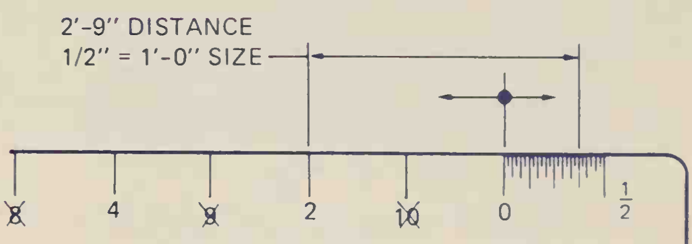


Figure 1-57 Architectural scale (half size)

Civil Engineer's Scale

A civil engineer's scale is also called a *decimal-inch scale*. The number 10, located in the corner of the scale in Figure 1-58, indicates that each graduation is equal to 1/10 of an inch or .1". Measurements are read directly from the scale. The number 20, located in the corner of the scale shown in Figure 1-59, indicates that it is 1/20 of an inch.

Using the same scale for civil drafting, one inch equals two hundred feet, Figure 1-60, and one inch equals one hundred feet, Figure 1-61.

A metric scale is used if the millimetre is the unit of linear measurement. It is read the same as the decimal-inch scale except that it is in millimetres, Figure 1-62.

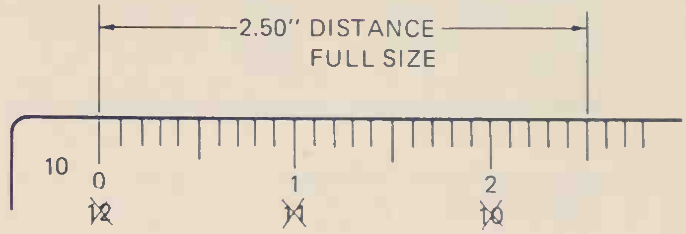


Figure 1-58 Civil engineer's scale

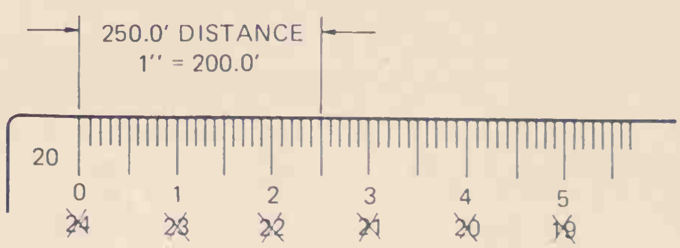


Figure 1-59 Civil engineer's scale (half scale)

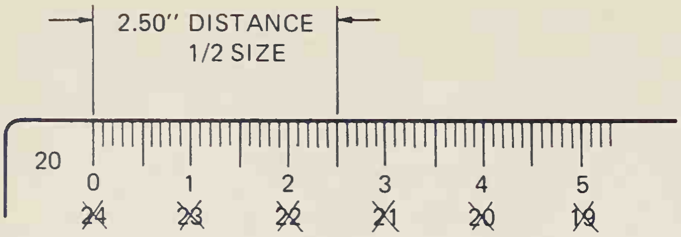


Figure 1-60 Mechanical scale (half size)

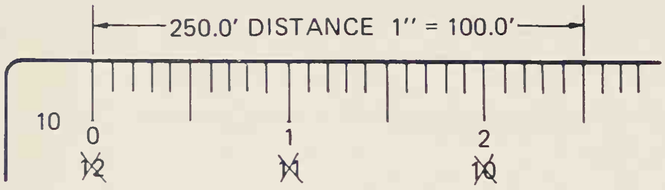


Figure 1-61 Civil scale

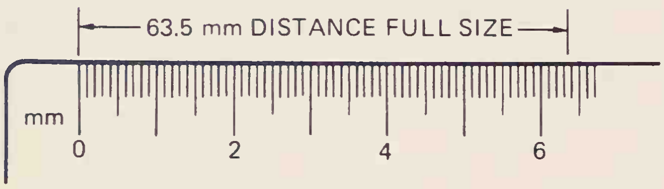


Figure 1-62 Metric scale

Pocket Steel Ruler

The drafter should make use of a pocket steel ruler. The pocket steel ruler is the easiest of all measuring tools to use. The inch scale, Figure 1-63, is six inches long, and is graduated in 10ths and 100ths of an inch on one side and 32nds and 64ths on the other side.

The metric scale is 150 millimetres long (approximately six inches) and is graduated in millimetres and half millimetres on one side, Figure 1-64. Sometimes metric pocket steel rulers are graduated in 64ths of an inch on the other side.

Measuring

The metric system uses the metre (m) as its basic dimension. A metre is 3.281 feet long or about 3 3/8 inches longer than a yardstick. Its multiples, or parts, are expressed by adding prefixes. These prefixes represent equal steps of 1000 parts. The prefix for a thousand (1000) is *kilo*; the prefix for a thousandth (1/1000) is *milli*. One thousand metres (1000 m), therefore, equals one kilometre (1.0 km). One thousandth of a metre (1/1000 m) equals one millimetre (1.0 mm). Comparing metric to English then:

One millimetre (1.0 mm) = 0.001 metre (0.01 m) = .03937 inch
One thousand millimetres (1000 mm) = 1.0 metre (1.0 m) = 3.281 feet
One thousand metres (1000 m) = 1.0 kilometre (1.0 km) = 3281.0 feet

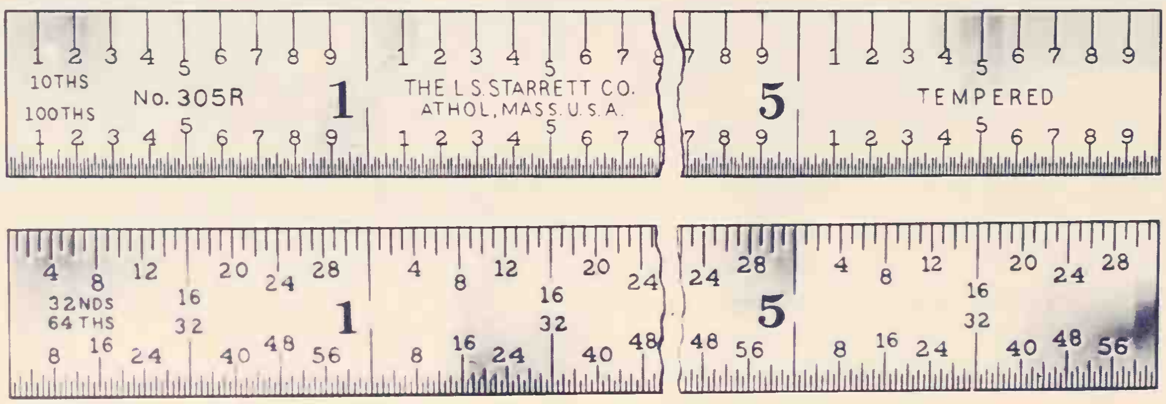


Figure 1-63 Steel scale (inch) (*Courtesy* L. S. Starrett Co.)

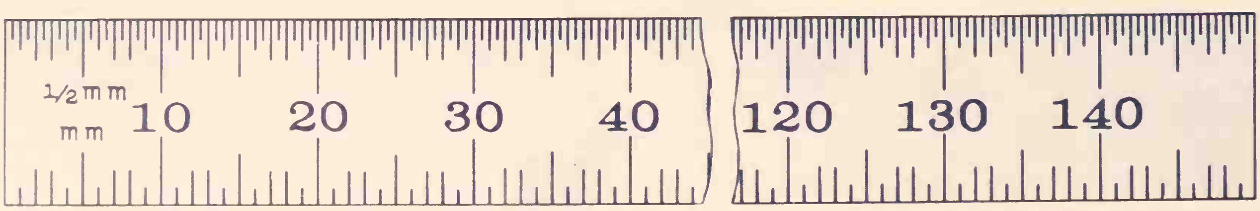


Figure 1-64 Steel scale (metric) (*Courtesy* L. S. Starrett Co.)

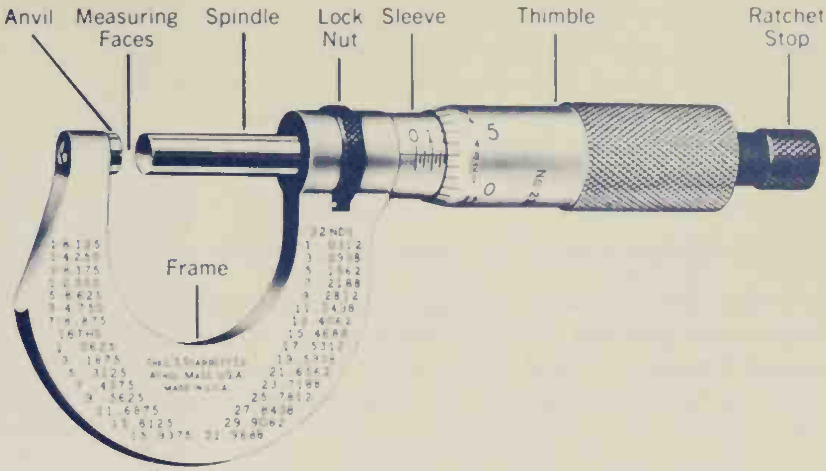


Figure 1-65 Micrometer (*Courtesy* L. S. *Starrett Co.*)

How To Read a Micrometer Graduated in Thousandths of an Inch (.001")

A micrometer consists of a highly accurate ground screw or spindle which is rotated in a fixed nut, thus opening or closing the distance between two measuring faces on the ends of the anvil and spindle, Figure 1-65. A piece of work is measured by placing it between the anvil and spindle faces, and rotating the spindle by means of the thimble until the anvil and spindle both contact the work. The desired work dimension is then found from the micrometer reading indicated by the graduations on the sleeve and thimble, as described in the following paragraphs.

Since the pitch of the screw thread on the spindle is 1/40" or 40 threads per inch in micrometers that are graduated to measure in inches, one complete revolution of the thimble advances the spindle face toward or away from the anvil face precisely 1/40 or .025 inch.

The reading line on the sleeve is divided into 40 equal parts by vertical lines that correspond to the number of threads on the spindle. Therefore, each vertical line designates 1/40 or .025 inch and every fourth line, which is longer than the others, designates hundreds of thousandths. For example: the line marked "1" represents .100", the line marked "2" represents .200", and the line marked "3" represents .300", and so forth.

The beveled edge of the thimble is divided into 25 equal parts, with each line representing .001" and every line numbered consecutively. Rotating the thimble from one of these lines to the next moves the spindle longitudinally 1/25 of .025" or .001 inch; rotating two divisions represents .002", and so forth. Twenty-five divisions indicate a complete revolution: .025 or 1/40 of an inch.

To read the micrometer in thousandths, multiply the number of vertical divisions visible on the sleeve by .025", and to this add the number of thousandths indicated by the line on the thimble which coincides with the reading line on the sleeve.

Example (See Figure 1-66):

The 1" line on the sleeve is visible, representing 100"

Three additional lines are visible, each representing .025". Thus, 3 x .025" = .075"

The third line on the thimble coincides with the reading line on the sleeve, each line representing .001". Thus, 3 x .001" = .003"

The micrometer reading is 100" + .075" + .003" = .178"

An easy way to remember how to read a micrometer is to think of the various units as if you were making change from a ten dollar bill. Count the figures on the sleeve as dollars, the vertical lines on the sleeve as quarters, and the divisions on the thimble as cents. Add up your change and put a decimal point instead of a dollar sign in front of the figures.

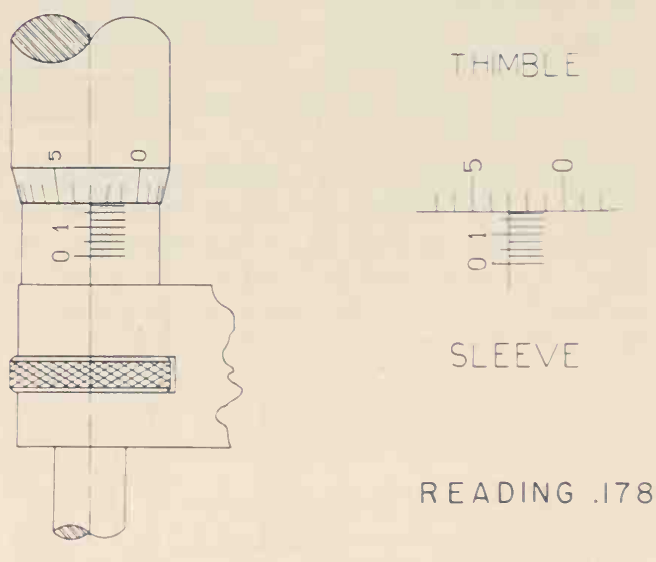


Figure 1-66 Reading a micrometer (*Courtesy* L. S. *Starrett Co.*)

Micrometers come in both English and metric graduations. They are manufactured with an English size range of 1 inch through 60 inches, and a metric size range of 25 millimetres to 1500 millimetres. The micrometer is a very sensitive device and must be treated with extreme care.

Vernier Caliper

Vernier calipers have the capability of measuring both the outside and the inside measurements of an object, Figures 1-67 and 1-68. Use the bottom scale when measuring an outside size. Use the top scale when measuring an inside size.

Microfinish Comparator

The microfinish comparator is a handy tool for the drafter to approximate surface irregularities. Various kinds of microfinish comparators are available. Figure 1-69 illustrates a comparator for cast surfaces.

Ellipses Instrument

Two unique instruments are used to draw large ellipses. An ellipsograph is shown in Figure 1-70A. The OvalCompass is shown in Figure 1-70B. With these tools, the height and width of the ellipse are measured, locked-in, and quickly drawn. A template is used to draw small ellipses.

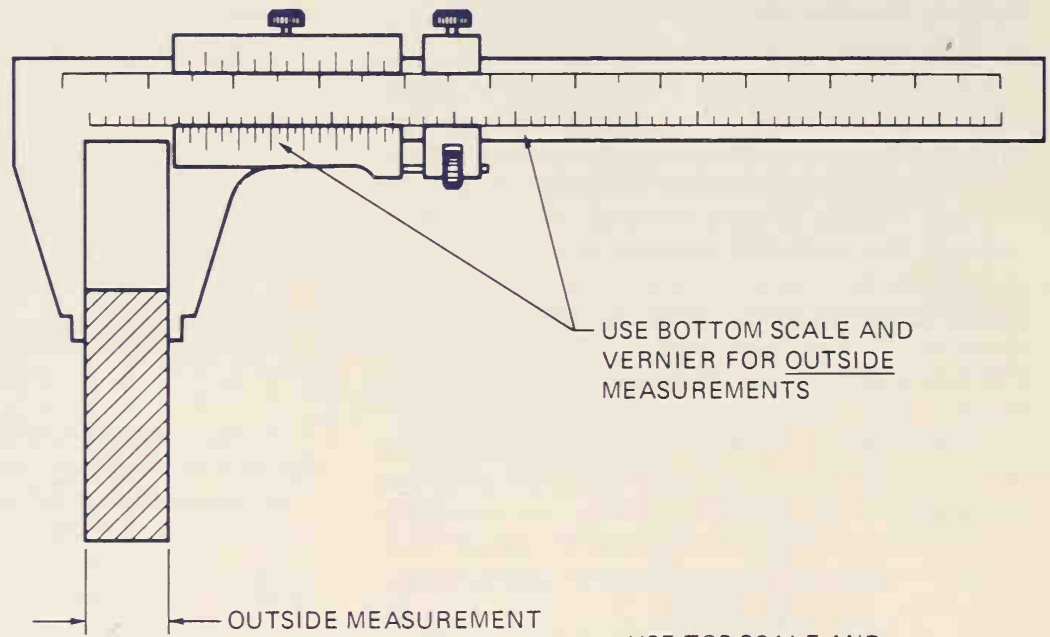


Figure 1-67 Caliper—outside measurement

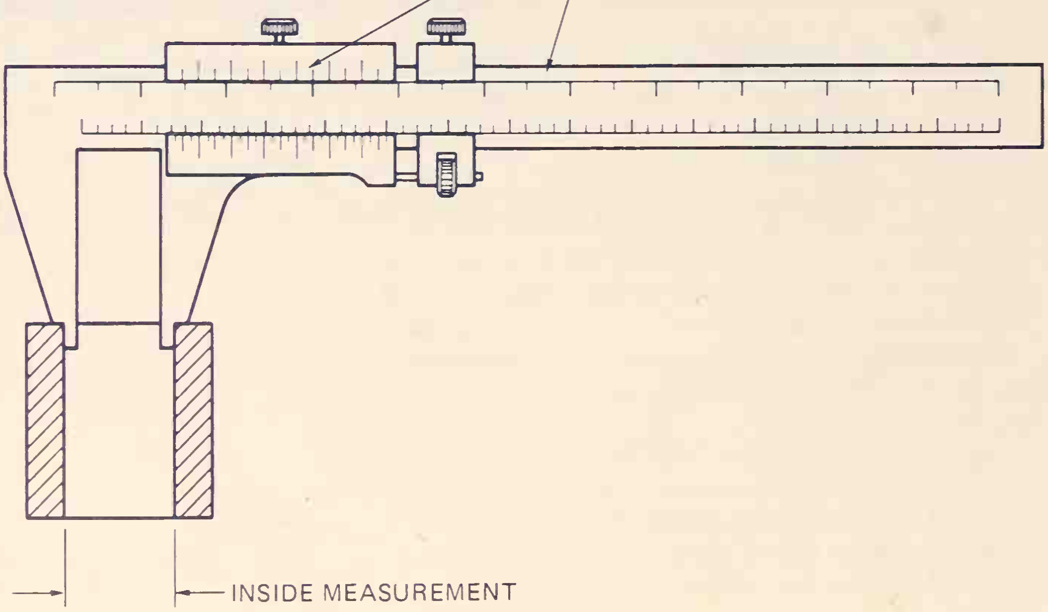


Figure 1-68 Caliper—inside measurement

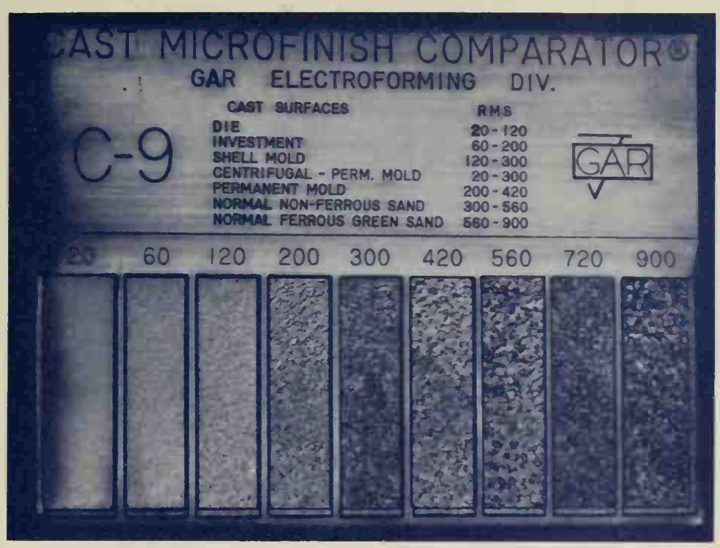


Figure 1-69 Microfinish comparator (*Courtesy* GAR *Electroforming* Div., Mite *Corp.*)

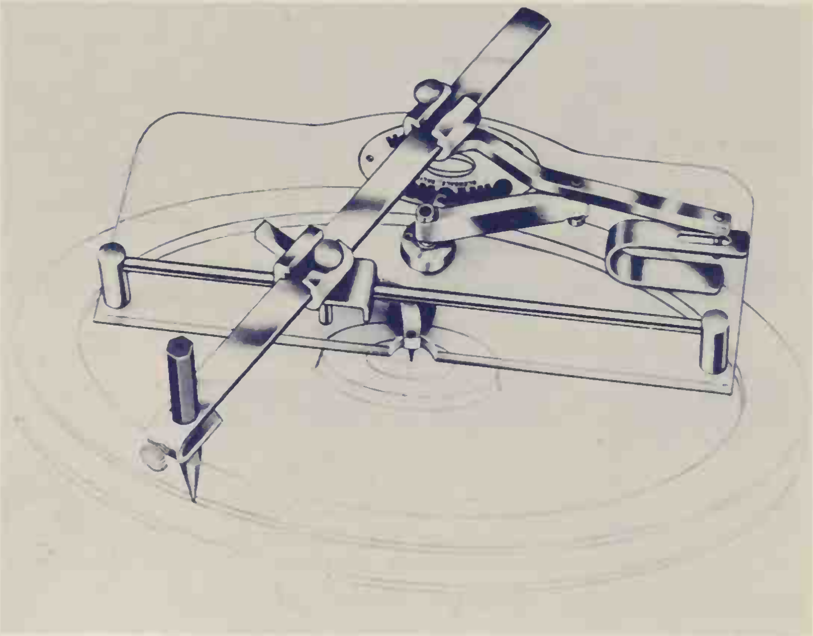


Figure 1-70A Ellipsograph (*Courtesy Omicron Co.*)

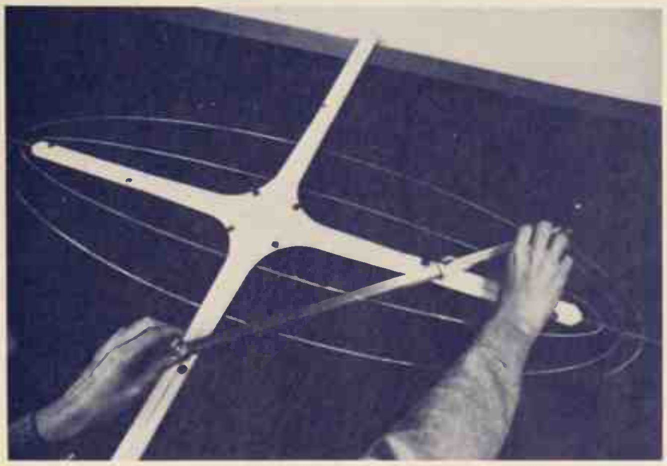


Figure 1-70 B Oval compass (*Courtesy Oval Compass*)

Ink Tools

Some fields of drafting, such as civil (map) drafting, require that all drawings be done in ink. Some companies ink their drawings so that they can be reduced and filed on film. All artwork that is to be reproduced by camera, such as in the field of technical illustration, is done in ink. Ink drawing is no more difficult than pencil drawing, Figure 1-71.

Technical Pens

The key to successful inking is a good technical pen, Figure 1-72. Technical pens are produced in two styles. Notice the ends of the two pens in the figure: one has a tapered end, the other a straight end. The

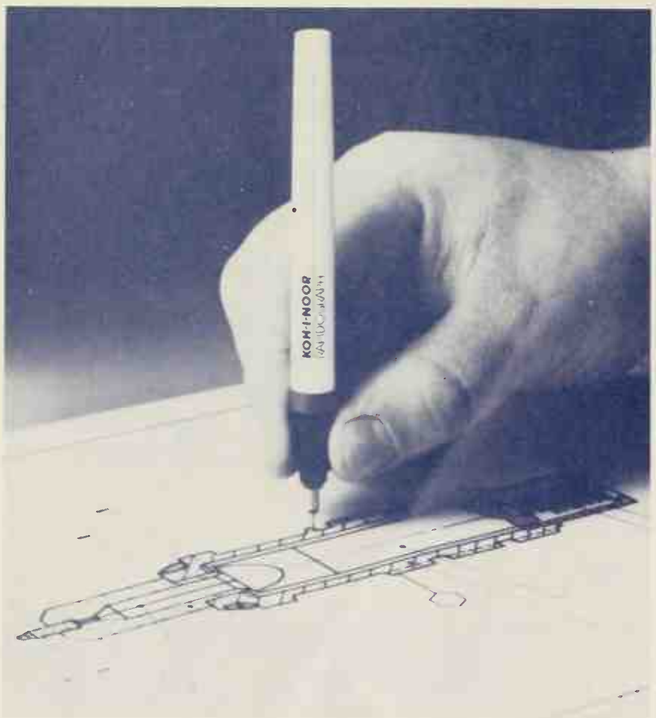


Figure 1-71 Technical inking pen (*Courtesy Koh-I-Noor Rapidograph*)

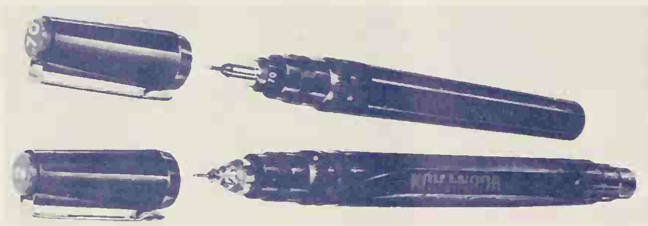


Figure 1-72 Drafting and art technical pens (*Courtesy Koh-I-Noor Rapidograph*)

tapered pen is used primarily for artwork; the straight end is used for drafting and mechanical lettering. Pens are available in various sizes and styles of pen-holder sets, Figures 1-73 and 1-74.

Technical pen points are manufactured of stainless steel, tungsten or jewels. The stainless steel point is chromium plated for use on tracing paper or vellum. Tungsten points are long wearing for use on abrasive, coated plotting film or triacetate. Jewel points are used on a plotter that has a controlled pen force.

Pen points are available in thirteen standard sizes of varying widths, Figure 1-75. For general drafting inking, numbers .45/1 and .70/2½ are recommended.

Cleaning Technical Pens

Pens should be cleaned when they get sluggish or before storing them for long periods of time. The parts of most technical inking pens are similar to those shown in Figure 1-76. When not in use, technical pens

Figure 1-73 Revolving pen holder (*Courtesy Koh-I-Noor Rapidograph*)

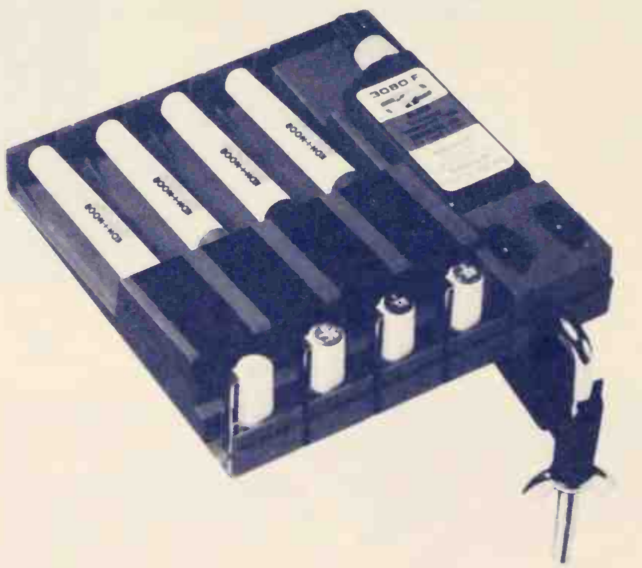


Figure 1-74 Flat pack pen holder (*Courtesy Koh-I-Noor Rapidograph*)

should be kept in a storage clamp or else capped to prevent ink from drying in the point. If a pen does get clogged, remove the point and hold it under warm tap water. This normally softens the ink. If the ink has dried, use an ultrasonic cleaner or a mild solvent. If the pens will not be used for a week or more, all

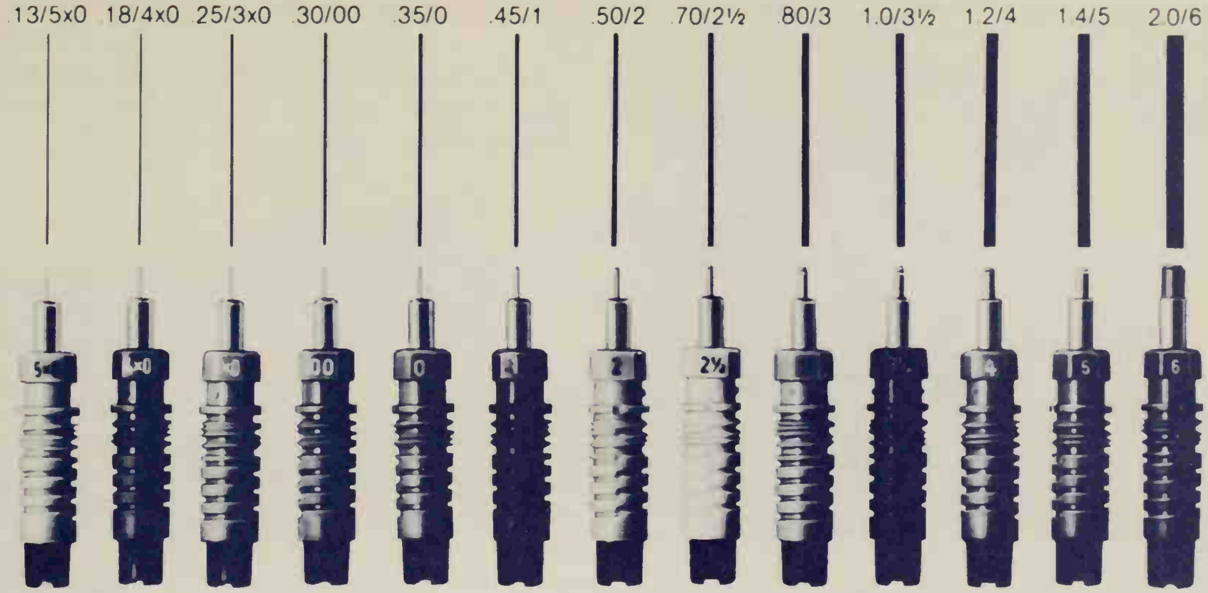


Figure 1-75 Pen sizes (*Courtesy Staedtler Mars*)

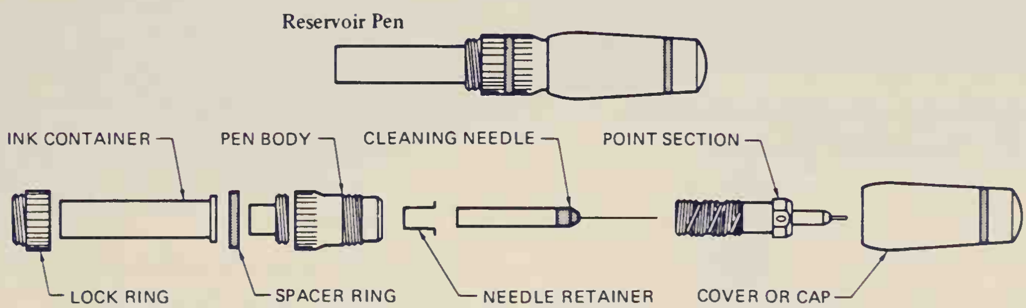


Figure 1-76 Internal parts of a technical inking pen

ink should be removed and the pens stored empty and clean. Care must be taken when removing and replacing the cleaning needle. An ultrasonic cleaner is used quickly and efficiently to clean technical pens, Figure 1-77.

When pens are to be cleaned by hand, use the following recommended steps:

Cleaning. Pens can be ruined by improper cleaning. Study Steps 1 through 5 and follow them closely when cleaning pens. (Refer again to Figure 1-76.)

Step 1. Remove the cap and the ink container.

Step 2. Soak the body of the pen in hot water. The ink container should also be soaked if ink has dried in it.

Step 3. After soaking, remove the pen body from the water. Hold the knurled part of the body with the top downward. Unscrew and remove the point section. Remove the end of the cleaning needle weight. Do not bend the cleaning needle or it will break.

Step 4. Immerse all body parts in a good pen-cleaning fluid or hot water mixed half with ammonia.

Step 5. Dry and clean.

Filling. To fill the pen, follow Steps 1 through 5:

Step 1. Unscrew and remove the knurled lock ring.

Step 2. Remove the ink container. Leave the spacer ring in place.

Step 3. Fill the ink container with lettering ink. Do not fill it more than ¾ inch from top.

Step 4. Hold the filled container upright and insert the pen body into the container.

Step 5. Replace the knurled lock ring.

Ink

A high-quality, fast-drying ink must be used in technical pens for the best results. The ink must be black

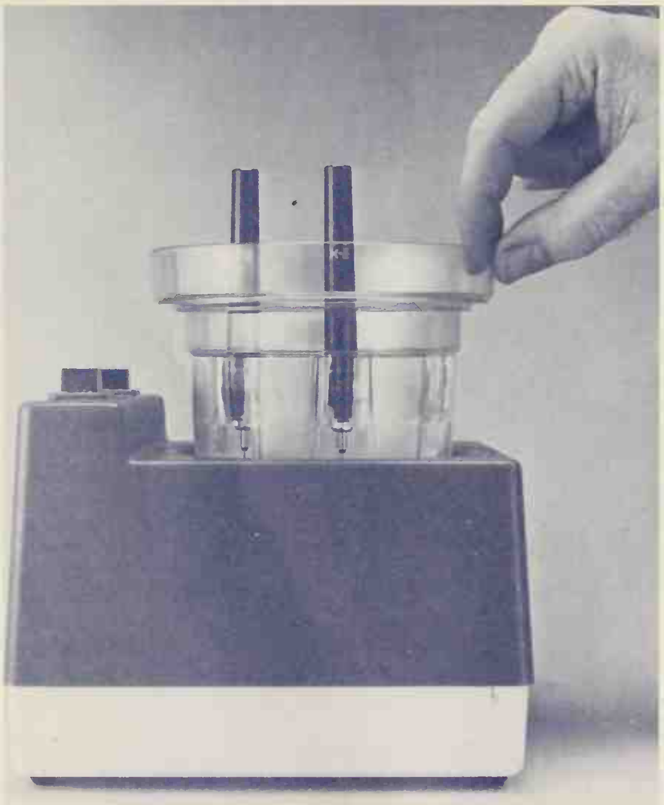


Figure 1-77 Technical pen ultrasonic cleaner (*Courtesy Keuffel & Esser Co.*)

Figure 1-78 Drawing ink

and erasable, and it must not crack, chip or peel, Figure 1-78. Keep inks out of extremely warm or cold temperatures. The bottles or jars should be kept airtight, and the excess ink should be cleaned from the neck of the container to keep it from drying in the cap. Inks in large containers should be transferred to smaller bottles or directly into pens, *away from working areas to avoid the possibility of spillage.*

Mechanical Lettering Sets

Lettering sets come in a variety of sizes and templates, Figure 1-79. All sets contain a scriber, and various pen sizes and templates.

Scriber Templates

Scriber templates consist of laminated strips with engraved grooves which are used to form letters. A tracer pin moving in the grooves guides the scriber pen (or pencil) in forming the letters, Figure 1-80.

Guides for different sizes and kinds of letters are available for any of the lettering devices. Different point sizes are made for special pens so that fine lines can be used for small letters and wide lines for large letters. Scribers may be adjusted to form vertical or slanted letters of several sizes from a single guide by simply unlocking the screw underneath the scriber and extending the arms, Figure 1-81.

One of the principal advantages of lettering guides is that they maintain uniform lettering. This is especially useful where many drafters are involved. Another important use is for the lettering of titles, and note headings and numbers on drawings and reports.

Letters used to identify templates are:

U = Uppercase
L = Lowercase
N = Numbers

Thus, a template identified as 8-ULN means it is 8/16 inch high (1/2"), and has uppercase letters and lowercase letters, and numbers.

Tracing Pin Better, more expensive scribers use a double tracing pin, Figure 1-82. The blunt end is used for single-stroke lettering templates or very large templates that have wide grooves. The sharp end is used for very small lettering templates, double-stroke letters or script-type lettering using a fine groove. Most tracing pins have a sharp point, but some do not. Always screw the cap back on the unused end after turning the tracing pin to the desired tip. Be careful with the points as they will break if dropped and can cause a painful injury if mishandled.

Standard Template

Learning to form mechanical letters requires a great deal of practice. Figure 1-83 shows a template having three sets of uppercase and lowercase letters. Practice forming each size letter and number until they can be made rapidly and neatly. Use a very light, delicate touch so as not to damage the template, scriber or pen.

Size of Letters The size or height of the lettering on a template is called out by the number used to iden-

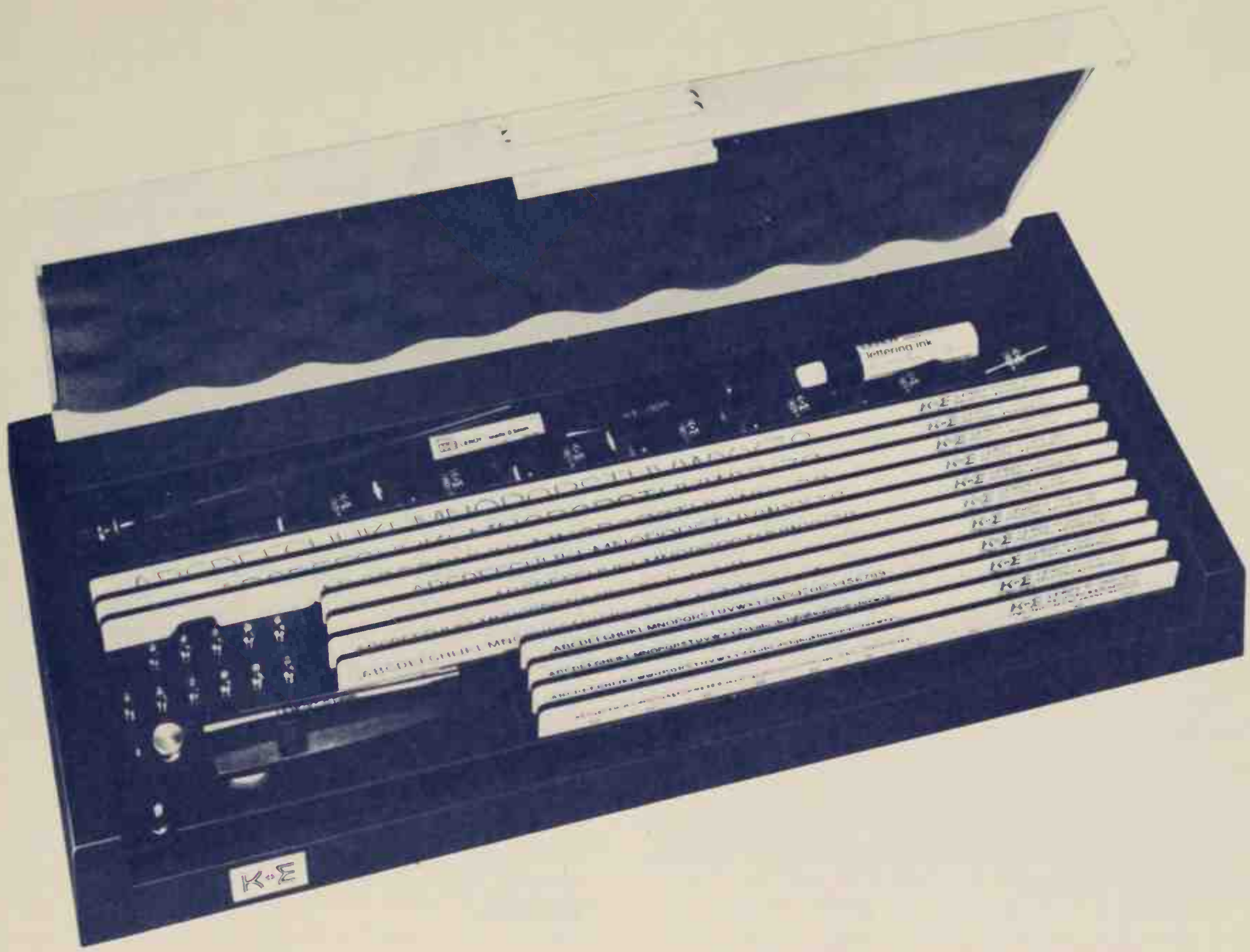


Figure 1-79 Lettering set (*Courtesy Keuffel & Esser Co.*)

Figure 1-80 Forming letters with a scriber (*Courtesy Koh-I-Noor Rapidograph*)

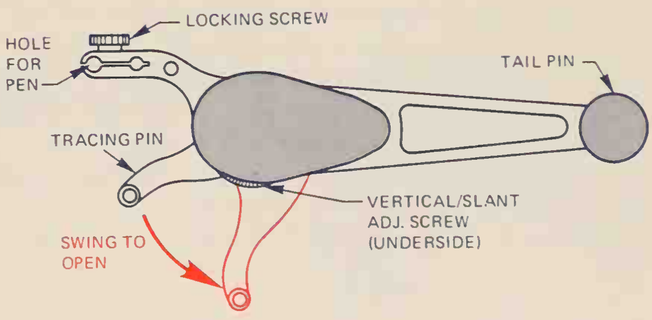


Figure 1-81 Scribers are adjustable

tify each set. Sizes are in thousandths of an inch. A #100 is .100 inch high, or slightly less than an eighth of an inch; a #240 is .240 inch high, or slightly less than a quarter of an inch.

Another system to determine template size uses simple numbers. These numbers are placed above

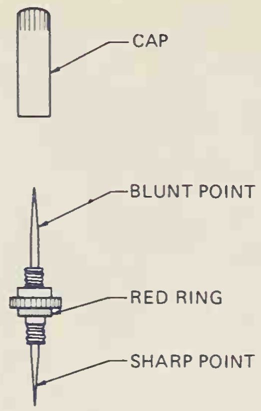


Figure 1-82 Double tracing pen

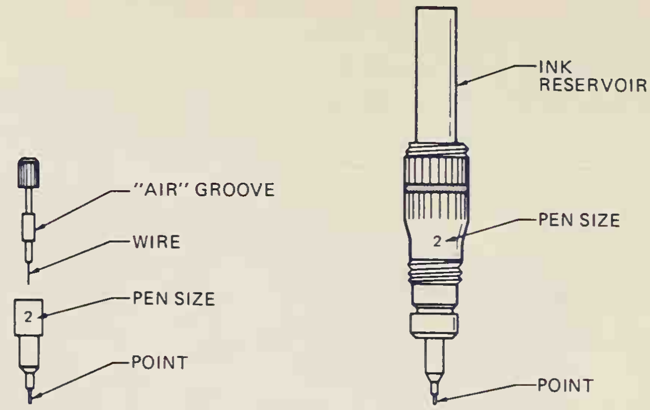


Figure 1-84 Ink pens used for lettering

the number 16 to indicate the fraction height of the letter. For instance, the number 3 placed above the number 16 would read as 3/16 inch in height.

Pens

There are two types of pens: the regular pen and the reservoir pen, Figure 1-84. The regular pen must be cleaned after each use. The reservoir pen should be cleaned when it gets sluggish or before being stored for long periods of time. This procedure is the same as it is for the cleaning of technical pens as described previously.

Butterfly-Type Scriber

Basic Parts

The butterfly-type scriber shown in Figure 1-85 is a delicate, precision tool that does its job without requiring any adjustments, repairs or maintenance. The clear plastic base of the scriber bears the setting chart used in adjusting the pen arm for enlargements, reductions, verticals, and slants to be produced by tracing the engraved letters of a letter guide template.

The pen arm of the scriber holds the pen accessories for the various jobs to be performed. The pen and the arm have a thumb-tightening screw device for securing the pen being used, and an adjustable pressure post screw with locking nut for controlling the amount of pressure at which the pen is set. The pressure post rides on the surface of the work when in use, and is used only in conjunction with the swivel knife. The bull's-eye setting marker at the opposite end of the pen arm offers a concise, accurate means of setting the scriber for the various percentages and angles desired.

The tracing pin is the hardened tool steel point used in tracing the template letter. The tail pin serves as the pivot point for the triangular action of the scriber. This pin travels in the center groove of the template.

Operation of the Butterfly Scriber

The butterfly scriber, a precision lettering tool, is the key to producing clean, sharp, controlled lettering. The setting chart, using the bull's-eye at the end of the pen arm for a marker, begins at the outer edge with a starting line marked "vertical." In this position, the scriber produces a vertical letter of normal size with the template being used. To enlarge this letter, set the bull's-eye at a position above the 100 percent intersection. At 120 percent, the scriber produces a letter 20 percent greater in height than it does at 100 percent. A reduction can be produced by setting the bull's-eye at a position below the 100

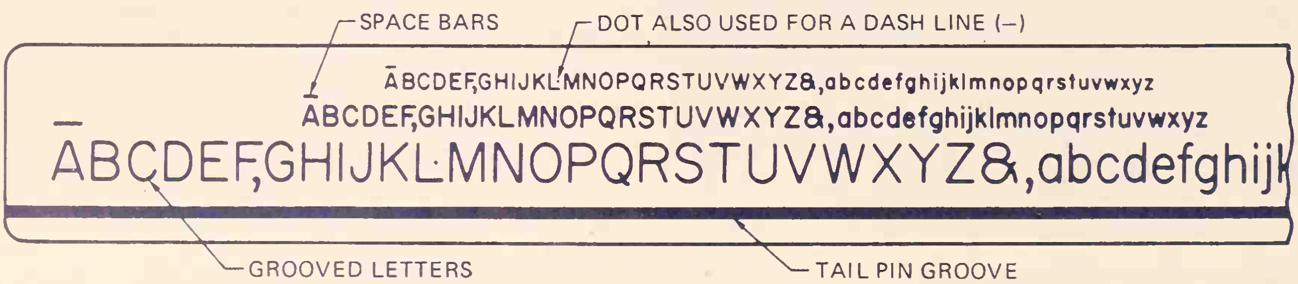


Figure 1-83 Lettering template

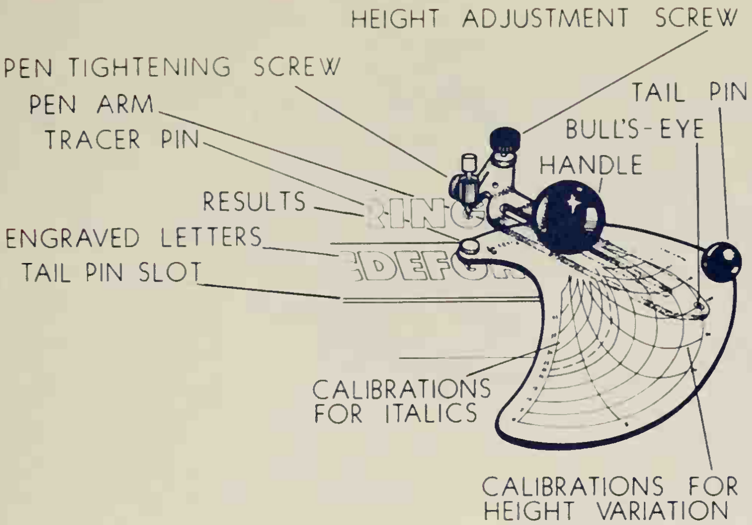


Figure 1-85 Butterfly-type scriber (*Courtesy Letterguide Inc.*)

percent intersection. Variations in height range from 100 up to 140 percent and down to 60 percent. The extreme settings produce condensed letters, and the intermediate settings produce headings, subheadings or large or small letters.

Slants in all sizes are easily produced by setting the bull's-eye on a line other than the vertical line. Normal slants or italics are produced in all height adjustments by setting the bull's-eye on either the 15-degree or 22 1/2-degree line, and at the desired percent of height of the letter on the template.

Variations may be produced in slants ranging from 0 degree to 50 degrees forward. Tracing the engraved template letter requires a very light and delicate touch. This results in more accurately traced letters and less wear on the equipment. Each lettering application requires its own specific pen, and will place at the fingertips of the drafter the very best in standard typeface and hand-lettered alphabets for fast, easy rendering.

Special Effects By using one's imagination many special effects can be achieved, Figures 1-86, 1-87 and 1-88.

Airbrush

Airbrush guns are used for such purposes as production designing, pictorial rendering, portrait figure rendering, architectural rendering, and technical illustration. There are two kinds of airbrushes: the single-action type and the double-action type. In the single-action airbrush, the trigger controls the flow of air only. The fluid control is adjusted in front by the nozzle. In the double-action airbrush, the trigger controls both the flow of air and the amount of fluid to be sprayed, Figure 1-89.

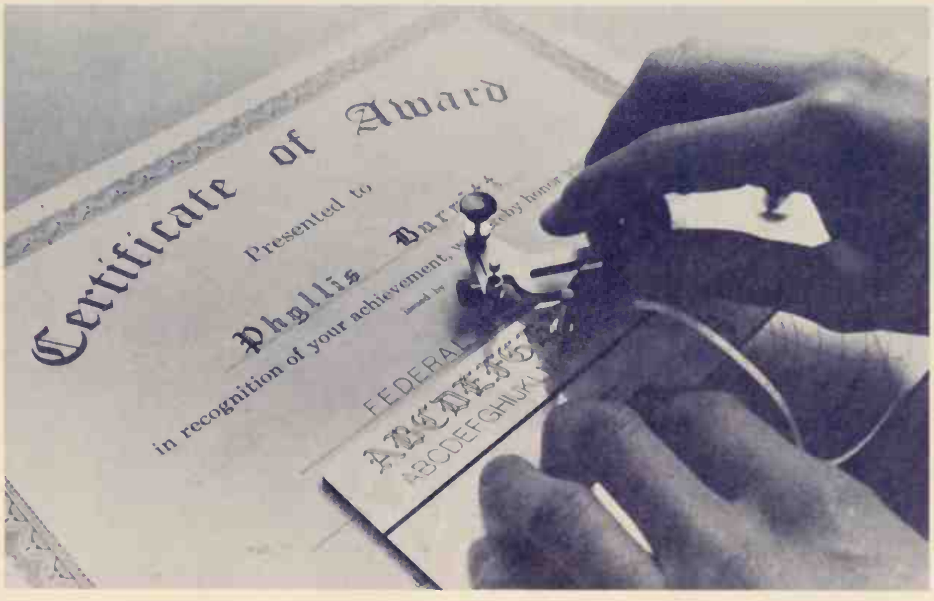


Figure 1-86 Adjustable scriber creates special effects (*Courtesy Letterguide Inc.*)

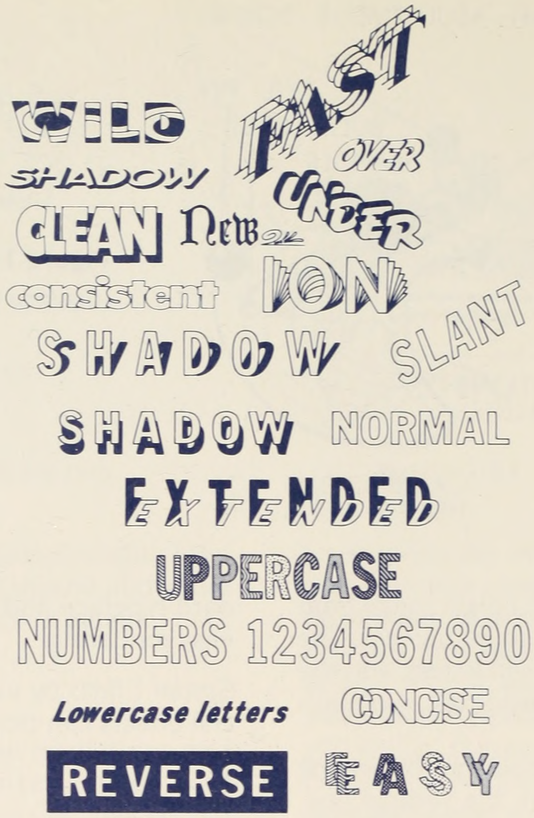


Figure 1-87 Sample lettering styles (*Courtesy Letterguide Inc.*)

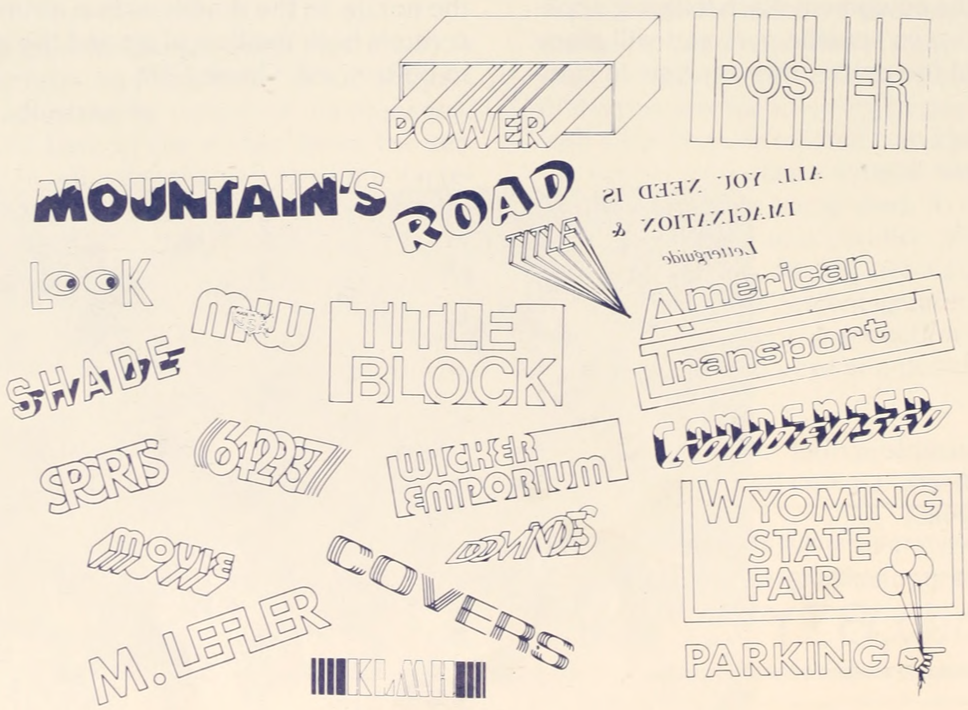


Figure 1-88 Additional special effects (*Courtesy Letterguide Inc.*)

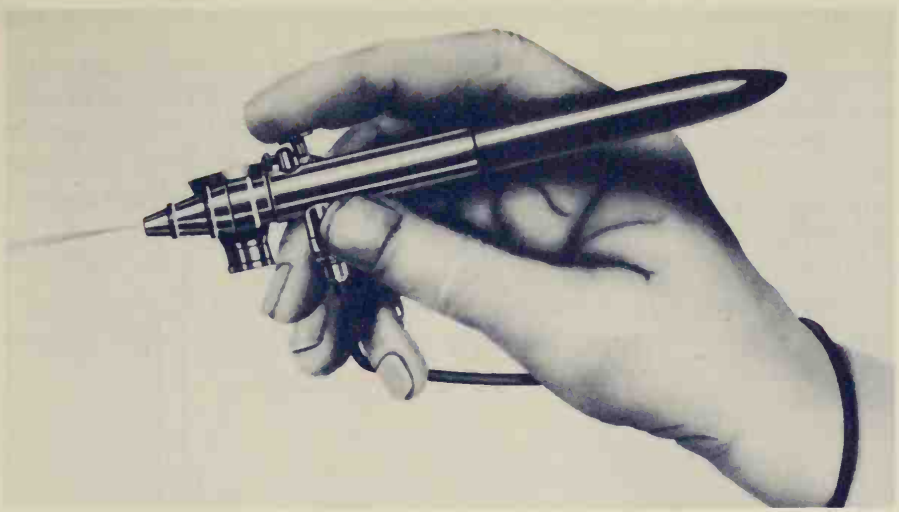
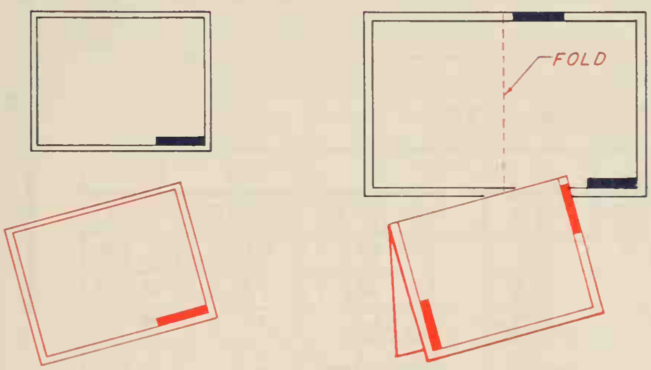


Figure 1-89 Airbrush
(Courtesy Badger Airbrush Co.)

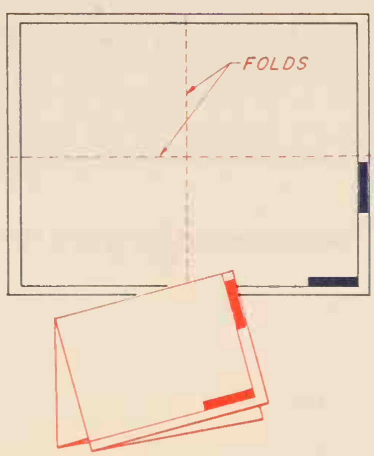
Figure 1-90 Paper sizes

INCHES			MILLIMETRES	
SIZE	DIMENSIONS		SIZE	DIMENSIONS
A	8 1/2 x 11	9 x 12	A-4	210 x 297
B	11 x 17	12 x 18	A-3	297 x 420
C	17 x 22	18 x 24	A-2	420 x 594
D	22 x 34	24 x 36	A-1	594 x 841
E	34 x 44	36 x 48	A-0	841 x 1189



Paper Sizes

Two basic standard paper sizes are 8 1/2 x 11 inches and 9 x 12 inches. The basic standard metric size, A-4, is 210 x 297 millimetres. See Figure 1-90. Examples of paper folded to A-size are shown in Figure 1-91.



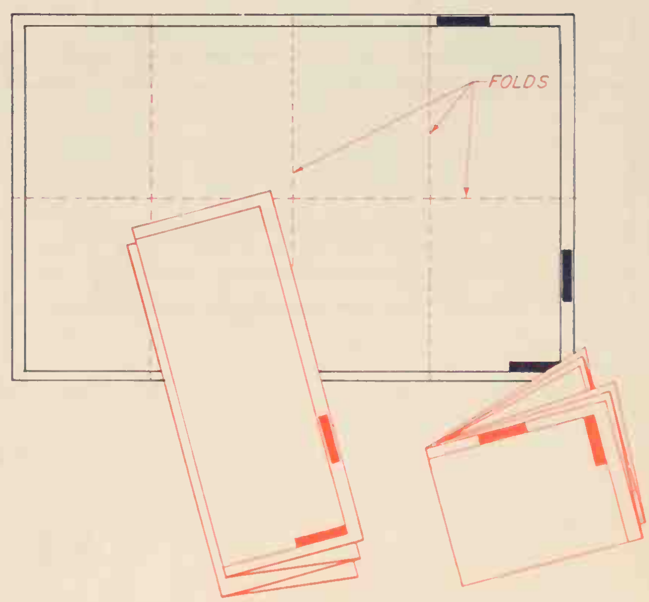
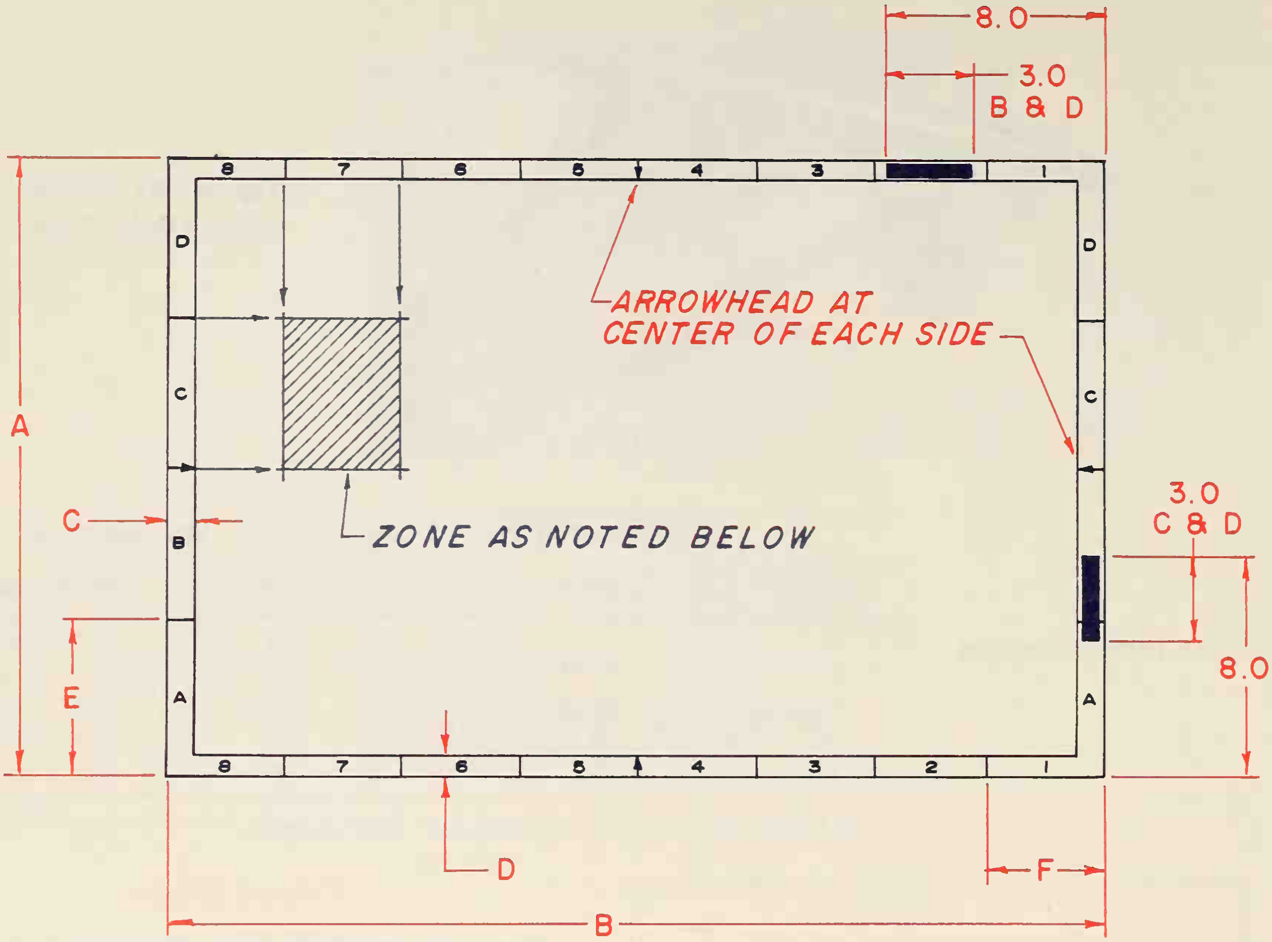
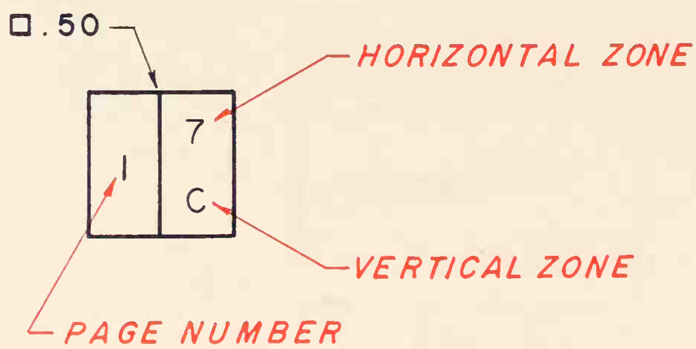


Figure 1-91 Paper folded to A-size



STANDARD BORDER SIZES

DRAWING SIZE	A	B	C	D	E	F
A HORIZONTAL	8.5	11.0	.25	.38	2 AT 4.25	2 AT 5.50
A VERTICAL	11.0	8.5	.38	.25	2 AT 5.50	2 AT 4.25
B	11.0	17.0	.62	.38	4 AT 2.75	4 AT 4.25
C	17.0	22.0	.50	.75	4 AT 4.25	4 AT 5.50
D	22.0	34.0	1.00	.50	4 AT 5.50	8 AT 4.25



ZONE IDENTIFICATION
SEE ZONE ABOVE

Figure 1-91A Standard border sizes

orders

The location of the borders varies with each size heet of paper, Figure 1-91A. This chart indicates the arious standard borders used today. A standard orizontal border is shown in Figure 1-91B. A stanard vertical border is shown in Figure 1-91C.

oning

Zoning is used to pinpoint a particular detail on a rawing. The exact rectangular zone is located by the use of numbers running horizontally and letters running vertically in the margins. By extending these imaginary lines, the exact rectangular zone, Zone 7-C, is located as shown in Figure 1-91A. See the corresponding symbol below the chart. The number at the left (1) indicates the page number, the number at the top right (7) indicates the corresponding number on the horizontal margin. The letter at the lower right (C) indicates the corresponding letter in the vertical margin.

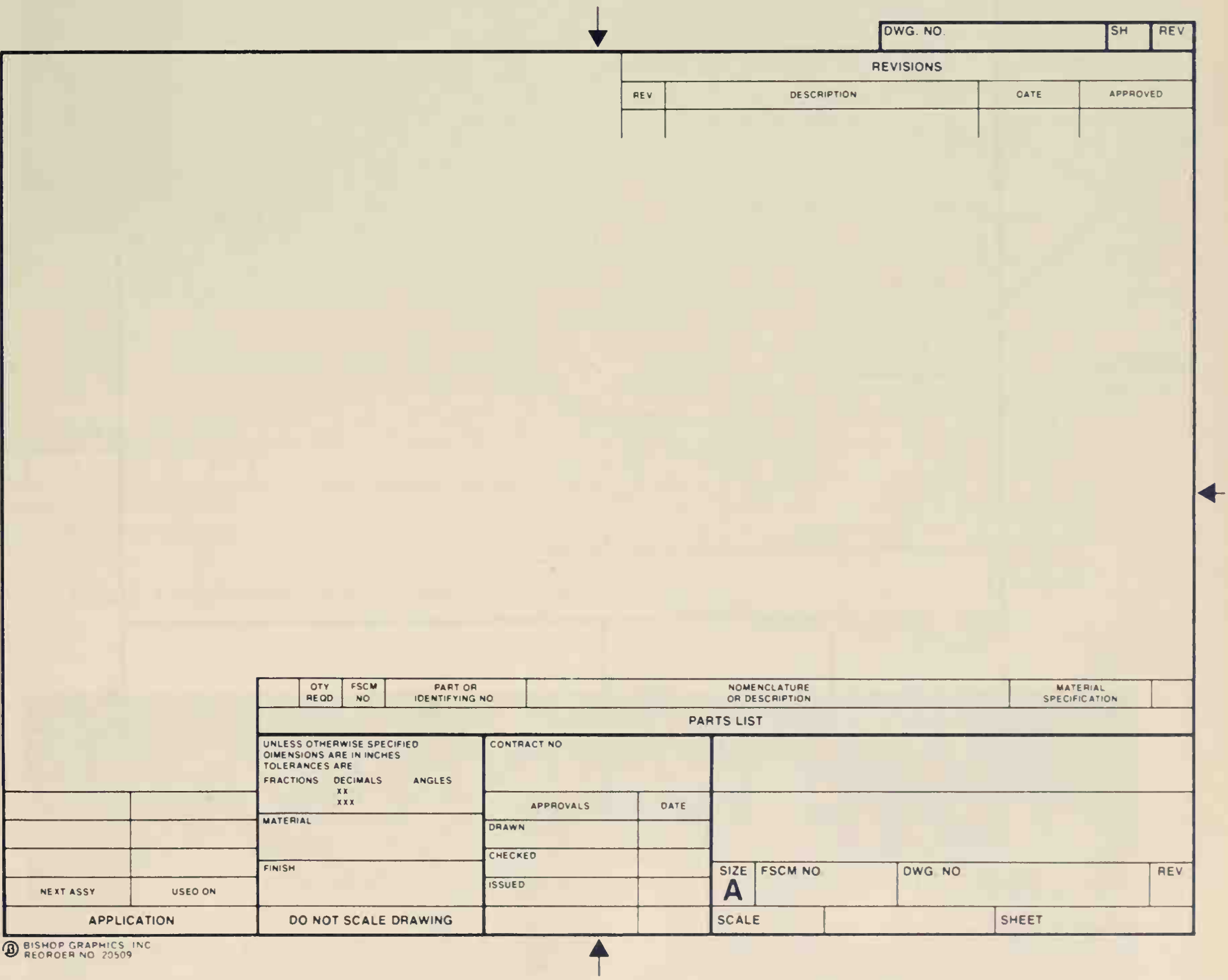


Figure 1-91B Standard horizontal border (*Courtesy Bishop Graphics Co.*)

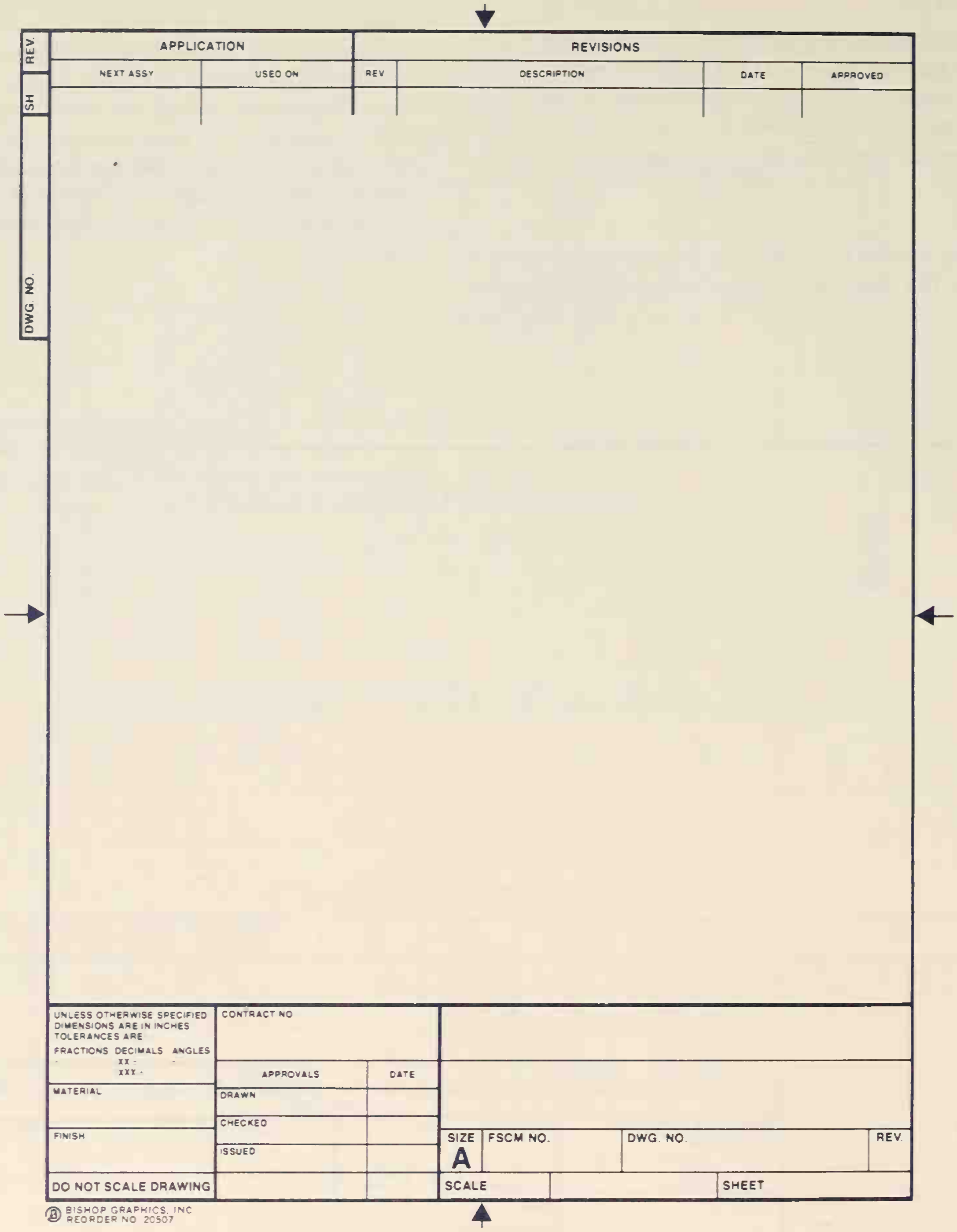


Figure 1-91C Standard vertical border (*Courtesy Bishop Graphics Co.*)

Whiteprinter

Many types of whitepapers are available for use in drafting rooms. A *whiteprinter*, Figure 1-92, reproduces a drawing through a chemical process. Most of these machines work on the same basic principle, Figure 1-93. A bright light passes through the translucent original drawing and onto a coated whiteprint paper. The light breaks down the coating on the whiteprint paper, but wherever lines have been drawn on the original drawing, no light strikes the coated sheet. Then the whiteprint paper is passed through ammonia vapor for developing. This chemical developing causes the unexposed areas – those that were shaded by lines on the original – to turn blue or black.

Most whiteprinters have controls to regulate the speed and flow of the developing chemical. Each type of machine requires different settings and has different controls. Before operating any whiteprinter, read all of the manufacturer's instructions.

Today, with the advent of new technology, copies are made on an outprint printer, Figure 1-94.

Figure 1-92 Whiteprinter (*Courtesy Blu-Ray Inc.*)

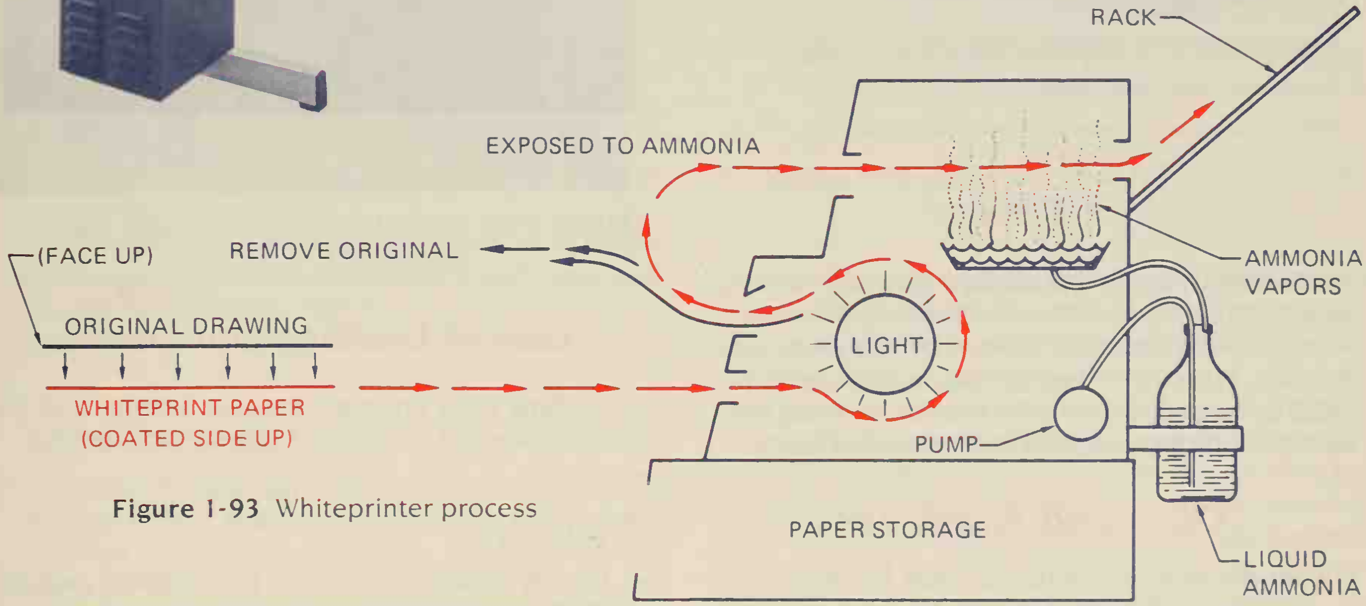


Figure 1-93 Whiteprinter process

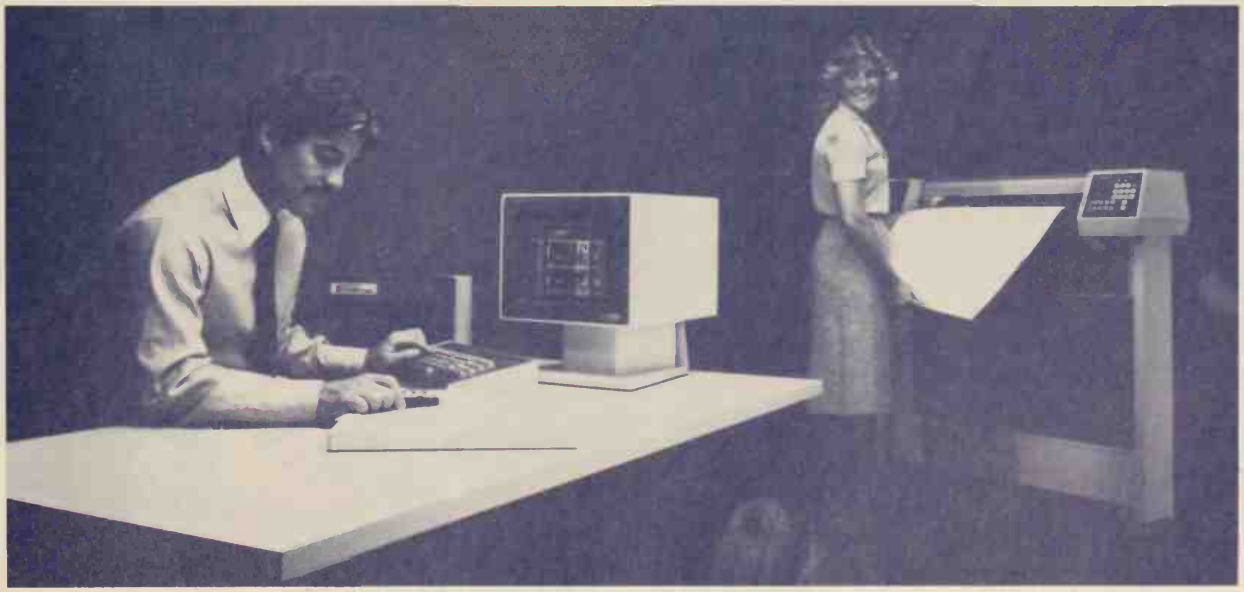


Figure 1-94 Copier (*Courtesy J. S. Staedtler Inc.*)

Figure 1-95 Drawing file system (*Courtesy Safco Products Inc.*)

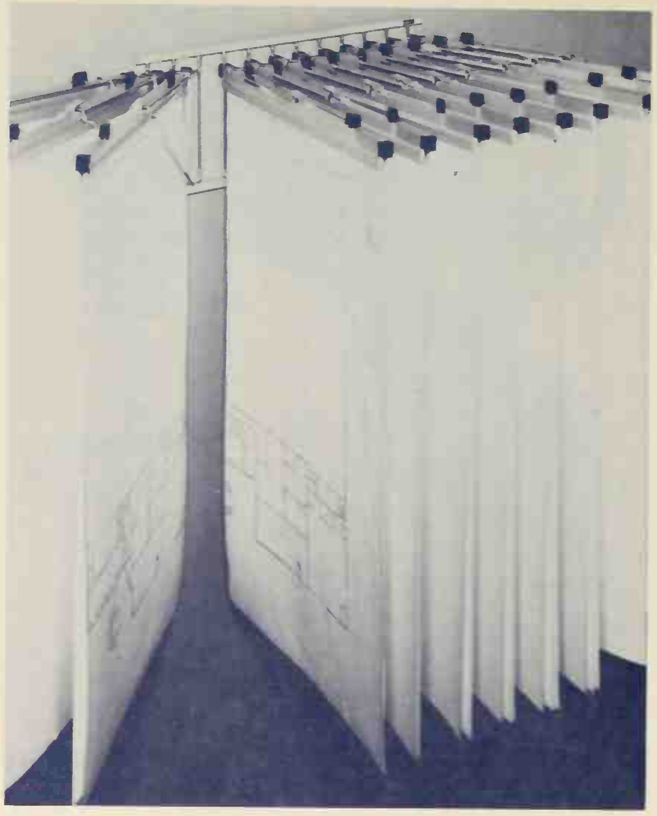


Figure 1-96 Vertical drawing file (*Courtesy Safco Products Inc.*)

Files

A finished drawing represents a great deal of valuable drafting time and is, therefore, a costly investment. Drawings must be stored flat in a clean storage area, Figure 1-95. Vertical drawing storage is provided by hangers, Figure 1-96. Most engineering firms keep their files in fireproof and theftproof vaults.

Open-End Typewriter

A word processor-equipped, open-end typewriter is used to speed up the lettering process on a large drawing, Figure 1-97.

Care of Drafting Equipment

Drafting tools are precision instruments, and the proper care will ensure that they last a lifetime.

Plastic Tools

Plastic drafting tools, such as T-squares, parallel straightedges, templates and triangles, should be wiped immediately after use with a damp cloth to

Figure 1-97 Open-end typewriter (*Courtesy Diagram Corp.*)

remove ink or graphite that may stain the tools or be carried to the next drawing. Once a plastic instrument is stained, a mild soap or ammonia solution will dissolve many water- and oil-based inks. Be careful *not* to use a solvent such as paint thinner, lacquer thinner or alcohol.

Plastic drafting tools should be kept out of direct sunlight and away from warm surfaces to prevent them from becoming brittle, cracked, and warped. They should be stored in a flat position with cloth or paper between them to reduce scratching the surface.

A great number of plastics are used in drafting instruments. Most are made from either styrene or acrylic plastic. Styrene is a more flexible and softer plastic than acrylic. Although acrylic instruments are harder, they are more prone to chipping. Because both types of plastic are relatively soft, plastic drafting instruments should never be used for a cutting edge.

Compasses

Almost all compasses are made of brass that is chrome- or nickel-plated. To clean these instruments, use a mild solution of soap and water to remove residue and dirt.

Compasses should not normally need oiling, unless they are kept in a damp area which could cause rust. If a compass is oiled unnecessarily, there is a risk of soiling the next drawing on which it is used.

Tables and Chairs

Wooden drafting furniture is cared for in the same manner as any other wooden furniture. It may be polished or waxed with ordinary products. Do not polish the insides of drawers or cabinets. These areas may retain the wax, which can then be transferred to drawings.

Steel furniture can be cleaned with soap and water, and then waxed.

The gears and joints on adjustable drafting tables are lubricated at the factory, and generally do not require further oiling. Additional oiling increases the risk of getting oil or grease on a drawing.

The tops of most drafting tables are coated with a vinyl film such as melamine or a phenol-laminate material. A glass cleaner or mild ammonia solution is used to clean these surfaces.

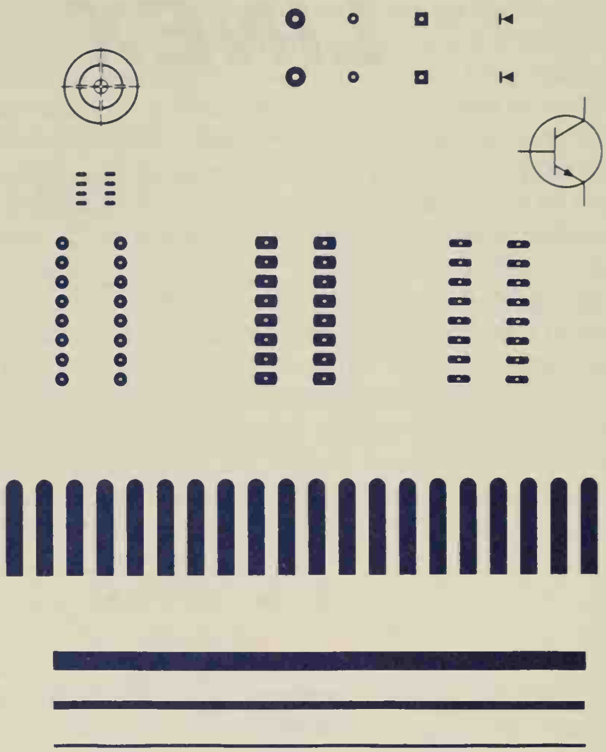


Figure 1-98 Tapes and pads for printed circuit board drafting

Use of Appliques

The word *applique* is a generic term used to describe a variety of shortcut products used in drafting. These products include such items as tapes, pads, and various other ready-made appliques for creating printed circuit board artwork, Figure 1-98. These same materials may also be used for a variety of tasks in other drafting fields, Figure 1-99. For example, architects use tapes for making lines and walls on floor plans.

Transfer cards are used primarily as substitutes for mechanical lettering, but any type of symbol or frequently used piece of graphic data can be placed on a transfer card. Transfer cards are especially designed to fit against a parallel bar, drafting rule or other straight edge for ease of alignment. Symbols are transferred from the card by rubbing them with a blunt point.

Dry transfer sheets are designed according to the same principles as transfer cards. The major differences are that transfer sheets are just that, sheets—not cards. Dry transfer sheets are used a great deal in architectural drafting and technical illustration. The transfer is made by rubbing the symbols on the sheet with a blunt, rounded point or a special burnisher.

Dry transfer materials do have some drawbacks. The heat of ammonia-developing print machines tends to lift dry transfer material from the sheet. In addition, the material may dry out and crack with age.

Use of Burnishing Plates

Burnishing is another shortcut for creating graphic symbology fast and easily. *Burnishing* involves placing an especially textured plate under the drafting

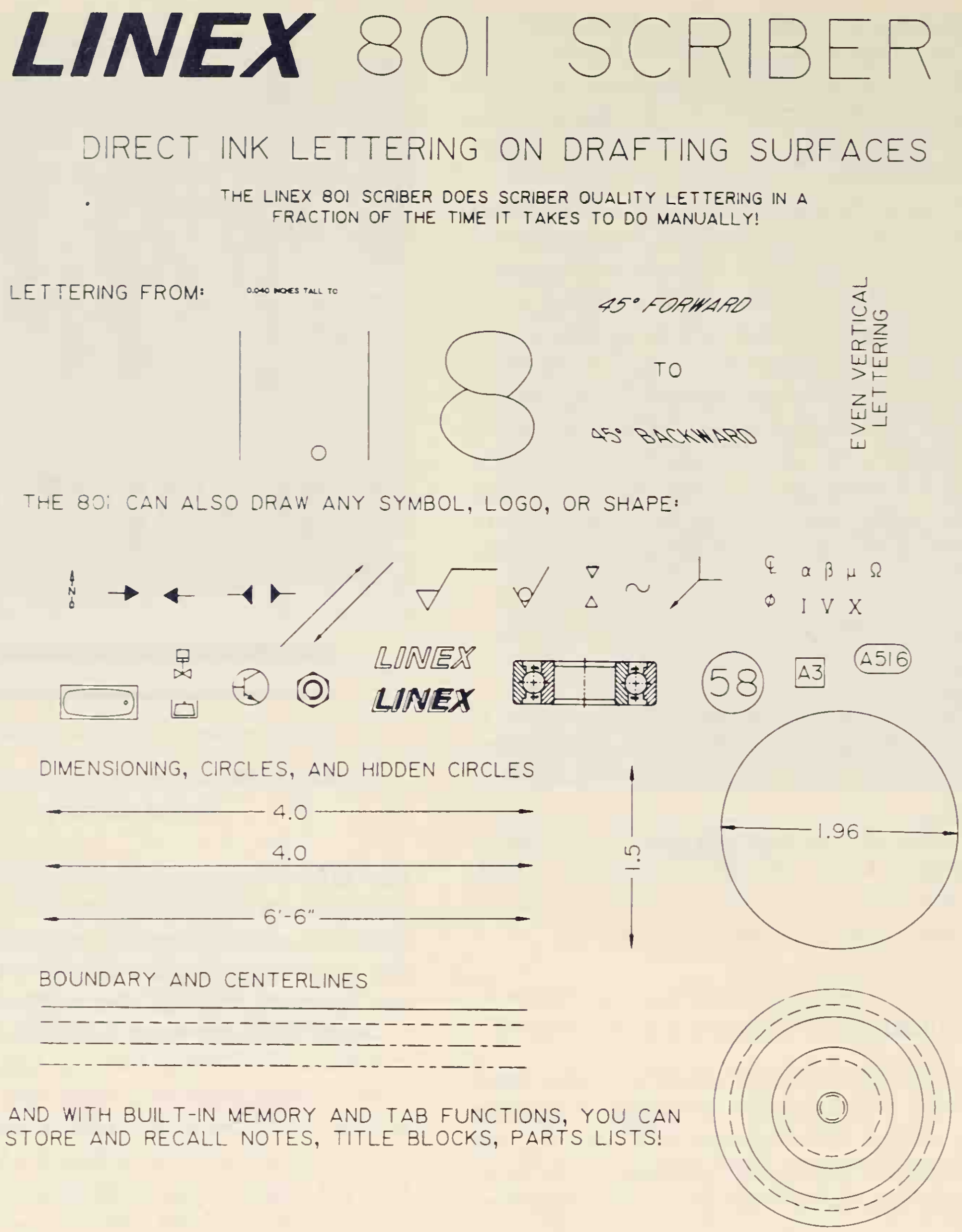


Figure 1-99 Sample applique (*Courtesy* A.D.S./*Linex, Inc.*)

medium (usually paper or vellum) and rubbing the drafting surface with a pencil. The pencil may be soft and dark or light and hard, depending on the amount of emphasis desired. Two of the most commonly used symbols on burnishing plates are bricks and stone, but any symbol could be made into a plate.

One weakness of burnishing plates is that the symbols they produce do not reproduce well.

Typewritten Text

Text on drawings and other types of documentation consists of dimensions, notes, and callouts. Creating text, or lettering, is one of the slowest, least productive manually performed tasks in drafting. Typewritten text is a shortcut for improving on lettering in manual drafting situations.

A number of different methods for typing text are used in drafting. The most frequently used are the open-carriage typewriter and the lettering machine. The *open-carriage typewriter* is any brand of typewriter that has been especially designed to hold larger-than-normal media, such as drawings, bills of material, and parts lists. Once a drawing is completed and ready for annotation, the drafter or engineering secretary rolls it into an open-carriage typewriter and types the required text. Typewritten text is fast, neat, and consistent. Figures 1-100 and 1-101.

Lettering machines provide another means for accomplishing typewritten text. Lettering machines are used primarily for titles on drawings, but may be used in any situation where Leroy lettering is used.

Lettering machines, such as the Kroy machine, output the letters on a clear tape that is pressed onto the drawing surface, Figure 1-102. Lettering machines are capable of producing text in a number of different sizes and styles. There are some drawbacks to this shortcut. The machine and its type fonts are expensive.

Another method used more and more frequently in modern drafting rooms for accomplishing typewritten text is the *computerized lettering machine*, Figures 1-103 and 1-104. This machine allows drafters to enter data through a keyboard and receive a simultaneous readout on a small display screen. If the text is correct as typed, an ENTER command will cause the lettering to be accomplished in ink automatically. If there are errors, they can be corrected before giving the ENTER command.

Overlay Drafting

Overlay drafting is a complete drafting process that uses advanced reproduction techniques and materials to reduce the amount of time spent in preparing drafting documentation. Actually more than a shortcut technique, the underlying principle of overlay drafting is nonrepetition. *Nonrepetition* means that once any type of graphic data or symbology has been drawn the first time, it should never have to be drawn again.

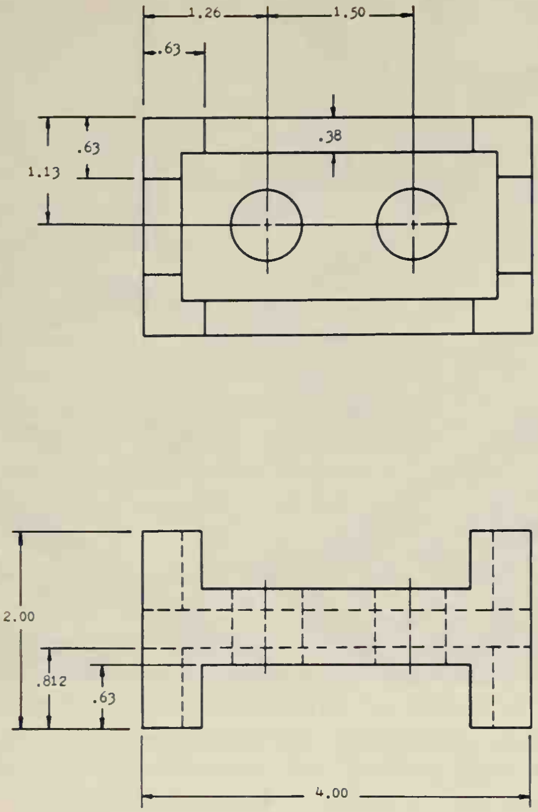


Figure 1-100 Typewritten text on drawings

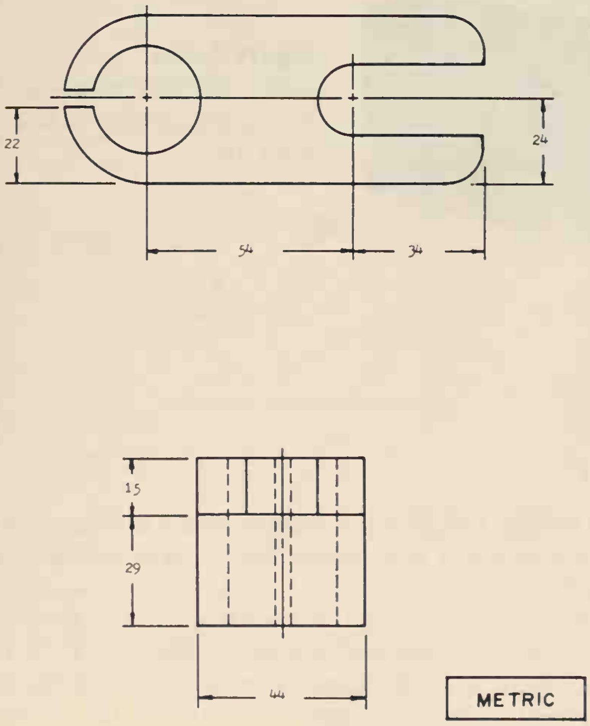


Figure 1-101 Typewritten text on drawings

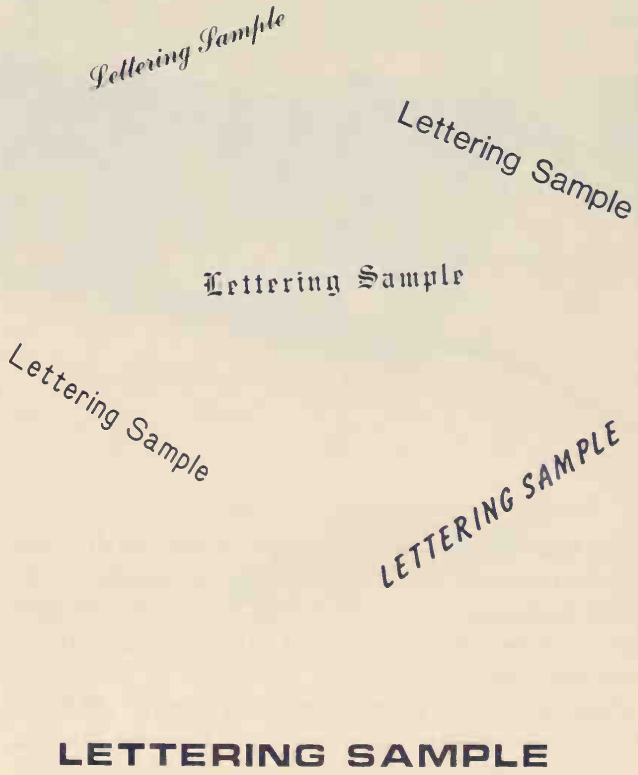


Figure 1-102 Kroy lettering samples

Figure 1-103
Computerized lettering machine (*Courtesy Ozalid Corp.*)

Figure 1-104
Computerized lettering machine (*Courtesy* A.D.S./*Linex, Inc.*)

The special tools and materials of overlay drafting include pin bars, registration tabs, prepunched polyester film or a punch to punch holes in standard film, a flatbed vacuum frame printer, and a diazo print machine.

Overlay drafting involves placing a punched base sheet on a drafting table over a pin bar and placing various overlay sheets on top of it. Each successive overlay sheet is automatically lined up (registered) by the pin bar. The simplest example of how overlay drafting works is in preparing a set of commercial architectural plans.

In manual drafting, this preparation requires drawing the floor plan four separate times: once for the floor plan, once for the electrical plan, once for the plumbing plan, and once for the HVAC plan. Overlay drafting eliminates this time-consuming repetition. In overlay drafting, the floor plan is drawn once. Then, before it is dimensioned, three additional originals are created from it, using a special sensitized polyester film, a flatbed vacuum frame printer, and a diazo print machine. In general terms, this is how the process works:

Step 1. A sheet of punched polyester film is placed on the drafting board. The holes across the top of the film fit over the pin bar which is permanently attached to the top edge of the drafting board. The floor plan is drawn on this base sheet, but, for the moment, the dimensions and all other annotation are left off. These will be added later, after the base sheet is used to reproduce several other originals that do not require dimensions or annotation.

Step 2. The base sheet is taken from the drafting board. A sheet of punched sensitized polyester film is placed on top of it. The two sheets are fastened together with plastic registration pins. Together, they are placed in the flatbed vacuum frame exposure unit. The lights in the unit expose the sensitized film, "burning away" all of the special light-sensitive emulsion, except where the light is blocked out by lines from the base sheet. The exposed polyester film is then run through the ammonia developing section of a print machine, producing what is called a slick. A *slick* is a polyester reproduction of the base sheet original. It is not drawn on; rather, it is used as a base sheet over which electrical, plumbing, and HVAC plans may be overlaid. The original base sheet of the floor plan may now be completed by adding dimensions and other annotation.

Step 3. The new slick may now be placed over the pin bar on a drafting board, and a clear sheet of polyester film placed on top of it. The electrical symbols for the electrical plan are added on this new sheet. Only information for the electrical plan is entered on this overlay sheet. To get a print of the electrical plan superimposed on the floor plan, the slick base sheet containing the floor plan and the electrical plan overlay are placed in the flatbed vacuum frame printer, along with a sheet of ammonia developing print paper. All three sheets are secured together with plastic registration pins. When the exposure step is completed, the sheets are separated and the print paper is run through the ammonia developing section of a diazo print machine, thus producing a print of the electrical plan. The same process is repeated for the plumbing plan and the electrical plan. To save even more time, three slicks of the floor plan could have been made and given to three different drafters; one of whom would create the electrical plan overlay, one the plumbing plan overlay, and the other the HVAC plan overlay. This process is illustrated in Figure 1-105.

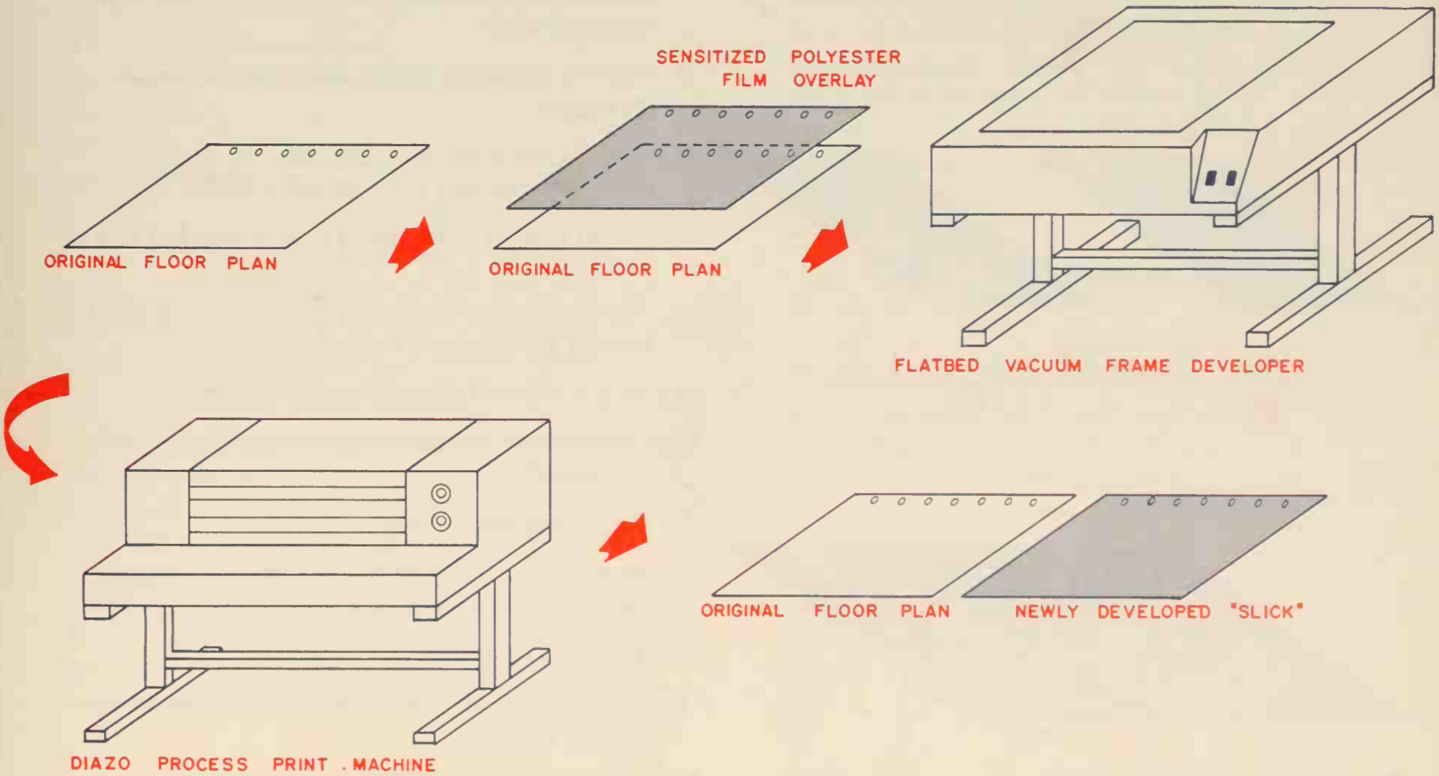


Figure 1-105 Overlay drafting process

Scissors Drafting Techniques

Scissors drafting is an extension of overlay drafting. The two combined can bring substantial productivity benefits in manual drafting situations. In *scissors drafting*, if any part of a set of drawings has ever been drawn before, say a typical detail or sectional view, it need not be redrawn. Rather, the techniques outlined previously to create a slick are used, and the details and other data needed from the slick are cut out and taped to a carrier sheet, Figure 1-106. A new slick is created using the carrier sheet as the original.

The scissors drafting technique is best illustrated by example. A mechanical drafter must construct a sheet of typical details and sectional views for a documentation package. All of the needed details have been drawn before, but in different jobs. Some of the details needed are in one job, some in another, and so on. Rather than redrawing, the drafter decides to use scissors drafting techniques.

First, the drafter locates all of the details needed and pulls the required sheets from the filing drawers.

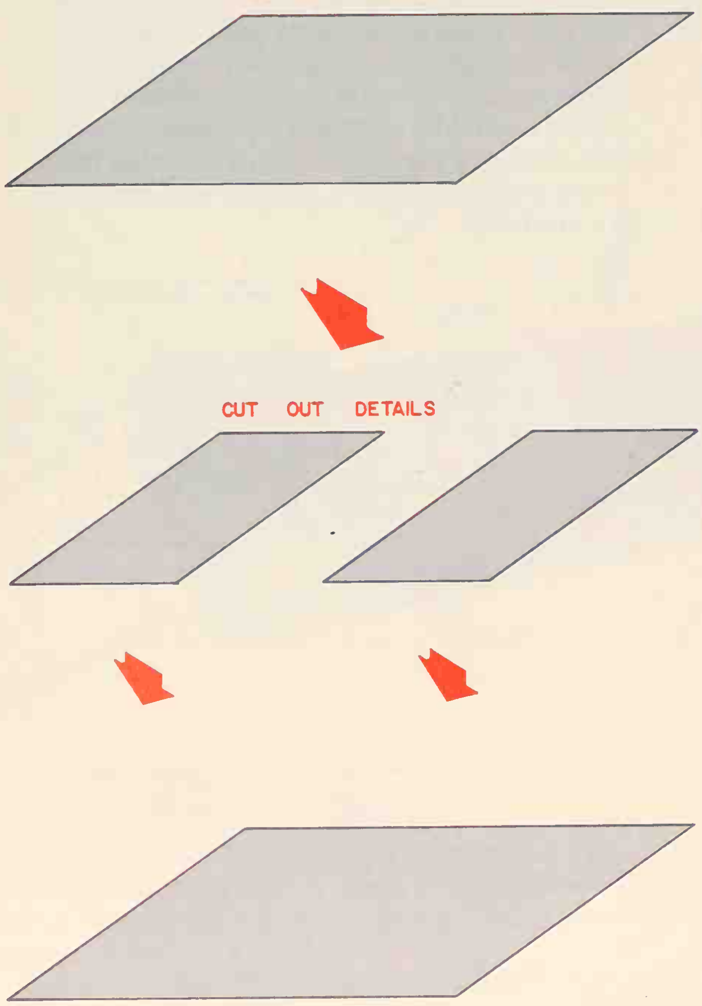


Figure 1-106 Scissors drafting

A slick of each sheet is then made. After cutting out the details from the slicks, the drafter assembles them on a carrier sheet. The first slicks allow the original drawings to be kept in case they are ever needed again.

Using the carrier sheet as an original, the drafter creates a slick containing all of the details. The slick may then be copied onto polyester film that accepts plastic lead or ink, and this new medium is used as any other original. The entire process takes about 20 minutes, whereas completely redrawing each detail would take hours.

Review

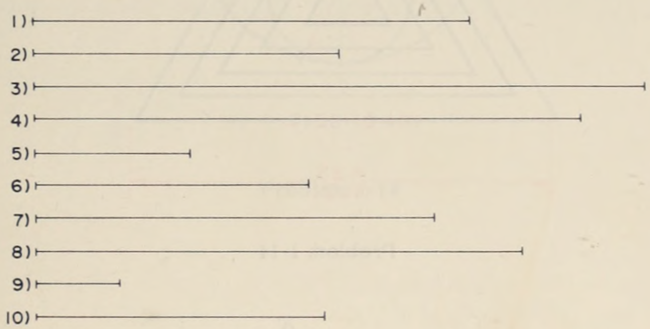
1. Among the pencil lead grades from hard to soft, which two are recommended for drafting?
2. Describe the whiteprinter process used in today's drafting rooms.
3. List three kinds of drafting triangles.
4. Explain how to read a micrometer.
5. Why are the drawing surface and top cover so important?
6. List the various kinds of drafting tools used to draw horizontal lines, and explain which is the best and why.
7. List the standard paper sizes used in industry today.
8. What is the difference between an open-divided scale and a full-divided scale?
9. Which kind of compass is recommended and why?
10. For what is dry cleaning powder used, and why must it be removed from the drawing?
11. Why is a dusting brush used in drafting?
12. Explain how to read a vernier protractor. Why is it used?
13. Define the term *applique*.
14. What is the difference between a transfer card and a dry transfer sheet?
15. What is a Kroy lettering machine?
16. What tools and materials are needed to do overlay drafting?
17. What is scissors drafting?

Chapter One Problems

Problems 1-1 through 1-6

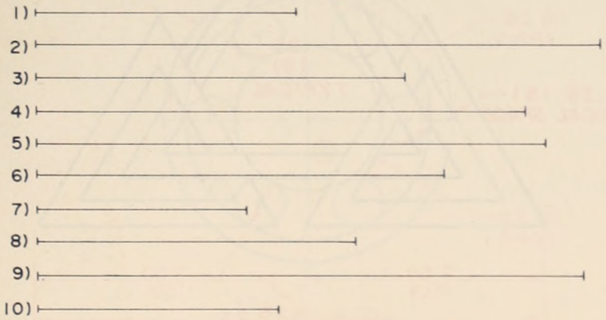
Carefully measure each line in inches, or in millimeters if metric is indicated. Neatly enter your answers on a sheet of paper. For extra practice, measure each line full size as given, half size as given, quarter size as given, or ten-times scale as assigned by the instructor.

FULL SIZE



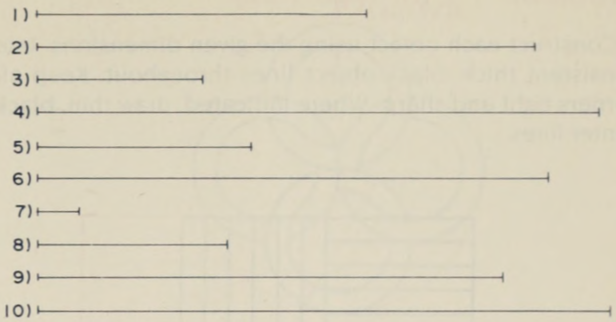
Problem 1-1

HALF SIZE



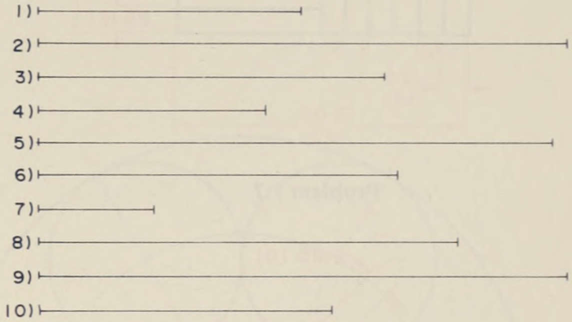
Problem 1-2

3/4 SIZE



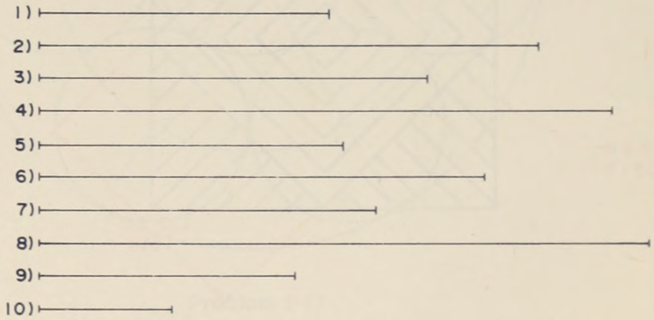
Problem 1-3

METRIC (FULL SIZE) MILLIMETERS



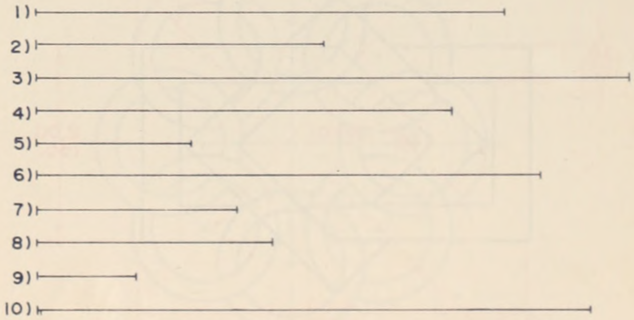
Problem 1-4

METRIC (HALF SIZE) MILLIMETERS



Problem 1-5

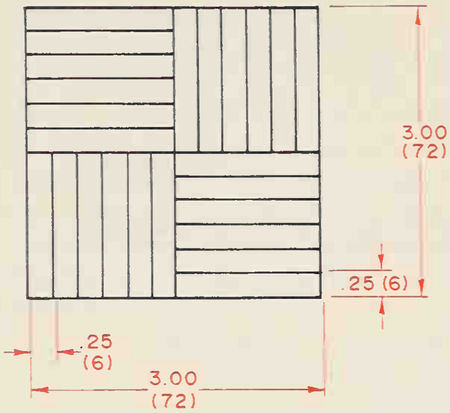
METRIC (QUARTER SIZE) MILLIMETERS



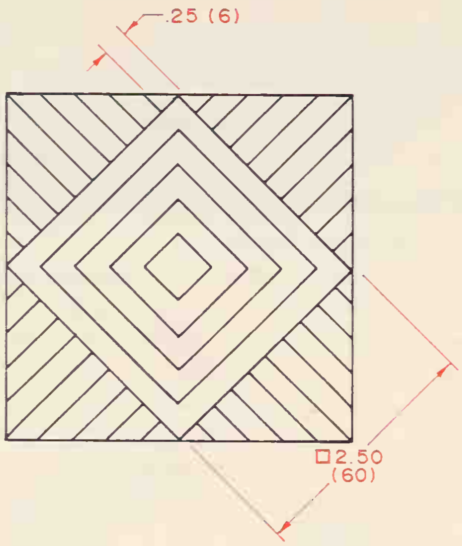
Problem 1-6

Problems 1-7 through 1-22

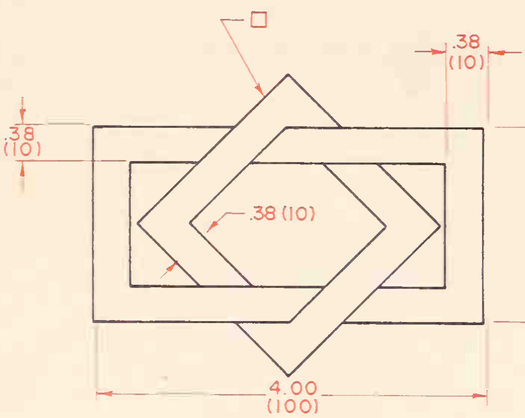
Construct each object using the given dimensions. Use consistent thick, black object lines throughout. Keep all corners tight and sharp. Where indicated, draw thin, black center lines.



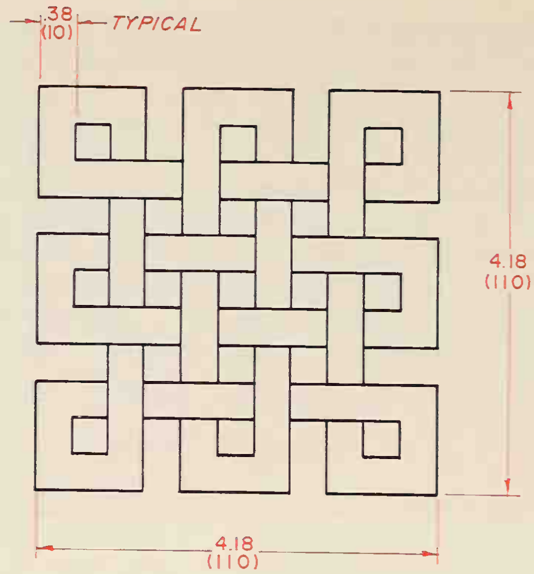
Problem 1-7



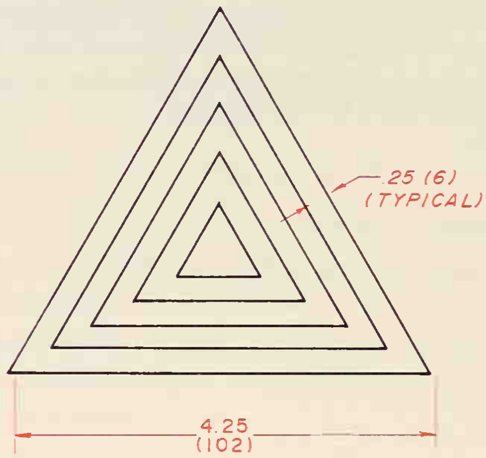
Problem 1-8



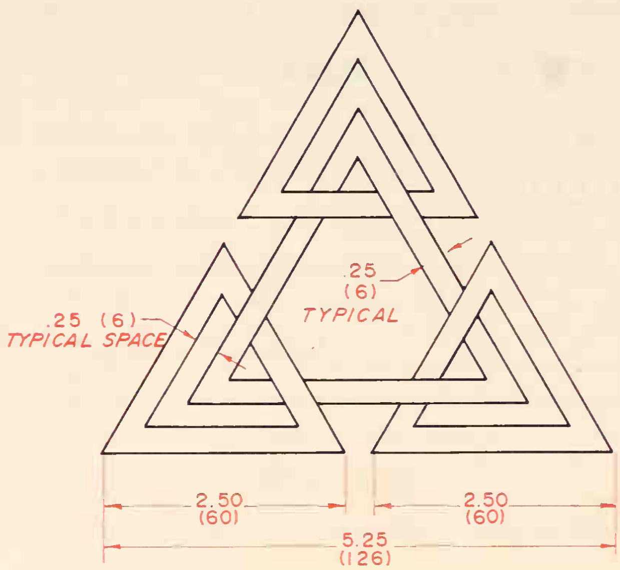
Problem 1-9



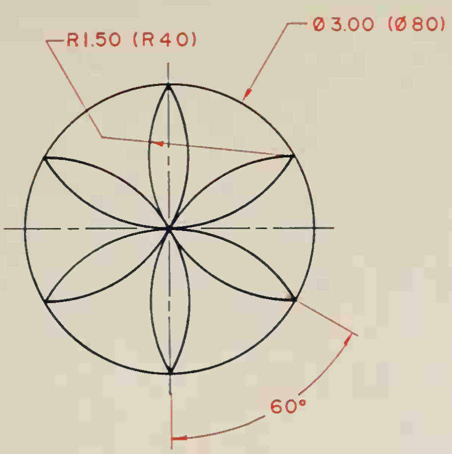
Problem 1-10



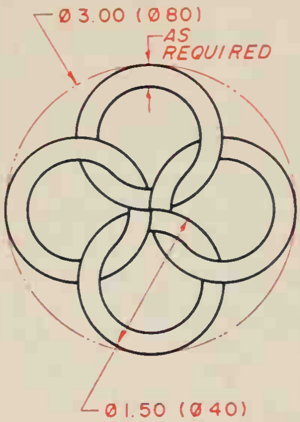
Problem 1-11



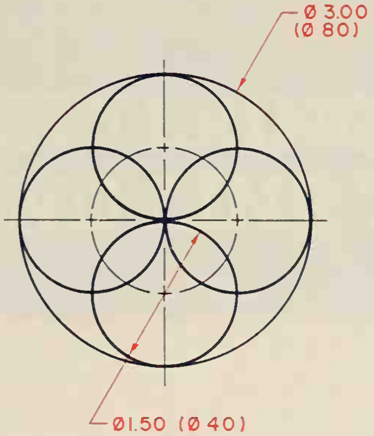
Problem 1-12



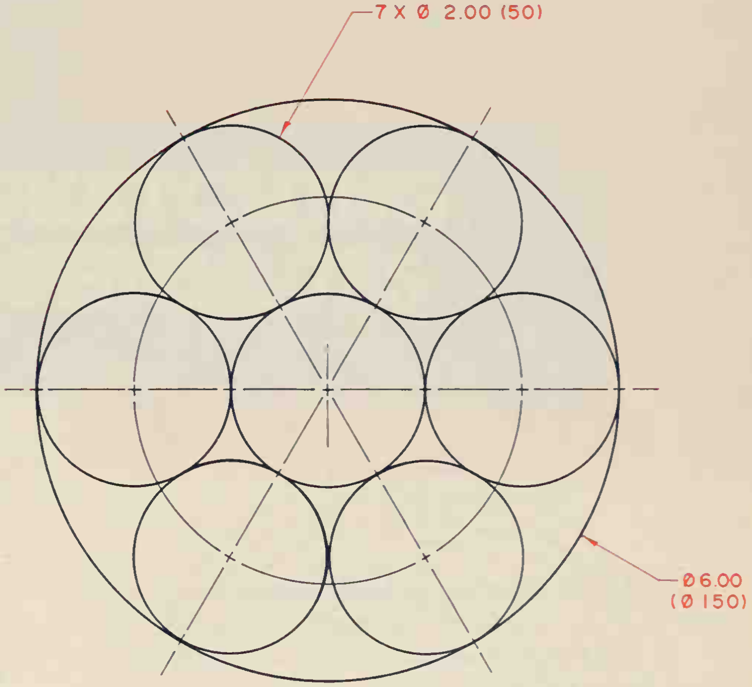
Problem 1-13



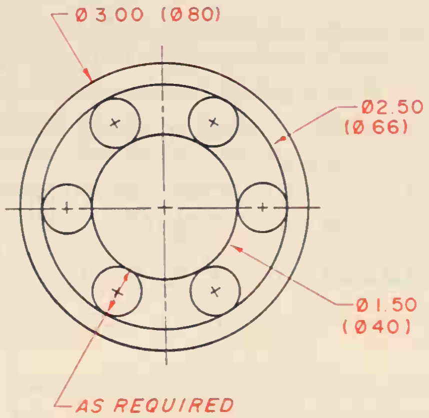
Problem 1-16



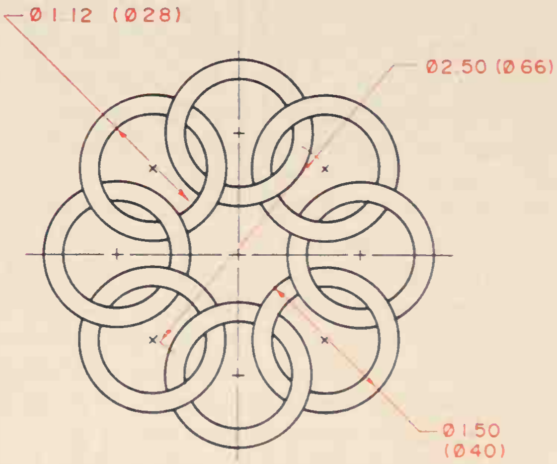
Problem 1-14



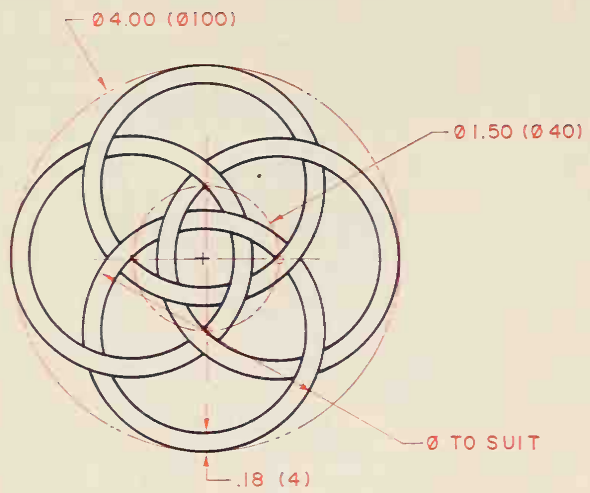
Problem 1-17



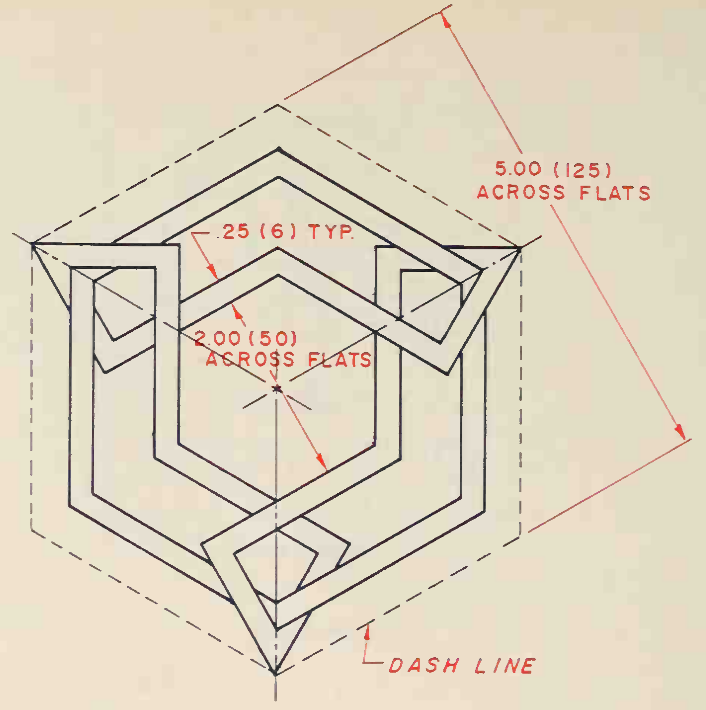
Problem 1-15



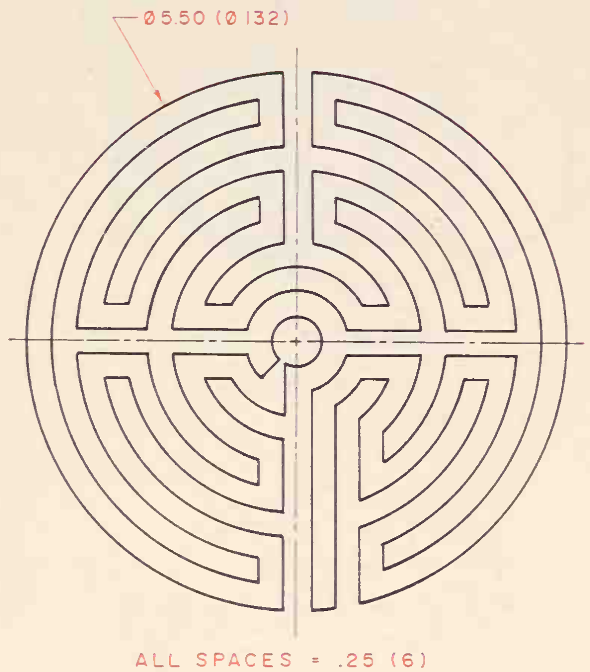
Problem 1-18



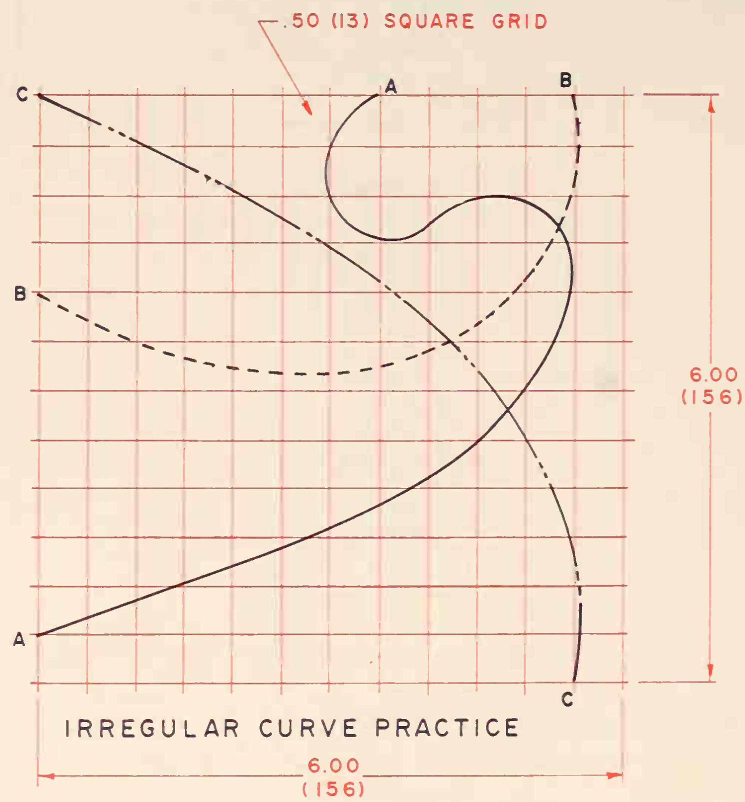
Problem 1-19



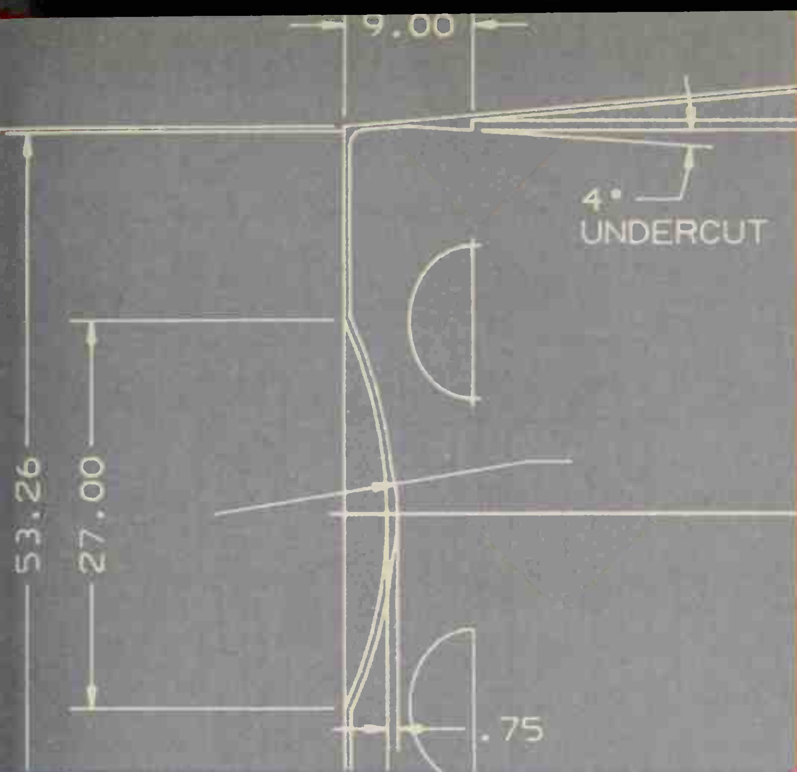
Problem 1-21



Problem 1-20



Problem 1-22



CHAPTER 2

This chapter covers three of the basics that are needed in preparing all types of technical drawings. All three concepts represent manual drafting techniques. Computer-aided drafting (CAD) techniques are covered in later chapters. The major topics covered in this chapter are freehand lettering, freehand lettering techniques, line work, and sketching.

LETTERING, SKETCHING, AND LINE TECHNIQUES

Freehand Lettering

Text is an important part of a technical drawing. Not all information required on technical drawings can be communicated graphically; the most obvious data being dimensions. *Text* on technical drawings consists of dimensions, notes, legends, and other data that are best conveyed using alphanumeric characters, Figure 2-1.

Several different ways are used to create text on technical drawings. The traditional method is by freehand lettering. Other methods include such mechanical lettering techniques as scriber templates, typewritten notation, and typed lettering generated by computer-aided drafting systems. This chapter focuses on freehand lettering. Other methods are described elsewhere in this text.

Lettering Styles

There are numerous different lettering styles or fonts, Figure 2-2. The standard style for freehand lettering on technical drawings, as established in American National Standards document Y14.2-1973, is single-stroke Gothic lettering. Vertical, single-stroke Gothic letters are the most universally used of the various styles available to drafters, Figure 2-3.

Some modifications of the standard Gothic configuration of letters are often made, without actually changing from the Gothic style of lettering. One way is through the use of uppercase and lowercase letters, Figure 2-4, but this is seldom acceptable on technical drawings. Another method is to condense or extend the letters, Figure 2-5.

The most common way of modifying Gothic letters is by inclining them slightly to the right, Figure 2-6. Inclined lettering is easier to make as it lends itself to a natural direction of wrist action. The correct angle of the inclined elements is a two-unit incline to the right for each five units of letter height. Errors are not as detectable with inclined letters as they are with vertical elements. As the inclined elements are longer, they are easier to read. However, inclined lettering is not universally accepted, and caution must be exercised to not conflict with customary drafting styles. A backhanded or left-leaning inclination is never an acceptable modification.

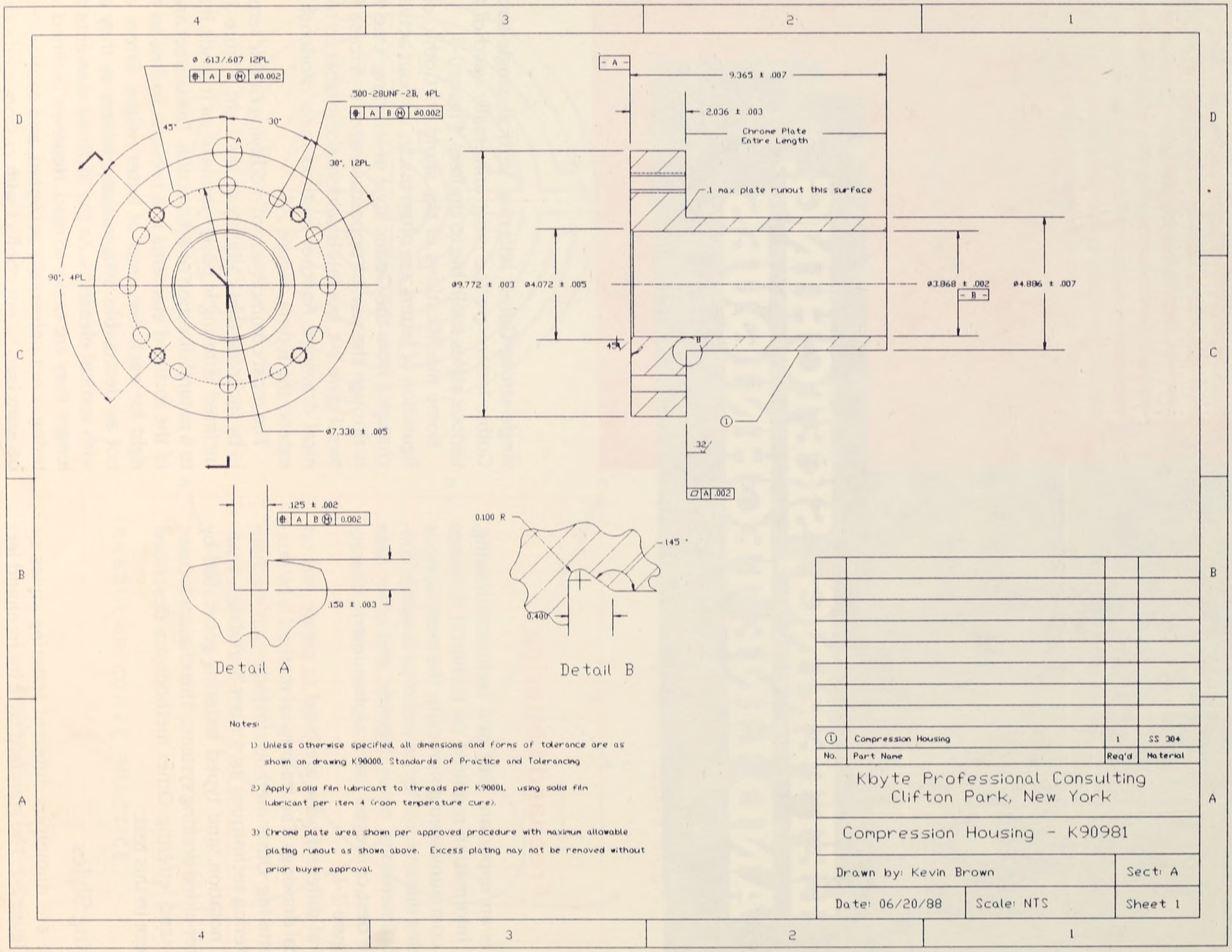


Figure 2-1 Examples of text on a technical drawing

THIS IS BLOCK FONT

THIS IS FAST FONT

THIS IS FUTURA FONT

THIS IS LEROY FONT

THIS IS OLD ENGLISH FONT

THIS IS RIVERA FONT

THIS IS TIMES FONT

THIS IS HELVET FONT

BAUSCH & LOMB FONTS

Figure 2-2 Sample lettering fonts (*Courtesy Bausch & Lomb, Inc.*)

SINGLE-STROKE GOTHIC

LETTERING SAMPLE

Figure 2-3 Single-stroke Gothic lettering

UPPERCASE GOTHIC

lowercase Gothic

Figure 2-4 Uppercase and lowercase Gothic lettering

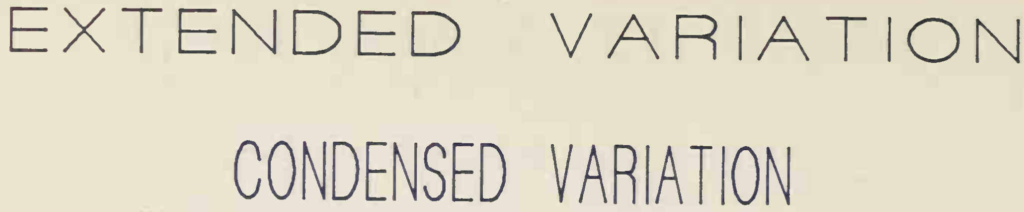


Figure 2-5 Extended and condensed variations of Gothic lettering

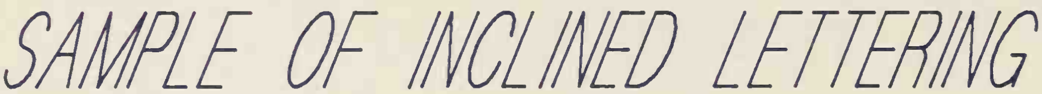


Figure 2-6 Inclined Gothic lettering

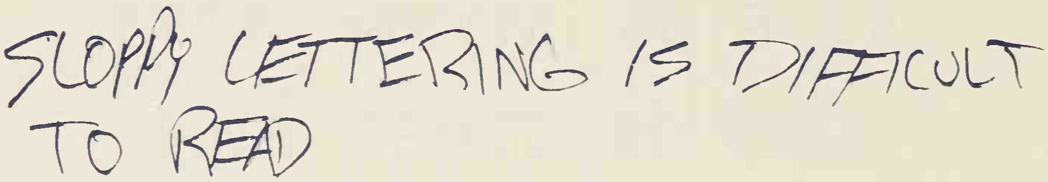


Figure 2-7 Sloppy lettering is difficult to read

Characteristics of Good Lettering

Good freehand lettering, regardless of whether it is uppercase or lowercase, condensed or extended or vertical or inclined, must have certain characteristics. These requisites include neatness, uniformity, stability, proper spacing, and speed.

Neat lettering is important so that the information being conveyed can be easily read. Few things detract from the appearance and quality of a technical drawing more than sloppy lettering, Figure 2-7.

For uniformity, all letters should be the same in height, proportion, and inclination. A necessary tactic for maintaining uniformity is the use of guidelines, Figure 2-8. The customary heights of characters in technical drawing are 1/8" (6 mm) for regular text, and 3/16" (9 mm) for headings and titles.

The proper stability or balance of letters is an important characteristic in freehand lettering. Each letter should appear balanced and firmly positioned to the human eye. Top-heavy letters are not balanced because they appear about to topple over, Figure 2-9.

The proper spacing of letters and words is important, and it takes a lot of practice to accomplish. A good rule of thumb to follow in terms of spacing is to use close spacing within words, and far spacing between words, Figure 2-10. The proper positions of letters relative to one another in words is accomplished by spacing the letters in the word equally in the area, not by trying to equalize the spacing between letters. This becomes automatic if the drafter concentrates on the word being lettered, not on each letter. Another rule of thumb for spacing is to allow the width of one round letter, such as O, C, Q or G, between words. Figure 2-11 illustrates how this type of spacing can make the lettering much easier to read.

In the modern drafting room, because time is money, speed in freehand lettering is critical. Typically, freehand lettering is one of the slowest, most time-consuming tasks drafters must perform. It takes many hours of practice to develop freehand lettering that is neat, uniform, balanced, properly spaced, and fast. Some drafters never reach this goal. Those who do, reach it through constant practice, coupled with continual efforts to improve.

Figure 2-8 Guidelines improve uniformity

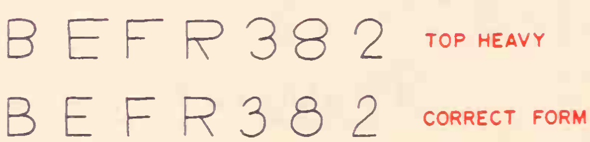


Figure 2-9 Top-heavy letters are not balanced

SPACING WITHIN WORDS SHOULD BE CLOSE.

SPACING BETWEEN WORDS SHOULD BE FAR.

Figure 2-10 The proper spacing of letters and words

THIS IS A PROPERLY SPACED SENTENCE.

THISISANIMPROPERLYSPACEDSENTENCE.

Figure 2-11 Spacing between words is important

Freehand Lettering Techniques

Freehand lettering techniques are learned by knowing what grades of lead to use, how to make the basic lettering strokes, and how to use guidelines; and by constantly practicing and trying to improve.

Lettering in ink has been greatly simplified in recent years. Old-fashioned tools, such as adjustable nib ruling pens and speedball pens, have been replaced by the less cumbersome, easier-to-use technical pen, Figure 2-12. When lettering in ink, drafters still use light guidelines made with pencil lead. The actual lettering is done with the desired pen point size. Commonly used pen points for lettering in ink are sizes 0, 1, and 2, which are standard American sizes. In metrics, these point sizes represent line widths of 0.35 mm, 0.50 mm, and 0.60 mm.

All letters and numbers are created using six basic strokes, Figure 2-13. The first stroke is a single stroke made downward and to the right at approximately 45 degrees. The second stroke is made downward and to the left at approximately 45 degrees. The third stroke is vertical, and is made from top to bottom. Stroke number four is horizontal, and is made from left to right. The fifth stroke is a half-circular stroke to the left, made from top to bottom. The sixth stroke is a half-circular stroke to the right, made from top to bottom. All alphanumeric characters can be created using combinations of these six strokes. Figure 2-14 shows how these strokes are used for making selected characters.

Lettering Guidelines

Guidelines are a critical part of freehand lettering. Uniformity, neatness, and stability cannot be achieved without using guidelines.

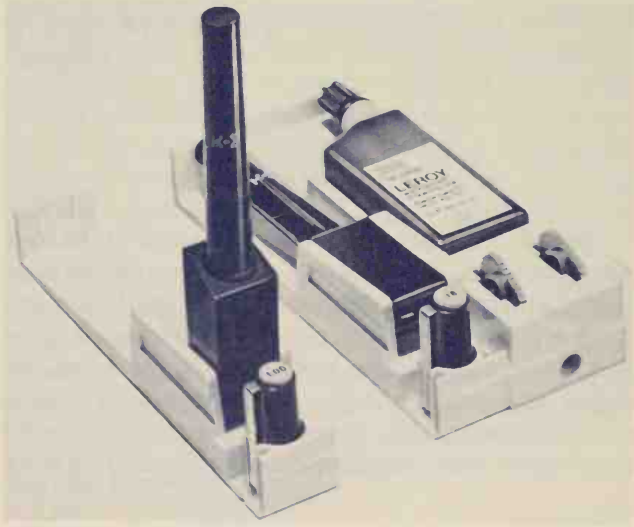


Figure 2-12 Modern technical pens (*Courtesy Keuffel & Esser Co.*)

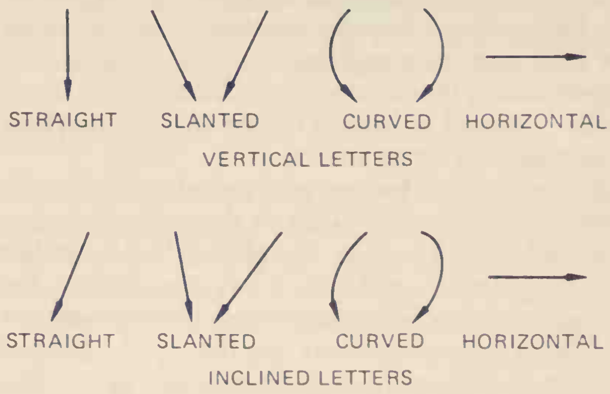


Figure 2-13 Basic strokes used for lettering

Figure 2-14 Forming uppercase Gothic letters and numerals—vertical style

Line Work

Line work is the generic term given to all of the various techniques used in creating the graphic data on technical drawings. Mechanical line work is made using either mechanical pencils or technical pens. Such devices as parallel bars, drafting machines, triangles, scales, and numerous other tools are used to guide the line-making. Since inking is dealt with in the first chapter, this chapter focuses on pencil line work.

Characteristics of Lines

Twelve basic types of lines are used in manual drafting. Each has its own individual characteristics. The *visible* line is thick and dark. The *hidden* line is a series of short dashes separated by even shorter breaks. The hidden line is thinner than the visible line. *Dimension* lines and *extension* lines are solid, thin lines of approximately the same width as hidden lines. *Dimension* lines should be broken for dimensions, and have arrowheads for terminations.

The *center* line is broken with one short dash in its center. It is the same width as the hidden, dimension, and extension lines. The *phantom* line is just like the center line except that it has two dashes. The dashes are repeated approximately every two inches. The *cutting plane* line is thick like the visible line and consists of a series of long, equally spaced dashes. All lines used on technical drawings should closely match those in Figure 2-15.

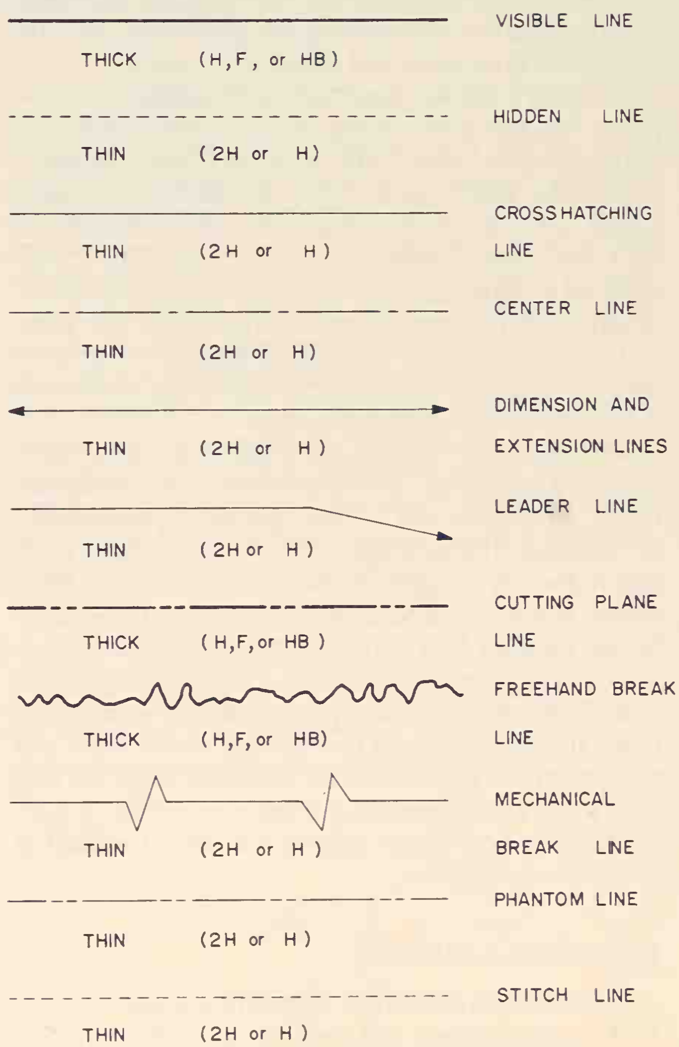


Figure 2-15 Line types used on technical drawings

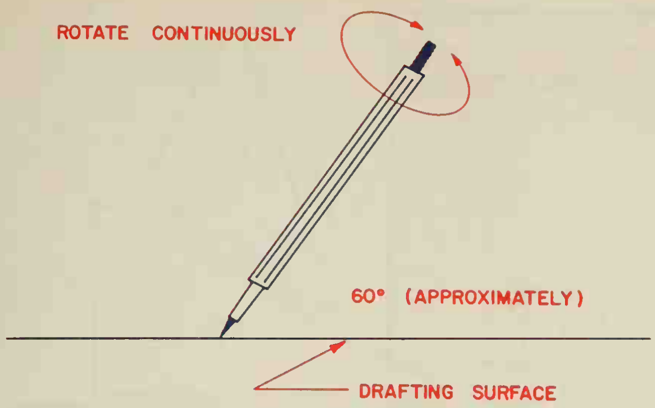


Figure 2-16 Maintaining uniformity of lines

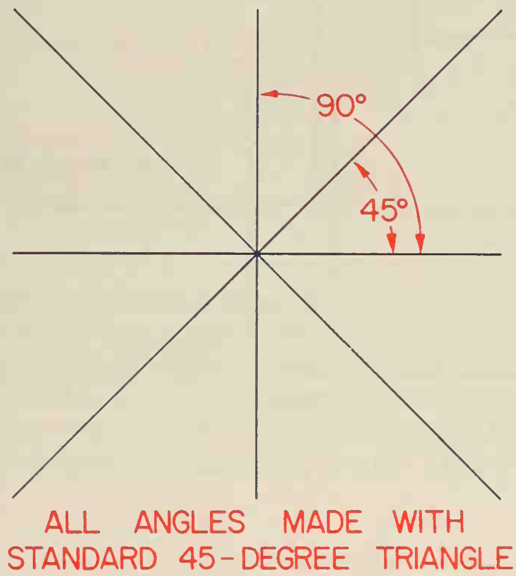


Figure 2-17 Making angular lines with the 45° triangle

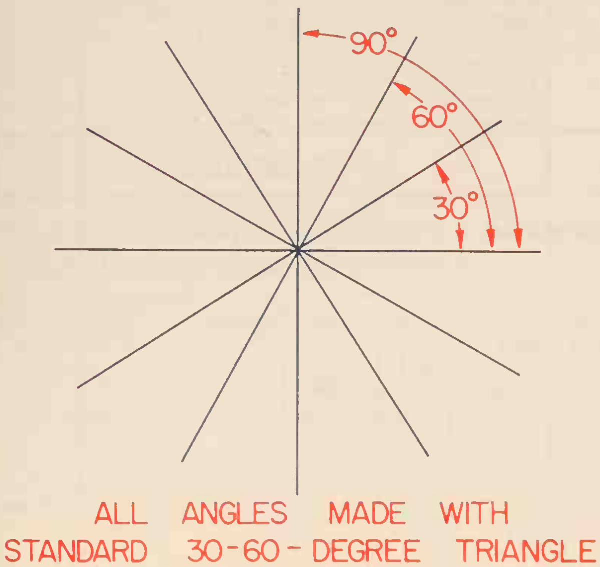


Figure 2-18 Making angular lines with the 30°-60° triangle

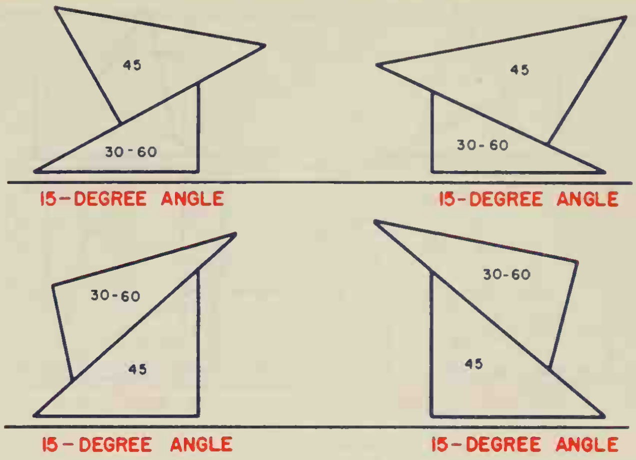


Figure 2-19 Making 15° angles

Horizontal and Vertical Lines

Horizontal lines are formed by pressing the straightedge (T-square, parallel bar, drafting machine scale, and so forth) against the worksheet with one hand and moving the pencil with the other. Uniformity of line widths and weights can be achieved by holding the pencil at approximately 60 degrees from the drawing surface, maintaining an even pressure downward, and slowly revolving the pencil axially as it moves across the drawing surface, Figure 2-16. This keeps the lead tip symmetrical.

Vertical lines are created according to the same principles, except that the drafter's hand moves upward rather than from left to right. The angle of inclination, the amount of pressure, and the rotating motion are the same as they are for horizontal lines.

Angular Lines

Many modern devices are available to assist drafters in making angular lines. These include protractors, adjustable triangles, and adjustable arms on drafting machines. However, most angular lines can be created simply by using the standard 30°-60° and 45° triangles alone, and in various combinations, Figures 2-17, 2-18, 2-19, and 2-20. These standard tools create angles of 15°, 30°, 45°, 60°, and 75°.

Parallel Lines

Parallel lines can be created in a number of different ways. Vertical (and horizontal) parallel lines are made by simply moving the straightedge the required distance and making each successive line, Figure 2-21.

Parallel lines at angles can be created by using the 30°-60° and 45° triangles in combination much the same as they are used for making angular lines. When using triangles to create angular lines, the first line is created at the desired angle. Aligning one edge of a

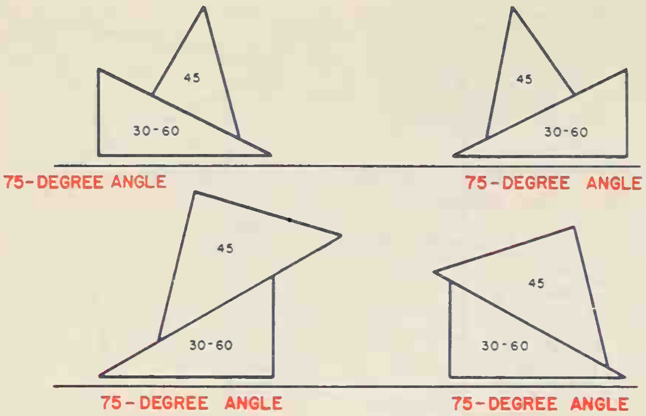


Figure 2-20 Making 75° angles

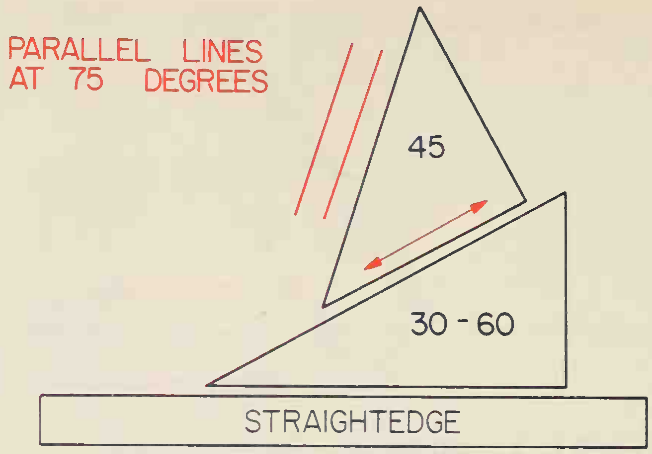


Figure 2-22 Creating successive parallel lines

triangle to the line, register any side of the second triangle against one of the nonaligned edges of the first triangle. Holding the second triangle to prevent it from moving, and sliding the first triangle along the engaged edge of the second triangle, will reposition the originally aligned edge to any desired parallel position. Successive parallel lines are created in the same way, Figure 2-22.

Perpendicular Lines

Drawing perpendicular lines can be accomplished in a manner similar to drawing parallel lines. Horizontal and vertical perpendicular lines can be created using a straightedge and a triangle, Figure 2-23.

Creating a line perpendicular to a nonhorizontal or nonvertical line is accomplished by using triangles in conjunction with a straightedge, Figure 2-24. Line 1 in this figure is drawn first. Then the 45° triangle is slid along the 30°-60° triangle, and the perpendicular line is created with the opposite side of the 45° triangle.

Sketching

Even in the world of high technology and computers, sketching is still one of the most important skills for drafters and designers. Sketching is one of the

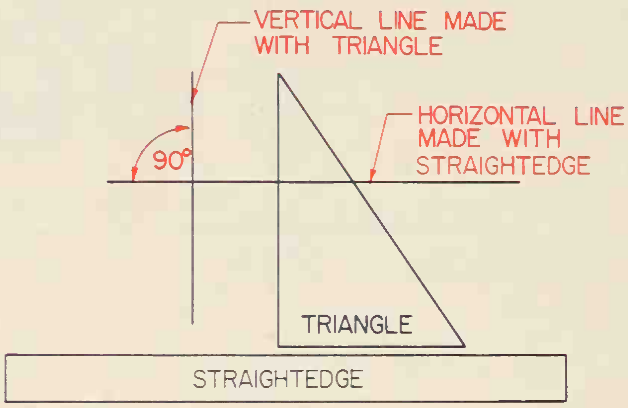


Figure 2-23 Making perpendicular lines

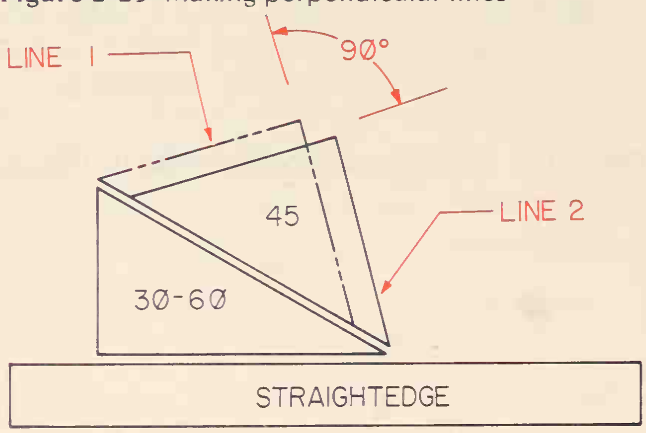


Figure 2-24 Creating a line perpendicular to a nonvertical or nonhorizontal line

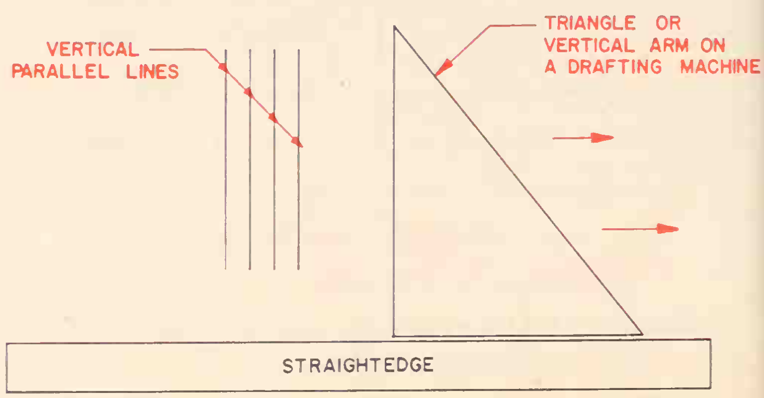


Figure 2-21 Making vertical parallel lines

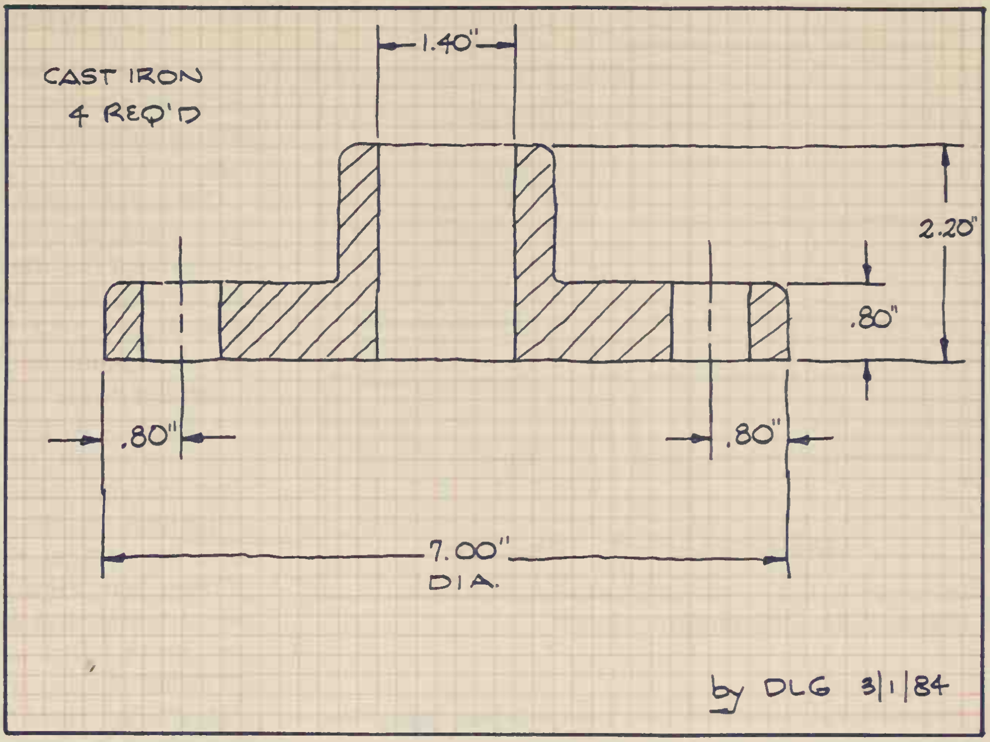


Figure 2-25
Typical design sketch

first steps in communicating ideas for a design, and it is used in every step thereafter. It is common practice for designers to prepare sketches that are turned over to drafters for conversion to finished working drawings. Figure 2-25 is an example of a typical design sketch.

Sketching Lines

The lines used in creating sketches closely correspond to those used in creating technical drawings except, of course, that they are not as sharp and crisp. Figure 2-26 illustrates the various types of lines used in making sketches.

The basic line types are: visible line, hidden line, center line, dimension line, sectioning line, extension line, and cutting plane line. These lines represent the various lines available for creating sketches. The character of each line, as illustrated in Figure 2-27, should be closely adhered to when making sketches.

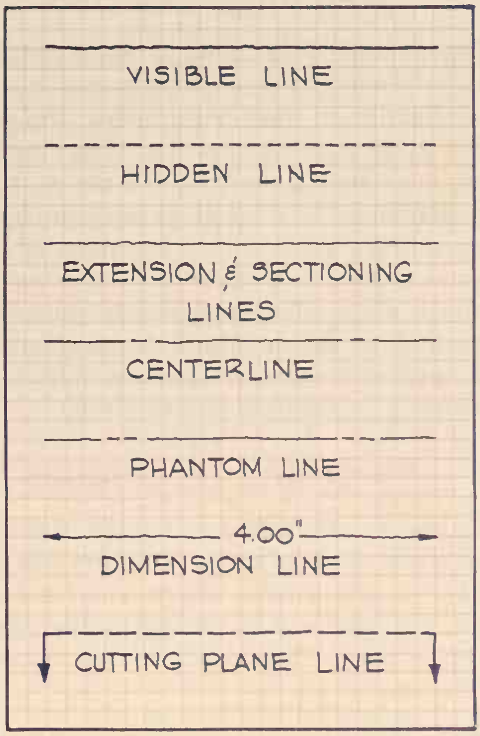


Figure 2-26 Lines used in sketching

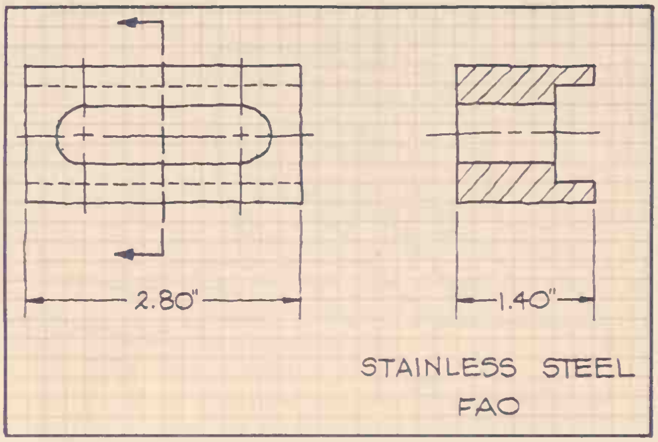


Figure 2-27 Sample design sketch

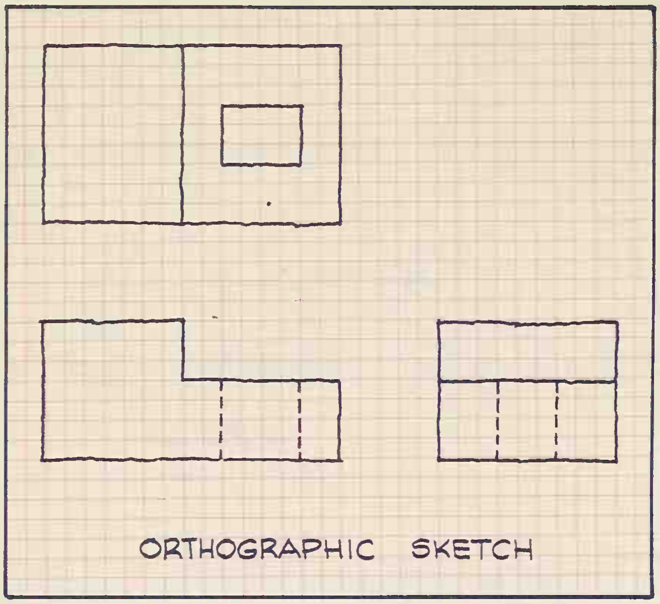


Figure 2-28 Orthographic sketch

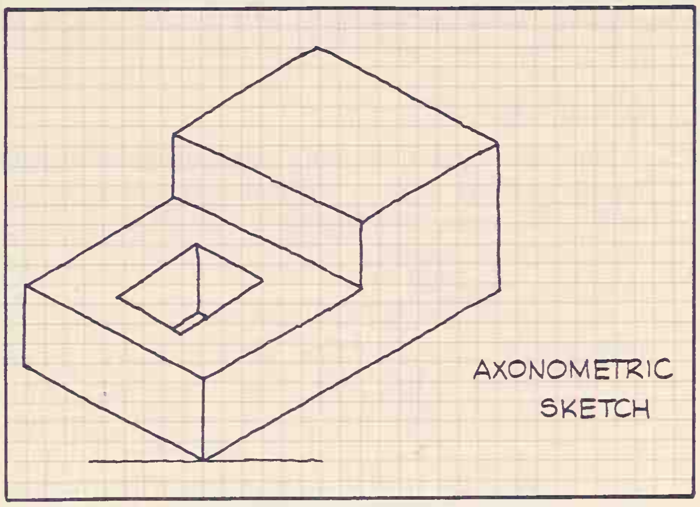


Figure 2-29 Axonometric sketch

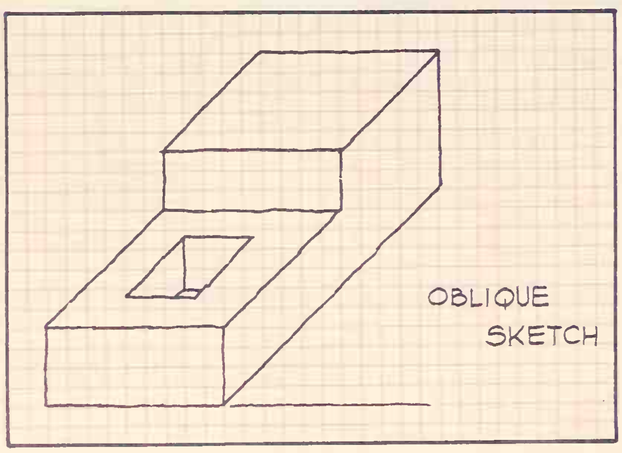


Figure 2-30 Oblique sketch

Types of Sketches

The types of sketches correspond to the types of technical drawings. There are four types of sketching: orthographic, axonometric, oblique, and perspective, Figures 2-28, 2-29, 2-30, and 2-31.

Orthographic sketching relates to flat, graphic facsimiles of a subject showing no depth. Six principal views of a subject may be incorporated in an orthographic sketch: top, front, bottom, back, right side, and left side, Figure 2-32. The views selected for use in a sketch depend on the nature of the subject and the judgment of the sketcher.

Axonometric sketching may be one of three types: isometric, dimetric, or trimetric, Figure 2-33. The type most frequently used is *isometric*, in which length and width lines recede at 30° to the horizontal and height lines are vertical, Figure 2-34. In sketching, the use of these terms is academic as they relate to proportional scales and angle positions of length, width, and depth, which are only estimated in sketching.

Oblique sketching involves a combination of a flat, orthographic front surface with depth lines receding at a selected angle (usually 45°), Figure 2-35.

Perspective sketching involves creating a graphic facsimile of the subject. Consequently, depth lines must recede to a hypothetical vanishing point (or points), Figures 2-36 and 2-37. In fact, all pictorial sketches naturally tend to assume characteristics of perspective sketches as a result of how the eye views the apparent relative proportions of objects. This is not necessarily undesirable.

Sketching Materials

An advantage of sketching is that it requires very few material aids. Whereas drafters must have a complete collection of tools, equipment, and materials in order to do working drawings, sketching requires nothing more than a pencil and a piece of paper. It is not uncommon for a sketch to be drawn on a paper napkin during a hurried luncheon meeting.

Sketching done in an office environment requires three basic materials: pencil, media (paper or graph paper), and an eraser. Graph paper simplifies the sketching process considerably, especially for students just learning, and should be used freely.

Sketching Techniques

Sketches, as with drawings, consist of straight and curved lines. With practice, drafters can become skilled in creating neat, sharp, clear examples – straight or curved – of all the various line types introduced previously. When sketching, the following general rules apply.

1. Hold the pencil firmly, but not so tightly as to create tension or hand fatigue.

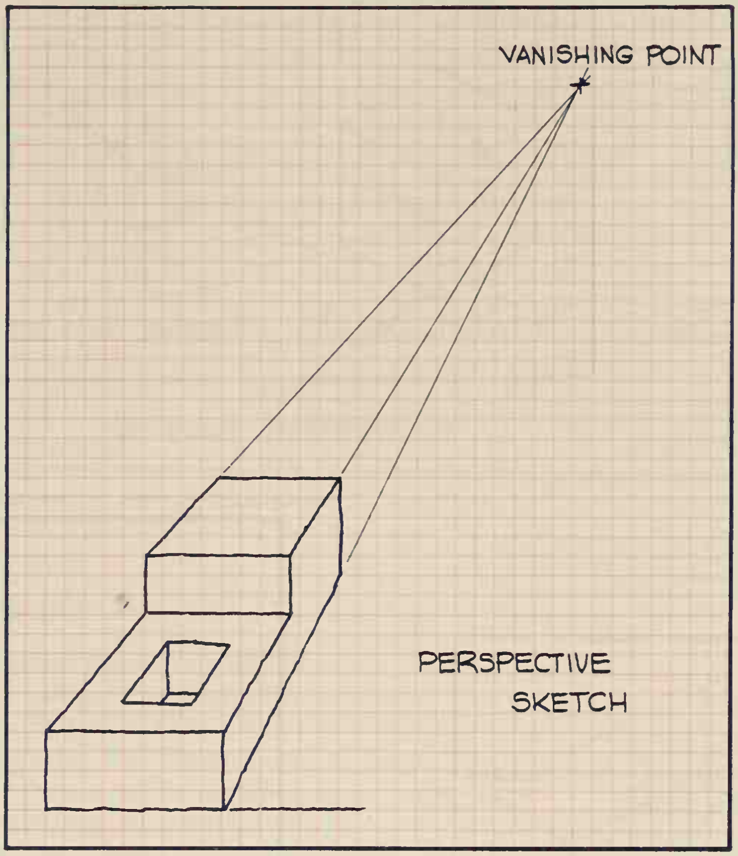


Figure 2-31 Perspective sketch

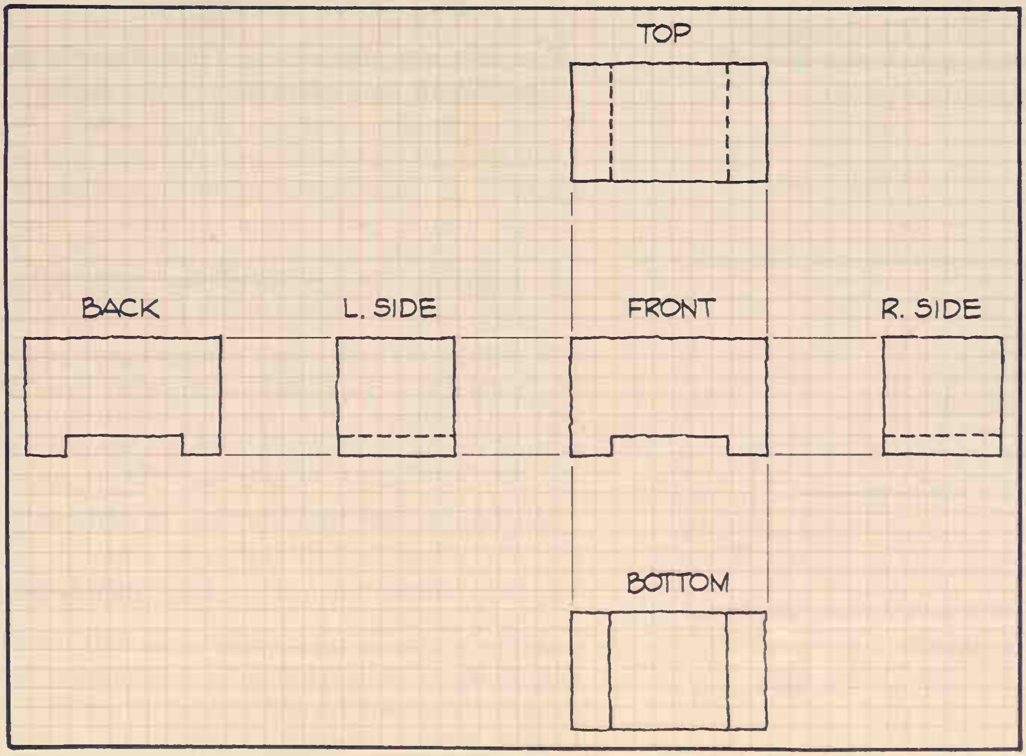


Figure 2-32
Six principal views in orthographic sketching

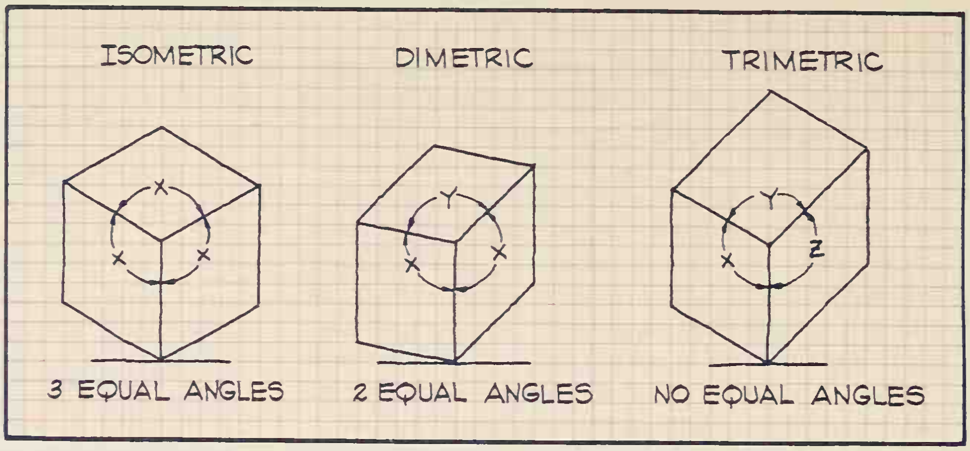


Figure 2-33 Three types of axonometric sketches

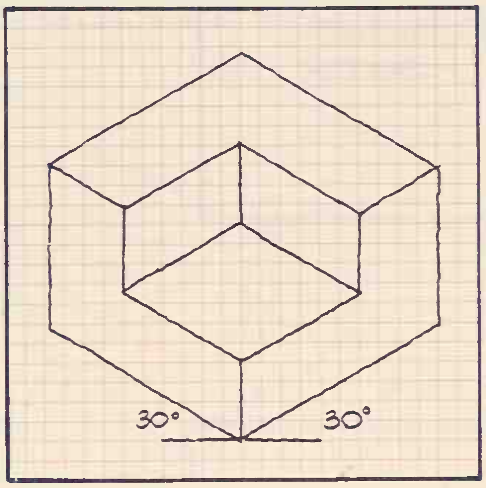


Figure 2-34 Isometric sketch

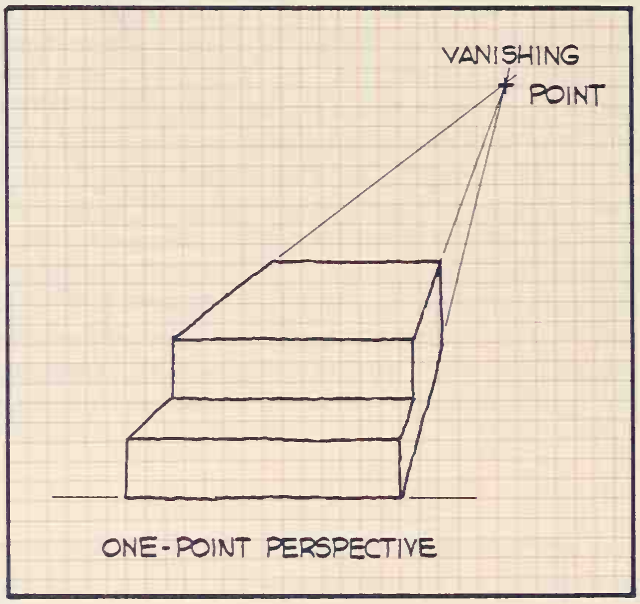


Figure 2-36 One-point perspective sketch

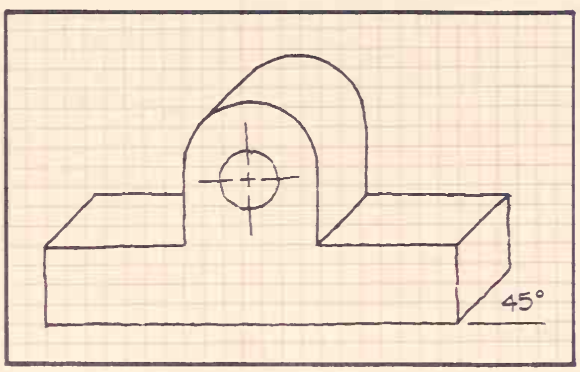


Figure 2-35 Oblique sketch

2. Grip the pencil approximately one inch to one and one-half inches up from the point.
3. Maintain a comfortable angle between the pencil and the sketching strokes.
4. Draw horizontal lines from left to right using short, slightly overlapping strokes.
5. Draw vertical lines from top to bottom using short, slightly overlapping strokes.
6. Draw curved lines using short, slightly overlapping strokes.

In addition to these general rules, some specific techniques are used in making the various line types for sketching.

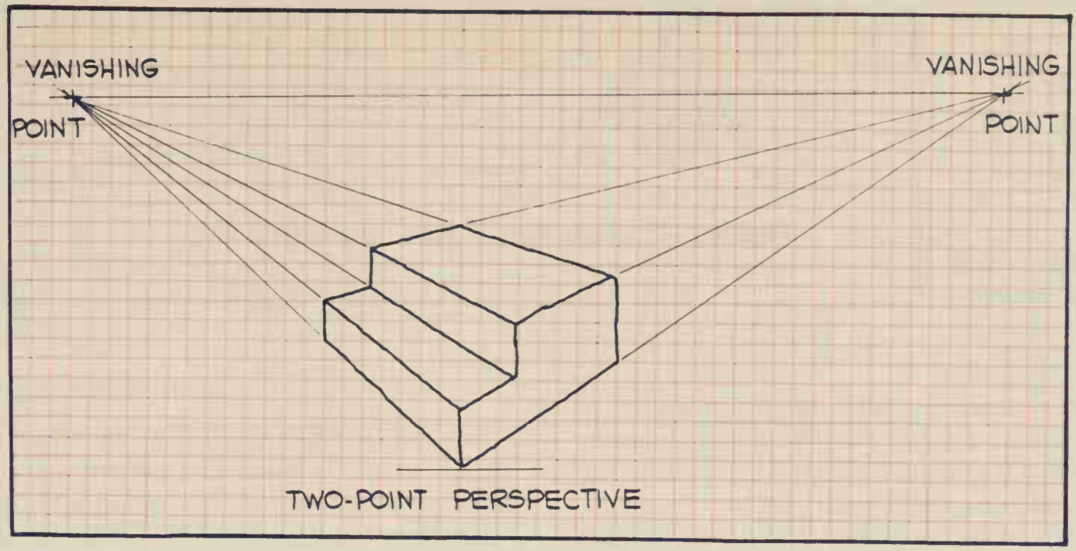


Figure 2-37 Two-point perspective sketch

Figure 2-38 Dots used as guides in sketching

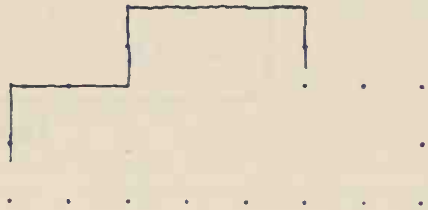


Figure 2-39 Using dots in sketching lines

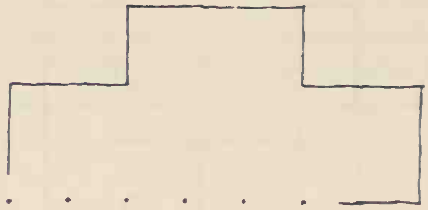


Figure 2-40 Continuing the sketch by connecting the dots

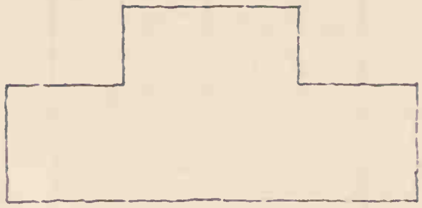


Figure 2-41 Completing the sketch made by using dots as guides

Sketching Straight Lines and Curves

Making straight lines on graph paper is a simple process of guiding the pencil using the existing lines. If graph paper is not available, pencil dots can be positioned to plot the path of the line, Figure 2-38. In this figure, the sketcher enters a series of pencil dots on the paper which provide a basic outline as to the shape of the object. Then, using a series of short, slightly overlapping strokes, the pencil dots are connected, Figures 2-39, 2-40, and 2-41. This technique is also used for curved lines, Figure 2-42.

Sketching Circles

Figure 2-43 illustrates a series of six steps that can be used for sketching a circle. Vertical and horizontal center lines are sketched, which positions the center of the circle (Step 1), and the radial distances of the desired circle size are marked on each of these lines, equidistant from the center (Step 2). A square is drawn symmetrically around the center, with the sides located at the radial line marks (Step 3). On the diagonals of the square (Step 4), the radial distances are again marked off from the center (Step 5). This provides four positions for the circumference to pass through at the sides of the square, and four more positions on the diagonals of the square. The right half of the circle is sketched in from top to bottom using short, slightly overlapping strokes, and then the left half is sketched in the same manner (Step 6).

Sketching Ellipses

A similar technique is used for sketching ellipses, except that the square becomes a rectangle, Figure 2-44. Ellipses are oriented on the object being sketched as shown in the diagram in Figure 2-45.

Figure 2-42 Using dots in sketching curved lines

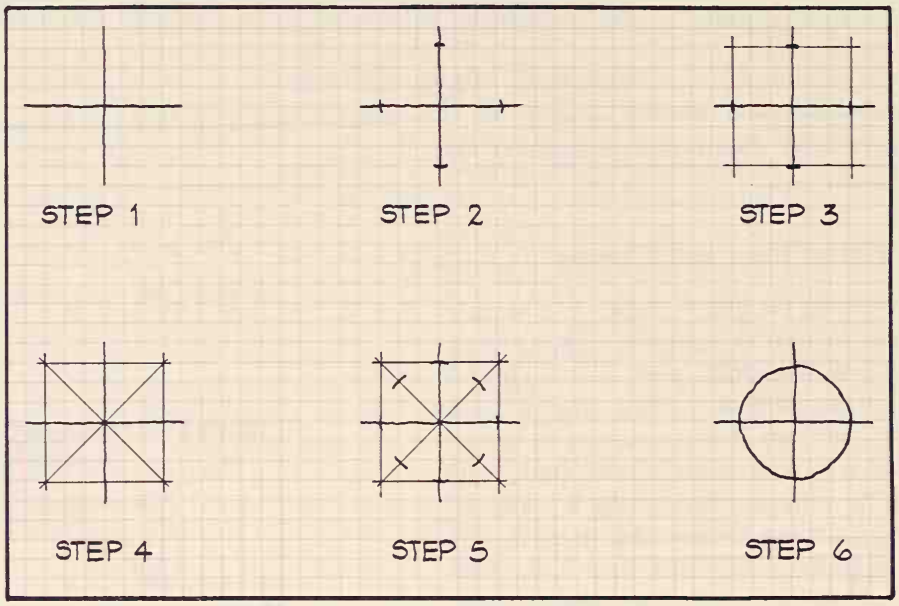


Figure 2-43 Sketching a circle

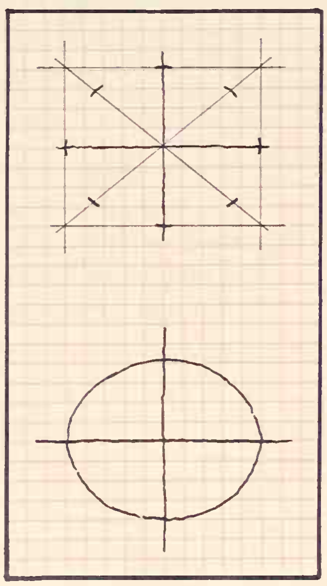


Figure 2-44
Sketching an ellipse

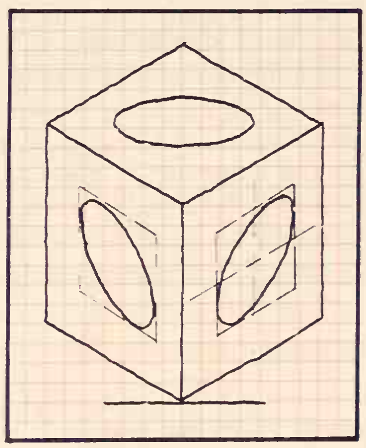


Figure 2-45 Orienting an ellipse on an object

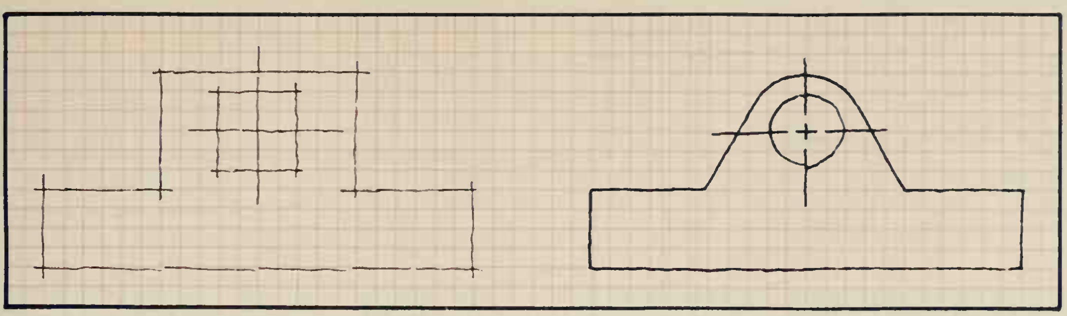


Figure 2-46 Blocking in components

Proportion in Sketching

Sketches are not done to scale, but it is important that they be made proportionately accurate. All of the various components of a sketch should be kept in proportion to those of the actual object. This technique takes a great deal of practice to master.

Some methods for achieving proportion recommend using a pencil or a strip of paper as a simulated scale. These techniques are not only unrealistic in terms of the real world, they defeat the very purpose of sketching. A skilled sketcher must learn to maintain proportion without the use of tools and aids. The best device for accomplishing proportion in sketching is the human eye. With practice, the drafter can become proficient in maintaining proportion without the use of extraneous, time-consuming devices. The following general rules relating to proportion will also help.

Step 1. In sketching, use graph paper whenever possible.

Step 2. Examine the object to be sketched and mentally break it into its component parts.

Step 3. Beginning with the largest components (length and width), estimate the proportion, such as the length is 4/3 times the width or 5/2 times the width, and so on.

Step 4. Lay out the largest component according to the proportions decided upon in Step 3. Use construction line squares and rectangles to block in irregularly shaped components, Figure 2-46.

Repeat Steps 3 and 4 until the entire object is finished.

Orthographic Sketching

Orthographic sketching may involve sketching any combination of the six principal views of the subject. The top, front, and right-side views are normally selected for representing an object in an orthographic sketch. However, these views are not always appropriate. The sketcher must learn to choose the most appropriate views. These are the views that show the most detail and the fewest hidden lines. A good rule of thumb to use in selecting views is to select the views which would give you all of the information you would need if you had to make the object yourself.

Once the views have been selected, the orthographic sketch may be laid out using the techniques set forth earlier in this chapter. To ensure that the sketched views align, the entire sketch should be blocked in before adding details, Figure 2-47. Once the layout is blocked in, the details can be added one view at a time, Figures 2-48, 2-49, and 2-50.

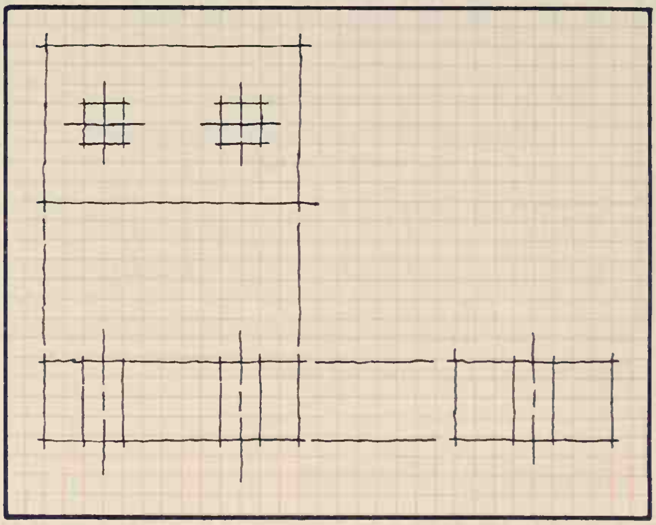


Figure 2-47 Blocking in an orthographic sketch

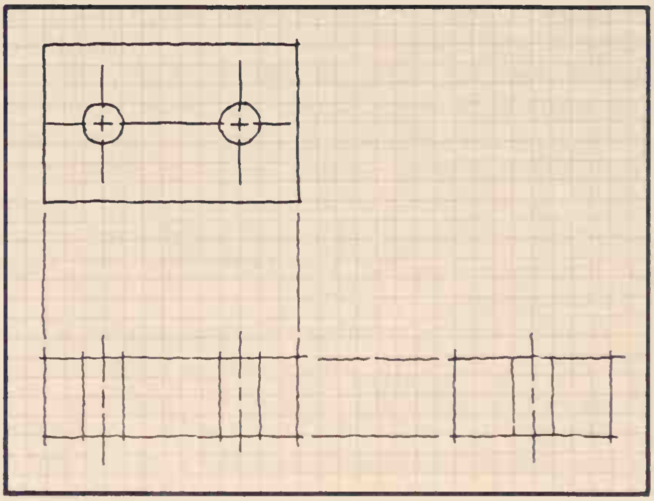


Figure 2-48 Completing the top view

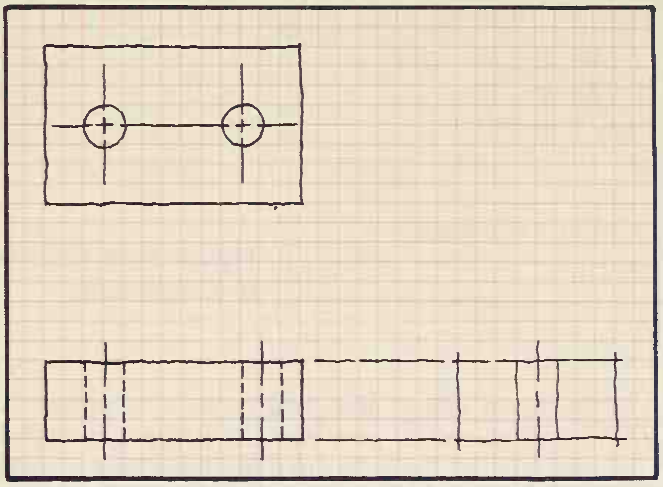


Figure 2-49 Completing the front view

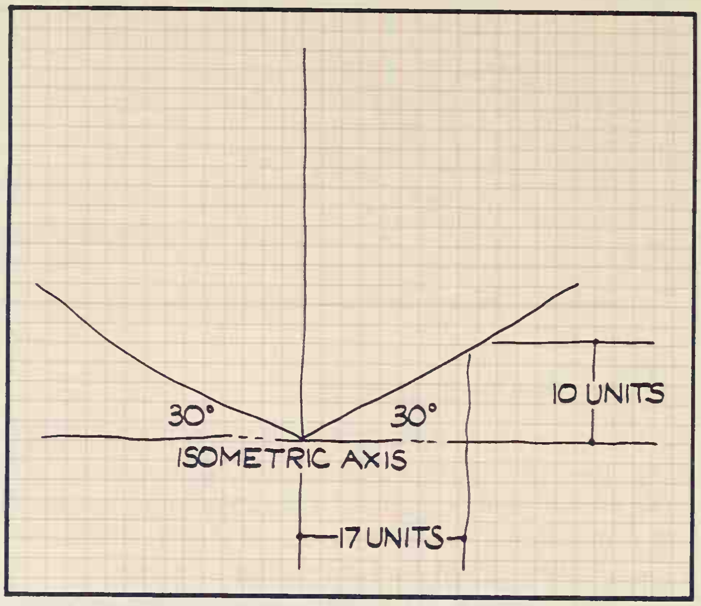


Figure 2-51 The isometric axis in sketching

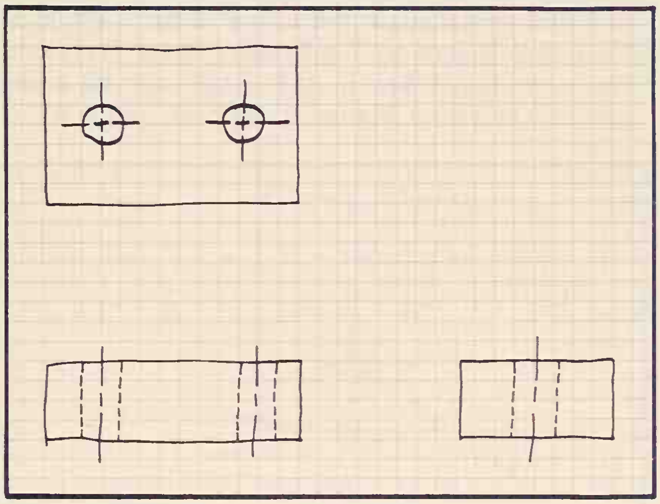


Figure 2-50 Completing the sketch

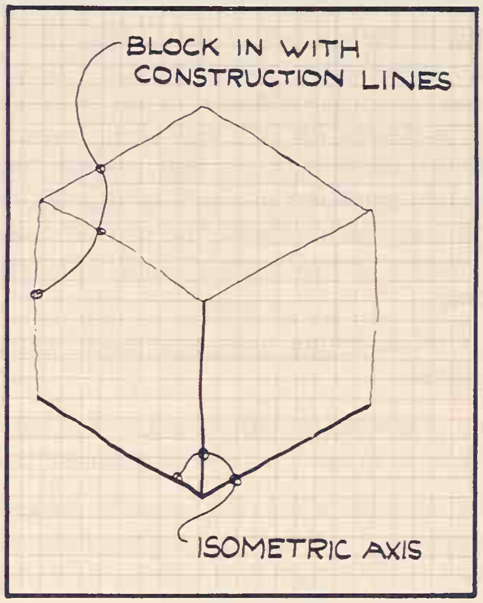


Figure 2-52 Blocking in the object

Axonometric Sketching

As was mentioned earlier, there are three types of axonometric projection: isometric, dimetric, and trimetric. Isometric projection is used in sketching. Dimetric and trimetric projection have little application in sketching, due to the difficulty in proportioning scale values of length, width, and height. Isometric views have the same scaling value in all three directions, eliminating the need to vary proportions among the three directions. In an isometric sketch, height lines are vertical, and width and length lines recede at approximately 30° and 150° (180°−30°) from the horizontal.

The first step in creating an isometric sketch is to lay out the isometric axis, Figure 2-51. All normal lines will be parallel to one of the axis lines. The next step is to block in the object using construction lines, Figure 2-52. Five steps in the development of an isometric sketch are shown in Figures 2-53, 2-54, 2-55, 2-56 and 2-57.

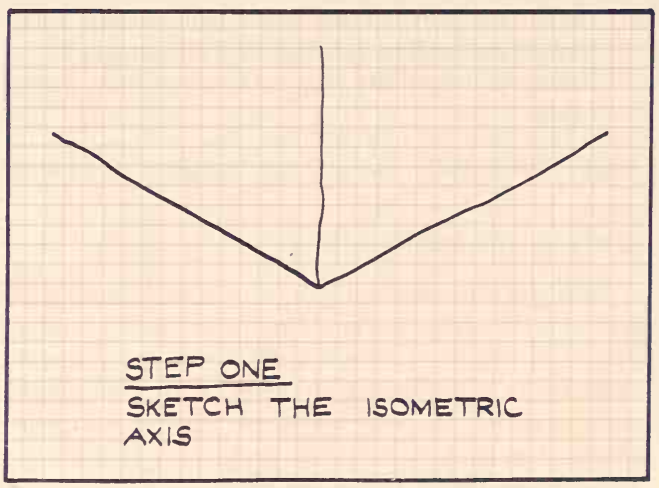


Figure 2-53 Step one in making an isometric sketch

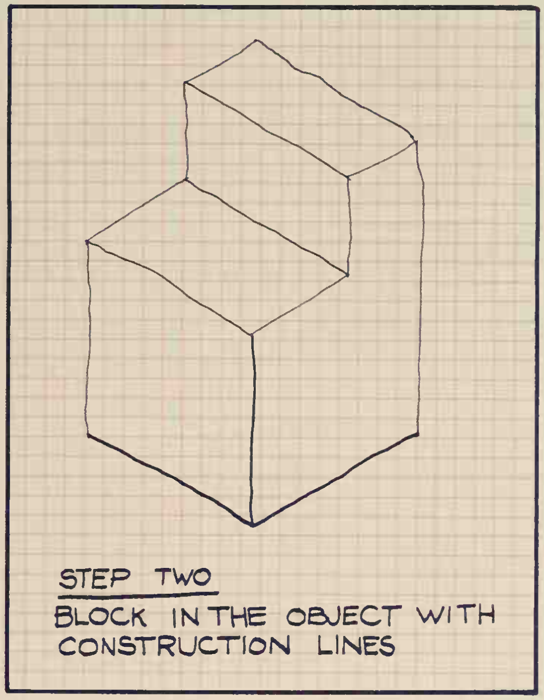


Figure 2-54 Step two in making an isometric sketch

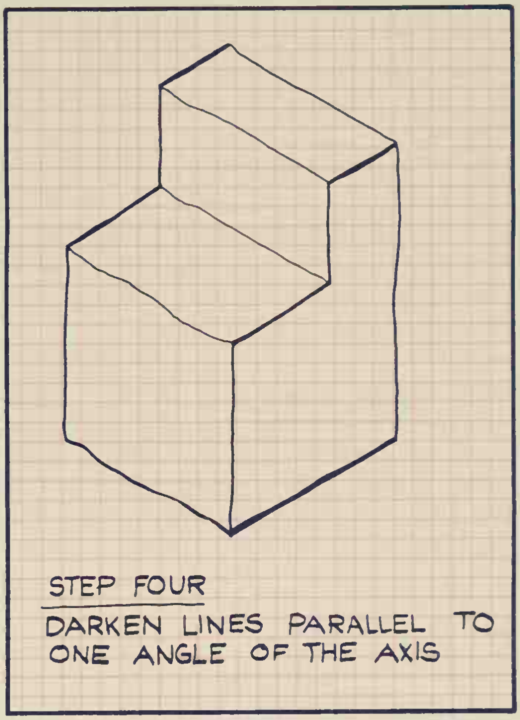


Figure 2-56 Step four in making an isometric sketch

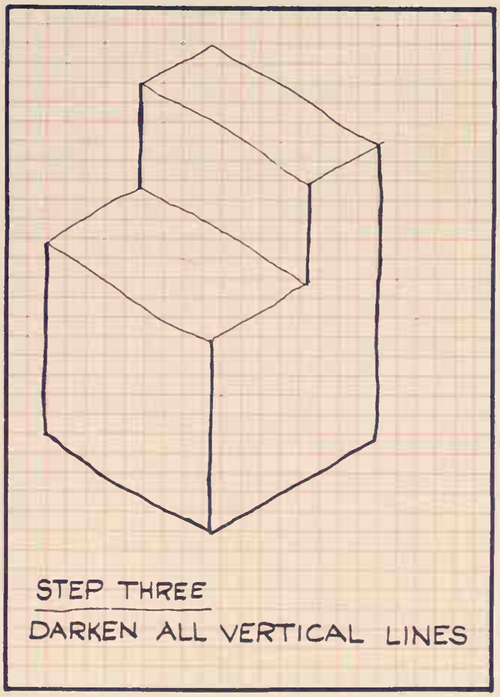


Figure 2-55 Step three in making an isometric sketch

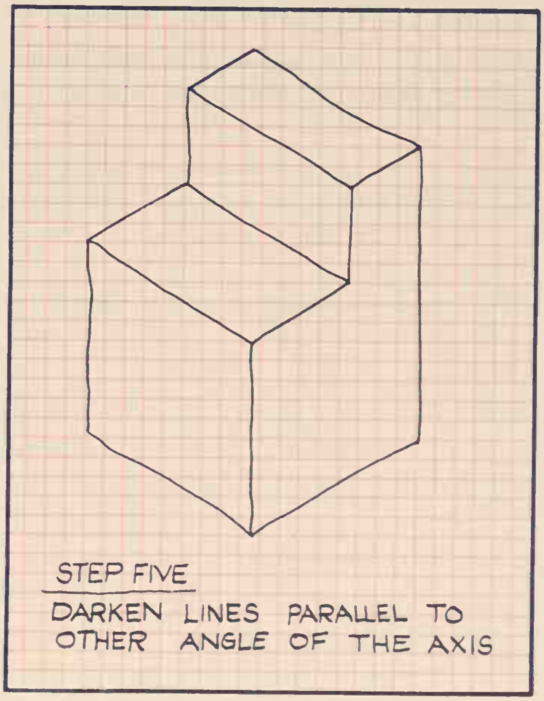


Figure 2-57 Step five in making an isometric sketch

Oblique Sketching

Oblique sketching involves laying out the front view of an object, and showing the depth lines receding at an angle (usually 45°) from the horizontal. Oblique sketching is particularly useful for dealing with an object having round components. Oblique sketching allows round components to be drawn round, rather than elliptical.

Using the blocking in method, the flat front surface of the object is laid out. The depth is then blocked in using parallel lines, and the sketch is completed by outlining the exposed profile of the rear surface. Figures 2-58, 2-59, and 2-60 illustrate three steps in creating an oblique sketch.

Perspective Sketching

Perspective sketching closely approximates how the human eye actually sees an object. Two common types of perspective sketches are one-point and two-point perspectives.

A one-point perspective sketch is similar to an oblique sketch, except that depth lines recede to a vanishing point instead of receding parallel to one another, Figure 2-61. In constructing a one-point perspective, the following procedures apply.

Step 1. Lay out the flat front surface of the object using the blocking in method, Figure 2-62.

Step 2. Select and mark a single vanishing point. Project all points on the front surface back to the vanishing point, Figure 2-63.

Step 3. Estimate the depth of the object and mark it off on all line projectors, Figure 2-64.

Step 4. Complete the sketch by outlining the exposed profile of the rear surface, Figure 2-65.

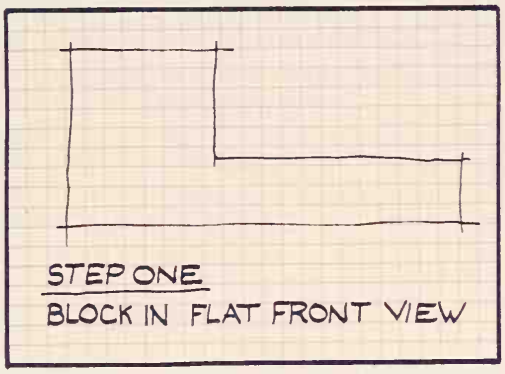


Figure 2-58 Step one in making an oblique sketch

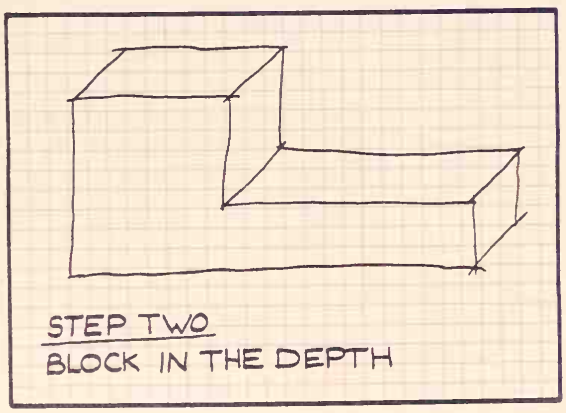


Figure 2-59 Step two in making an oblique sketch

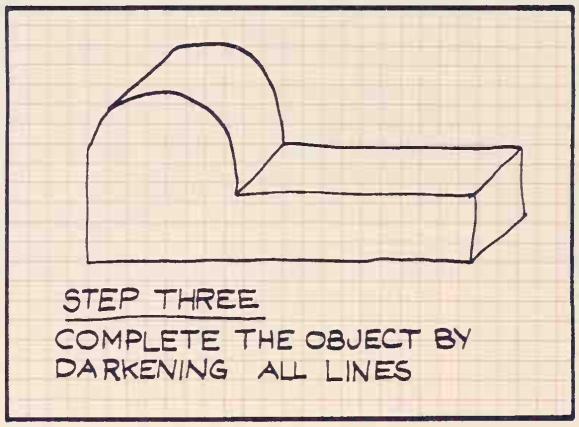


Figure 2-60 Step three in making an oblique sketch

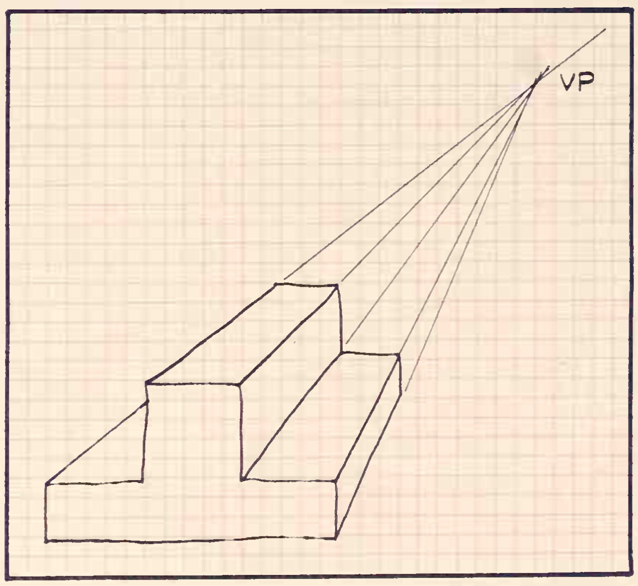


Figure 2-61 One-point perspective sketch

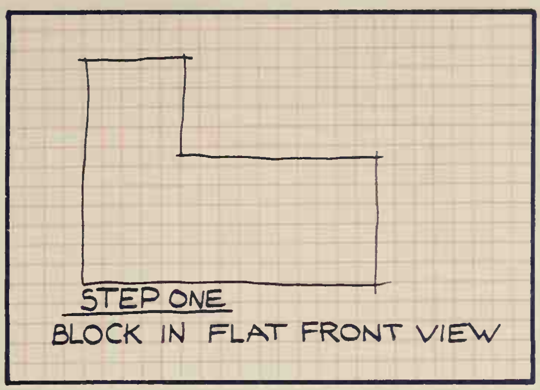


Figure 2-62 Step one in making a one-point perspective sketch

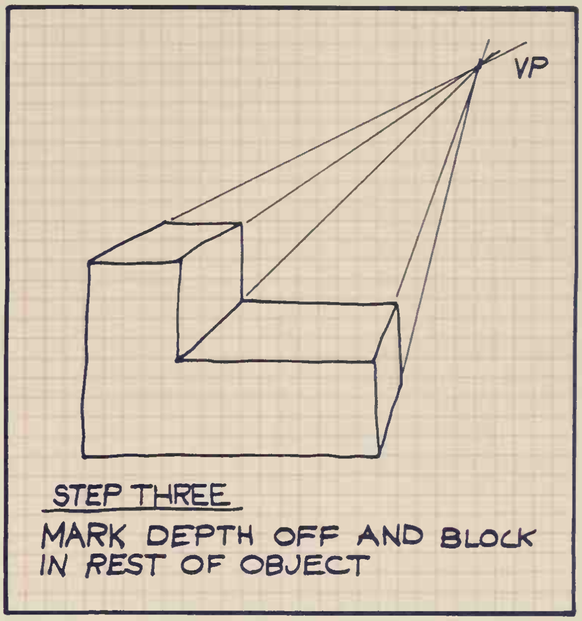


Figure 2-64 Step three in making a one-point perspective sketch

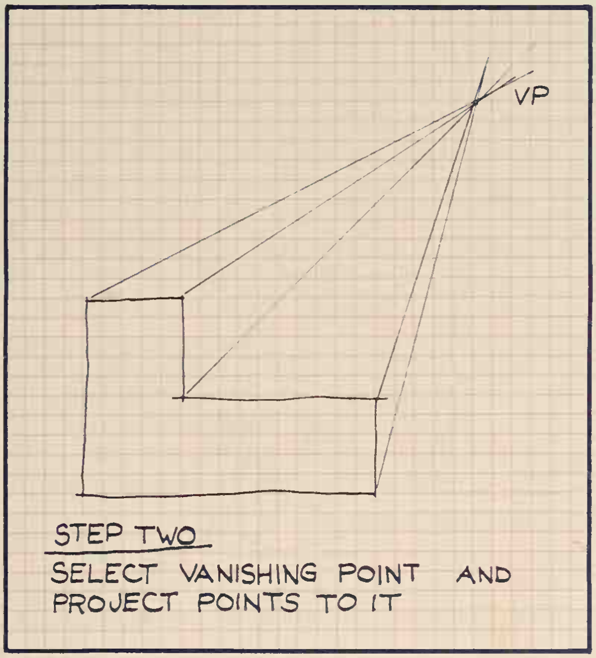


Figure 2-63 Step two in making a one-point perspective sketch

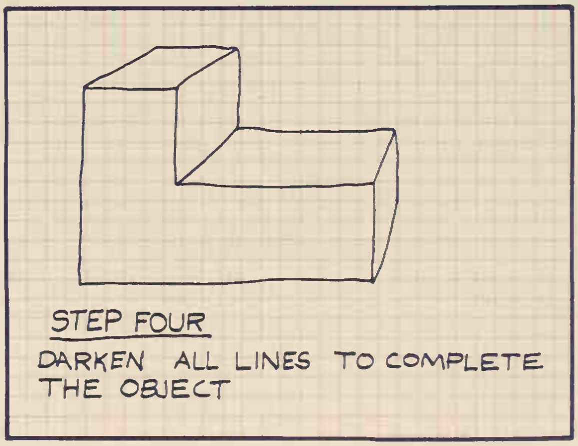


Figure 2-65 Step four in making a one-point perspective sketch

A two-point perspective resembles an isometric sketch, except that width and depth lines recede to the left and right vanishing points rather than receding in parallel, Figure 2-66.

In constructing a two-point perspective, the following procedures apply.

Step 1. Lay out the two-point perspective frame which consists of the vertical height line, the vanishing point left, the vanishing point right, and the receding lines (all estimated locations), Figure 2-67. The horizon line when positioned below the view provides a view of the bottom of the object, and when positioned above shows the top. The vanishing points must be on the horizon.

Step 2. Block in the object, estimating the length and width for proportion, Figure 2-68.

Step 3. Lay out the details, lightly giving special attention to proportion, Figure 2-69.

Step 4. Complete the two-point perspective sketch, Figure 2-70.

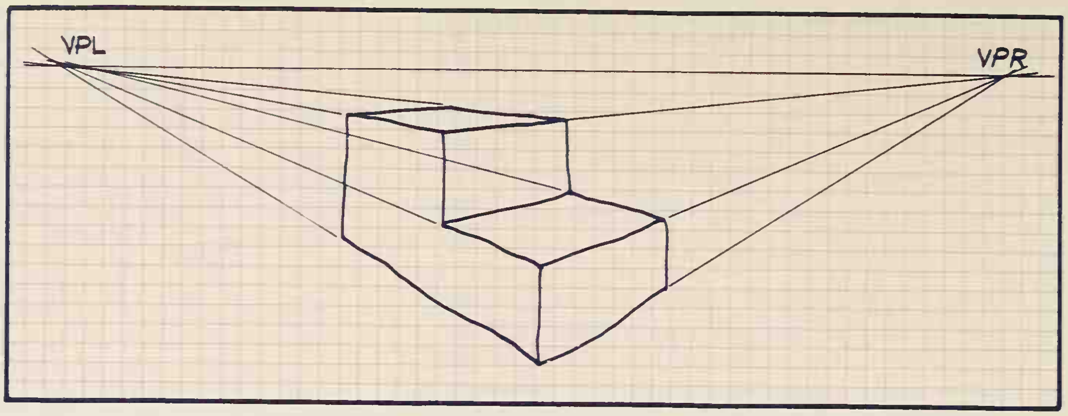


Figure 2-66 Two-point perspective sketch

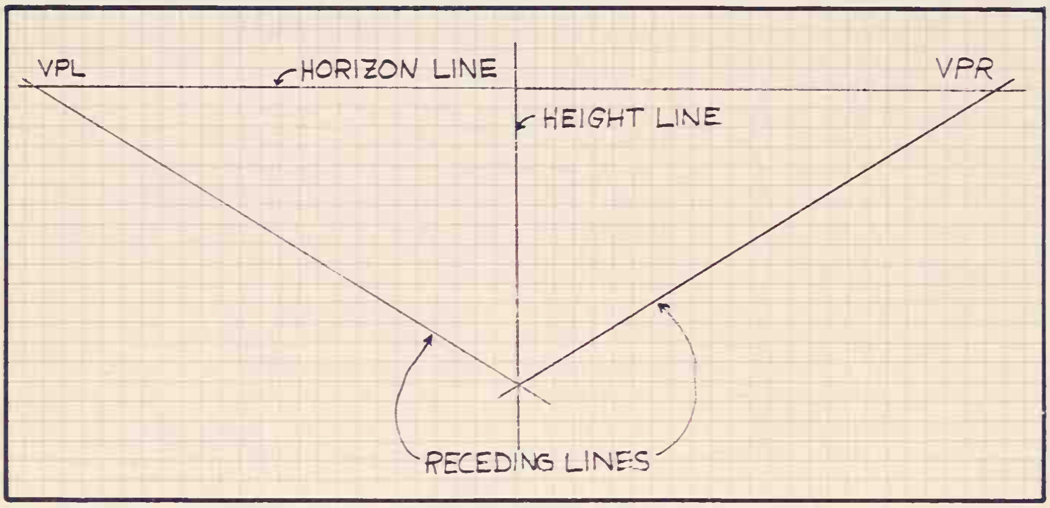


Figure 2-67 Laying out the two-point perspective frame

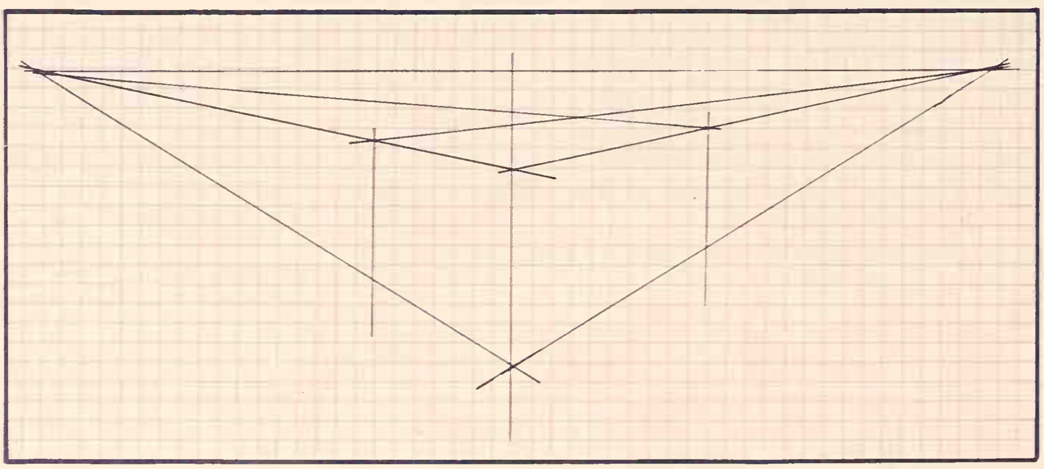


Figure 2-68 Blocking in the object

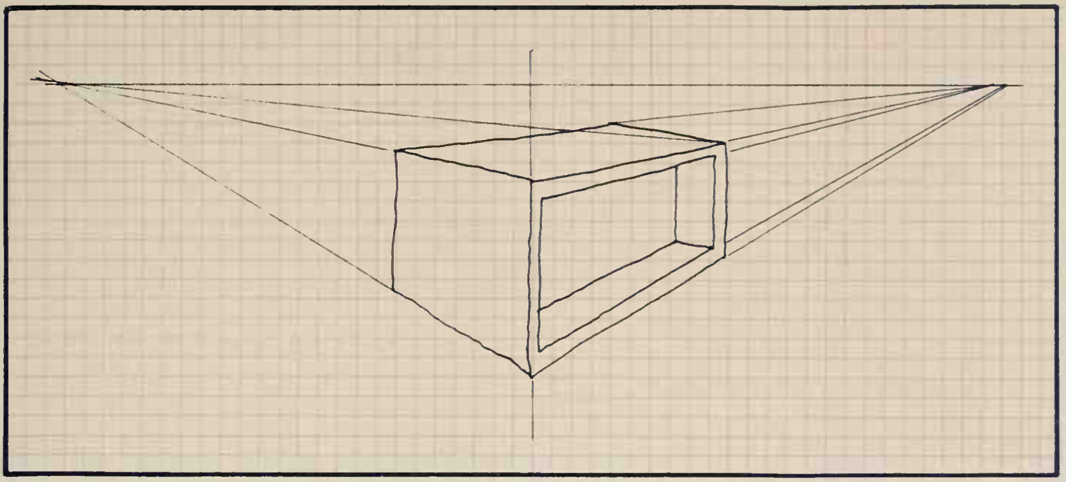


Figure 2-69 Laying out the details

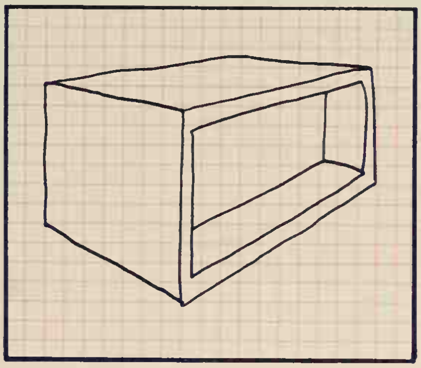


Figure 2-70 Completing the two-point perspective sketch

Review

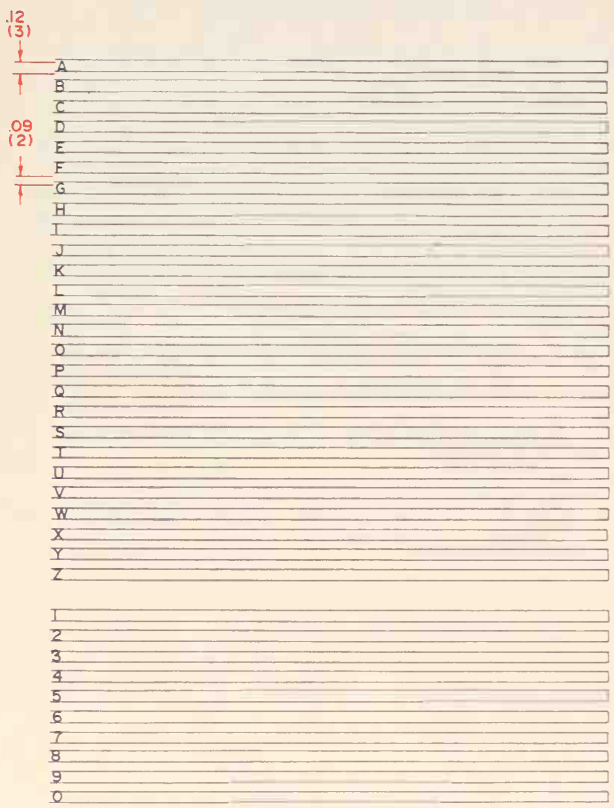
1. What is the standard style of freehand lettering on technical drawings?
2. What is the slope of slanted lettering?
3. What are the five characteristics of good freehand lettering?
4. How many strokes are required to make a letter B?
5. How high should fractions be?
6. How much space should be left between words?
7. What are two grades of lead commonly used for freehand lettering?
8. What are guidelines?
9. Why are guidelines important?
10. A setting of 8 on a lettering guide will produce letters of what height?
11. Define the term *line work.*
12. Name ten basic lines types used on technical drawings.
13. What are two advantages of sketching over mechanical drawing?
14. What are the six principal views of orthographic projection?
15. Which axonometric projection is preferred for sketching?
16. What kind of projection exhibits a circle as an elliptic shape?

Chapter Two Problems

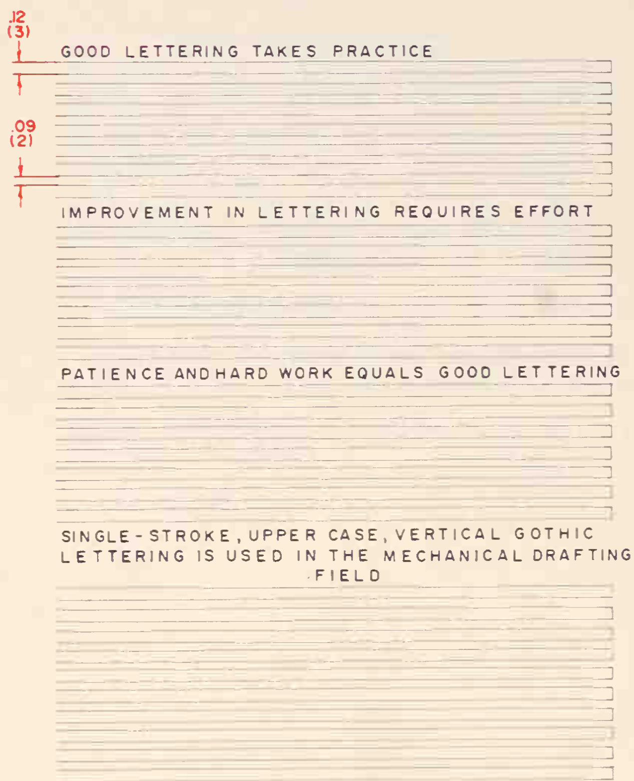
Problems 2-1 through 2-4

The following problems are intended to give the beginning drafter practice in making neat uppercase, vertical, and Gothic-style letters and numbers. On an A-size sheet of vellum, carefully lay out light, .12 spaces as shown. Use .50 borders all around and *be sure to skip a space* between lines of letters or numbers. Practice letters, numbers, words, sentences, and paragraphs, as given.

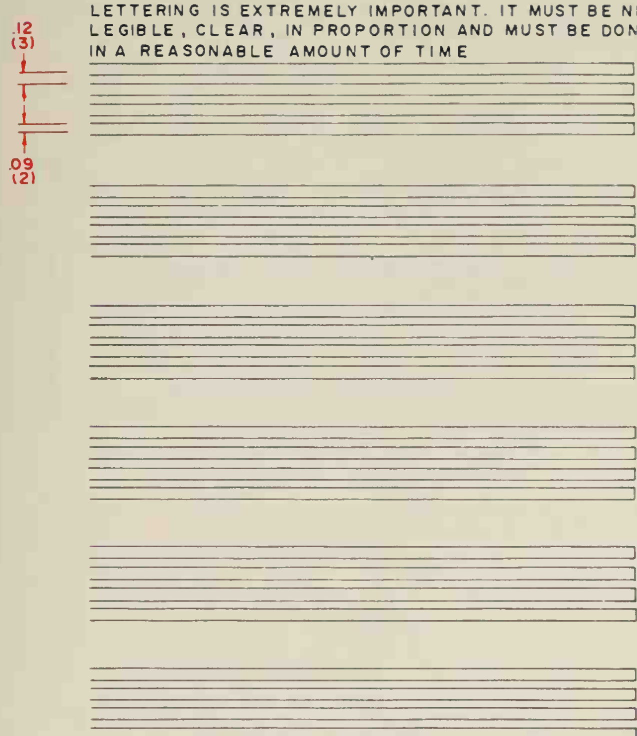
Problem 2-2



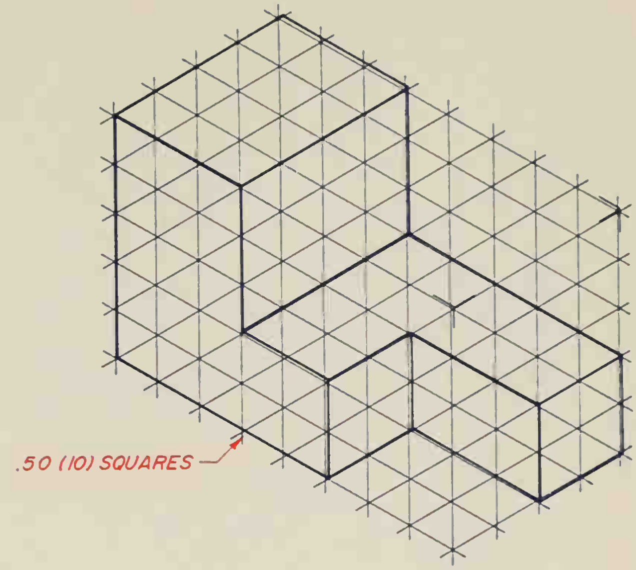
Problem 2-1



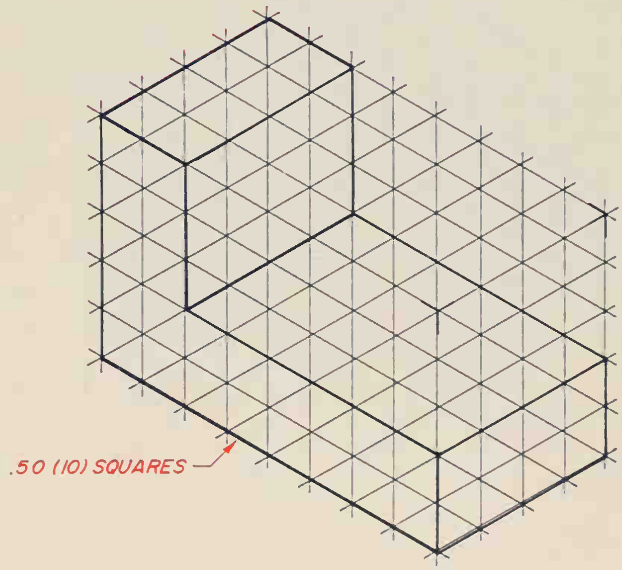
Problem 2-3



Problem 2-4



Problem 2-5

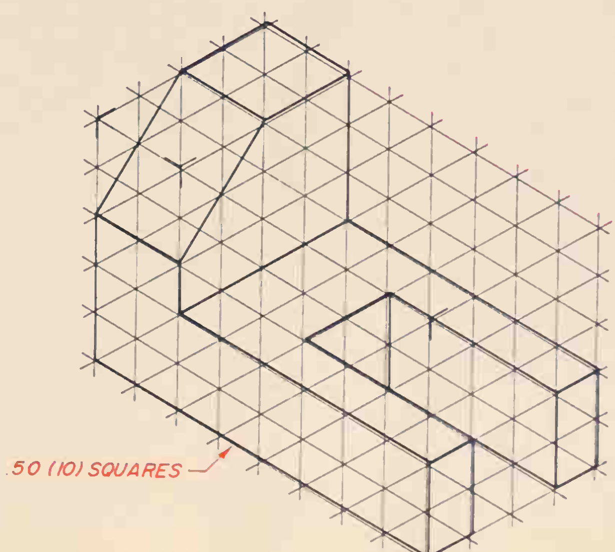


Problem 2-6

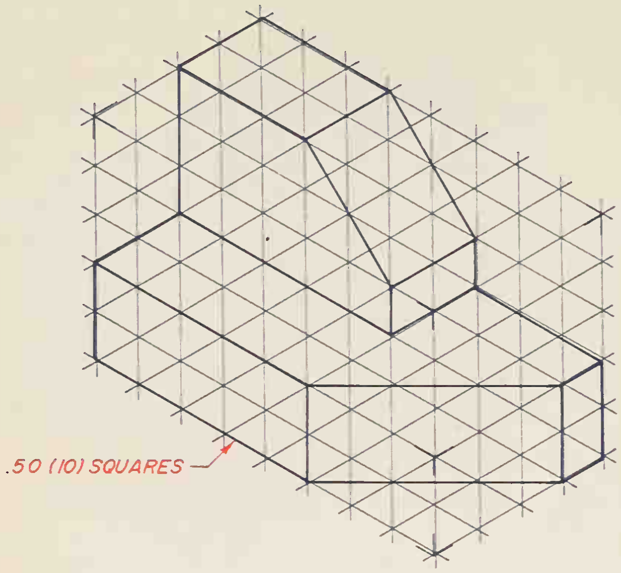
Problems 2-5 through 2-24

These problems are intended to give the beginning drafter practice in sketching. On an A-size sheet of vellum, neatly sketch the top, front, and right-side view of each pictorial figure shown. The grid is provided for proportion only. Try to keep the object in scale as you sketch; keep all parallel lines parallel, and sketch as neatly as possible. Do not use any drawing instruments. Add all lines, including hidden lines and center lines.

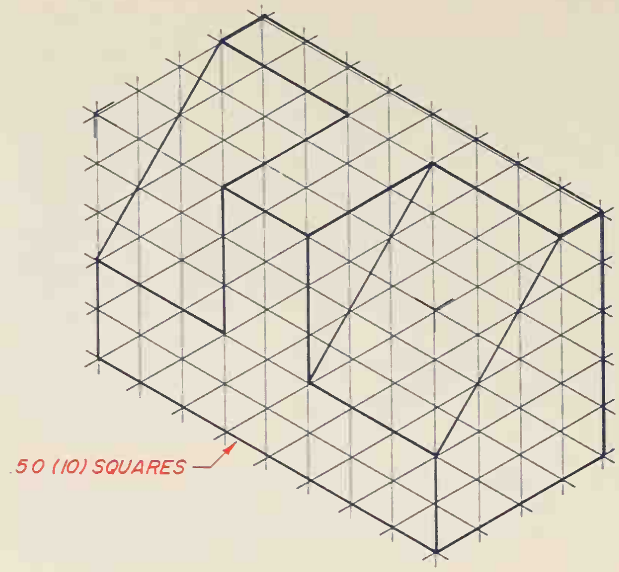
Next, sketch each object from your three-view drawings into isometric pictorial views.



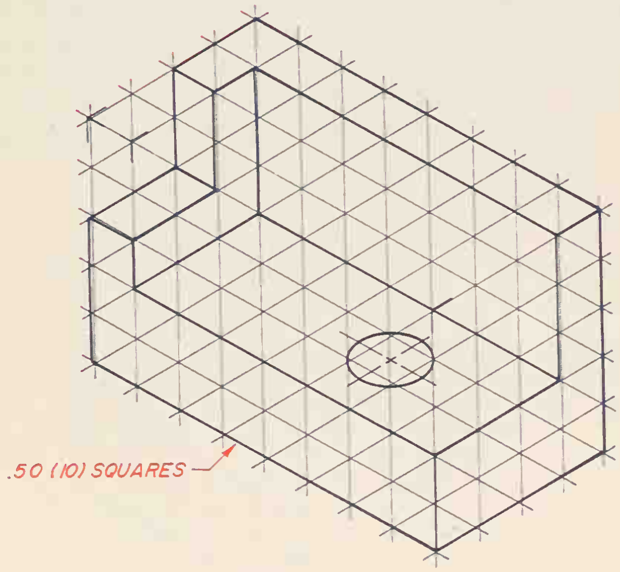
Problem 2-7



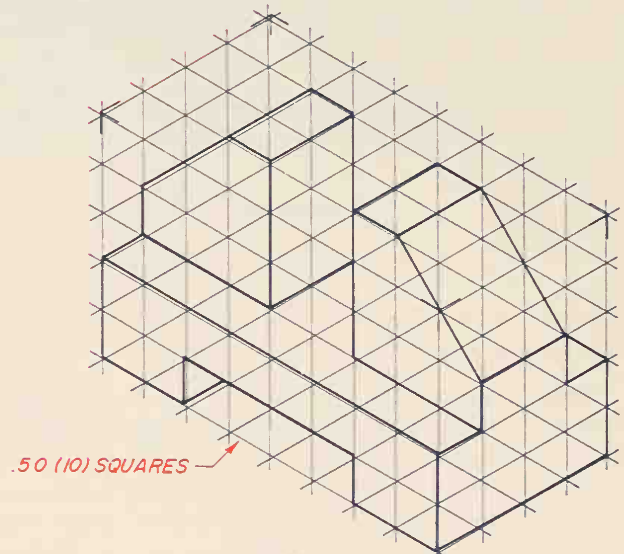
Problem 2-8



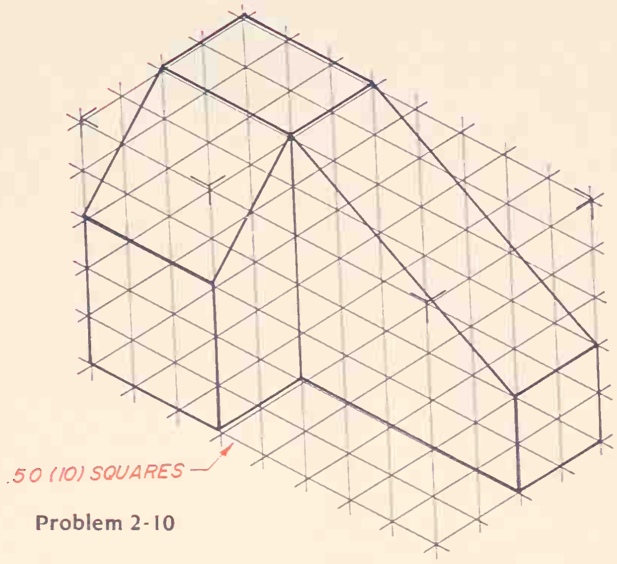
Problem 2-11



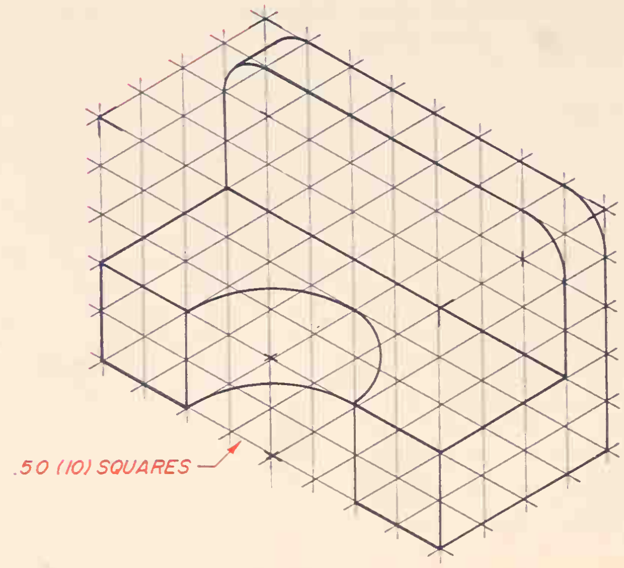
Problem 2-9



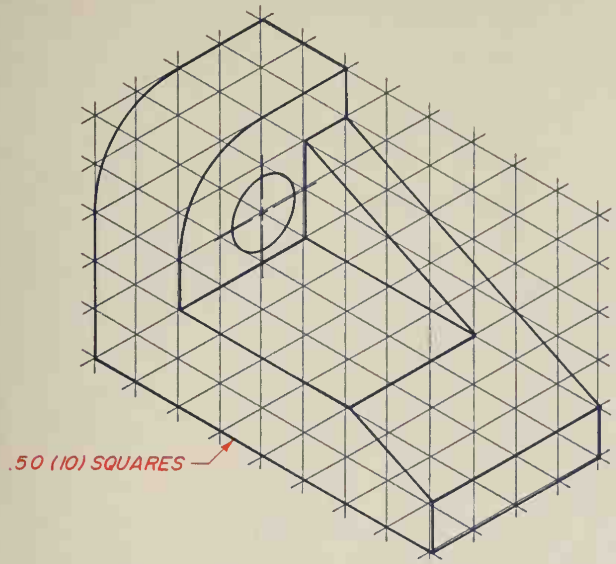
Problem 2-12



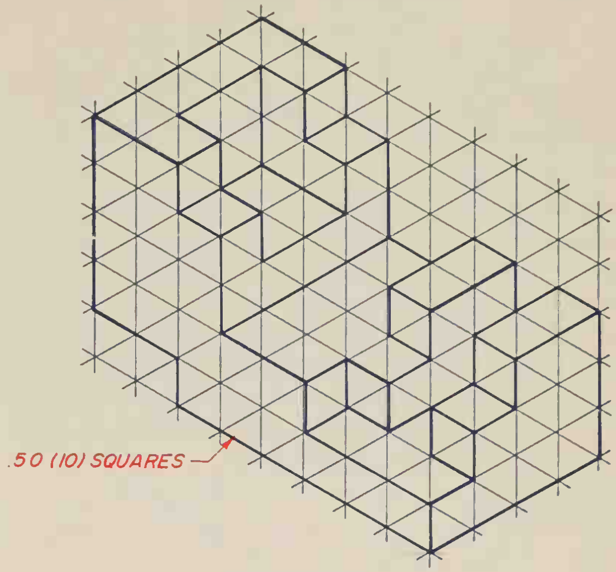
Problem 2-10



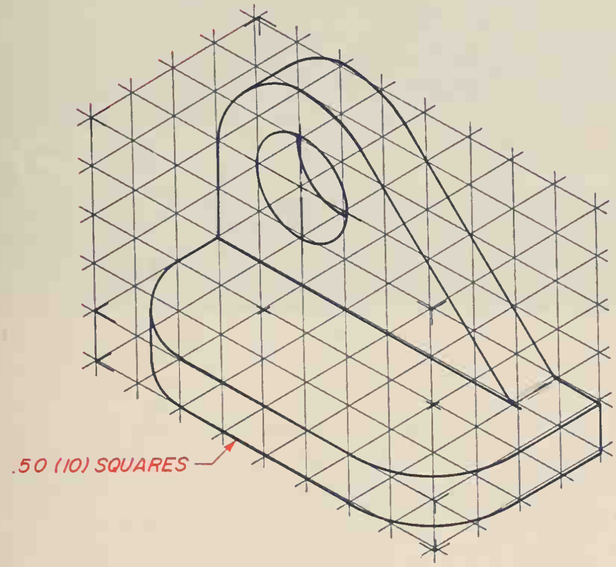
Problem 2-13



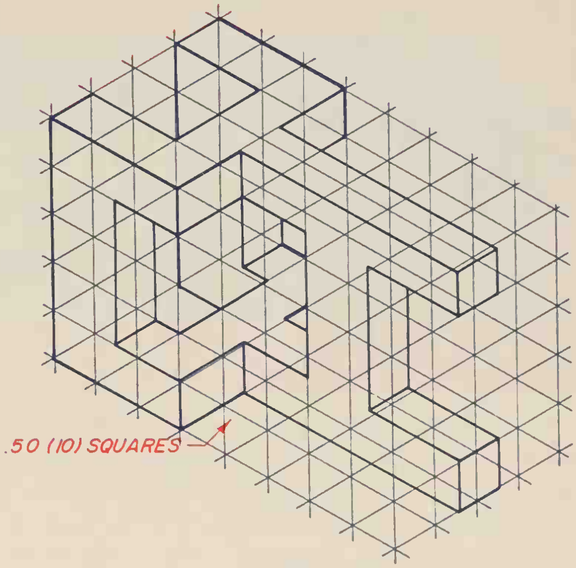
Problem 2-14



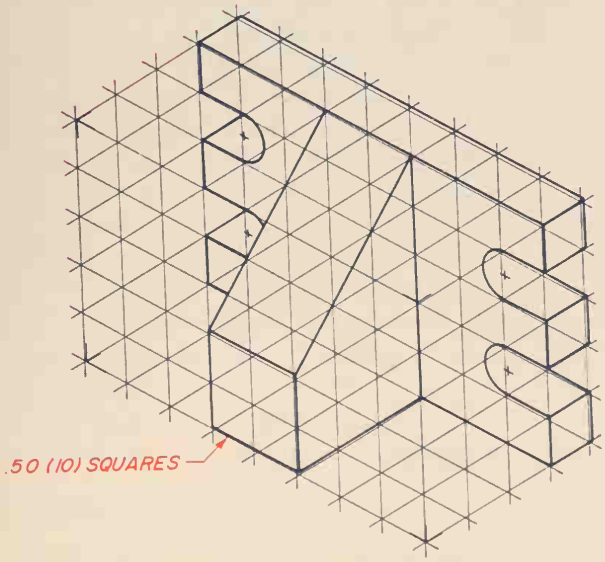
Problem 2-17



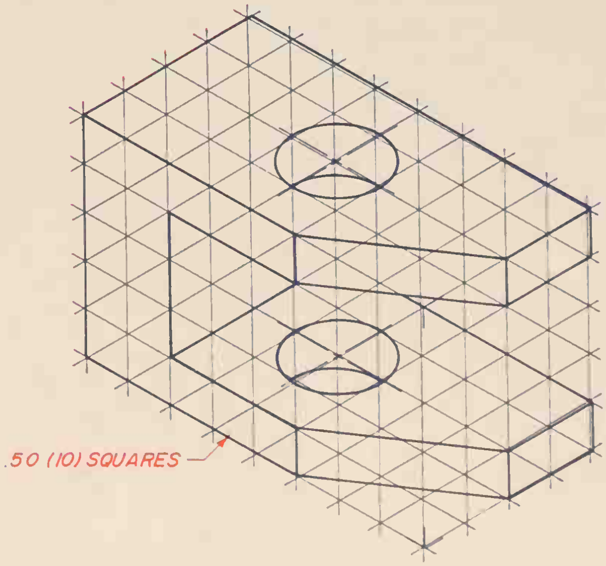
Problem 2-15



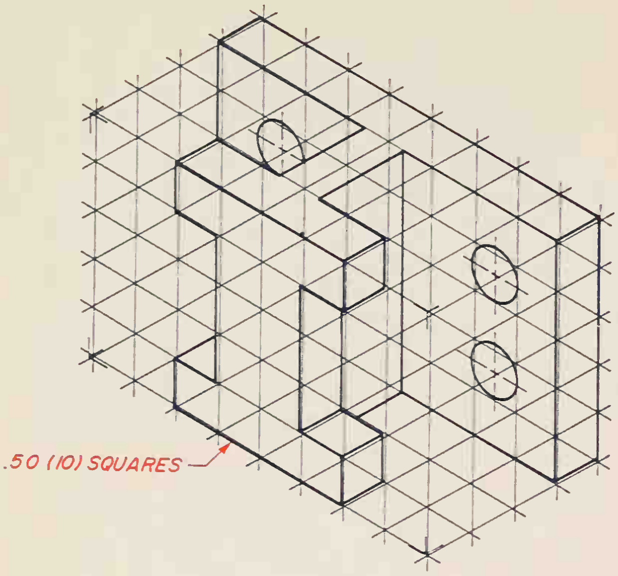
Problem 2-18



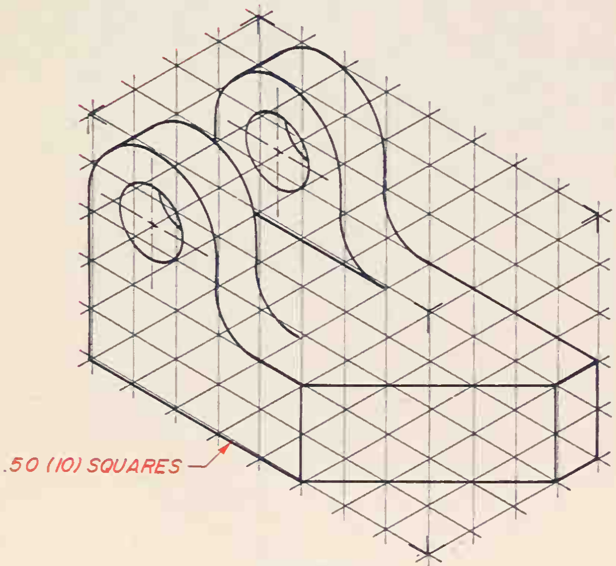
Problem 2-16



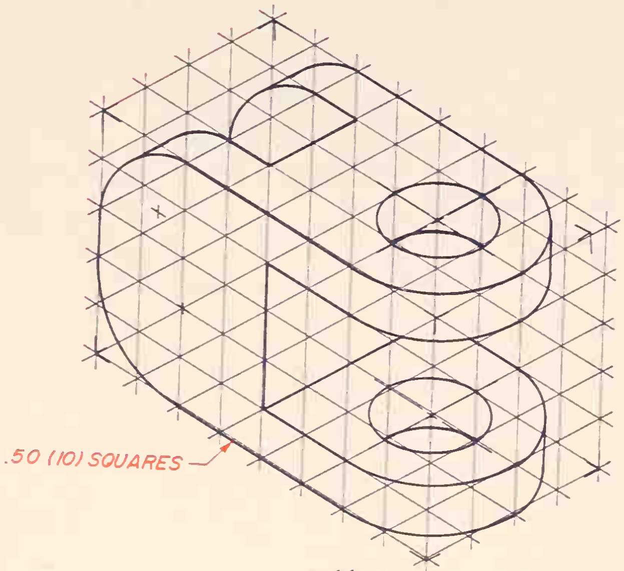
Problem 2-19



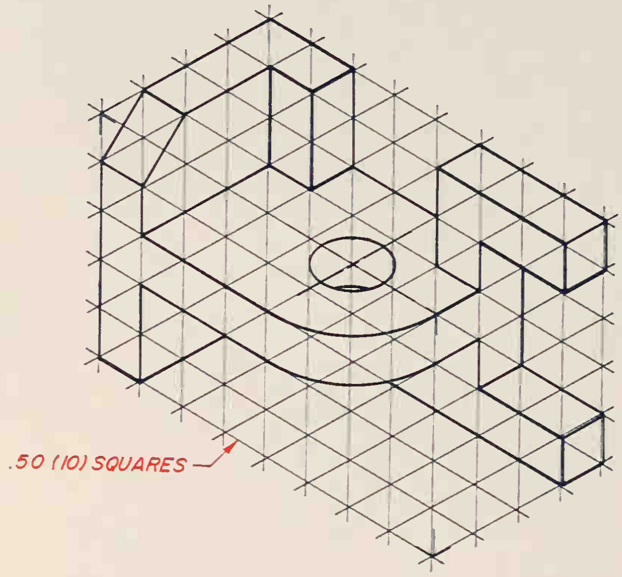
Problem 2-20



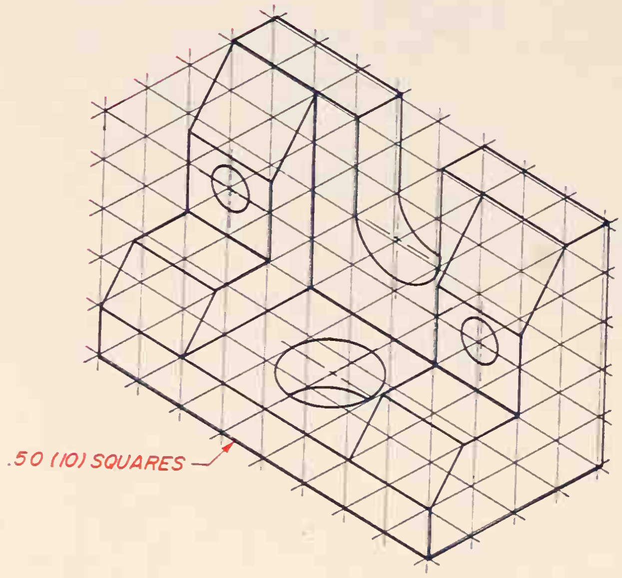
Problem 2-21



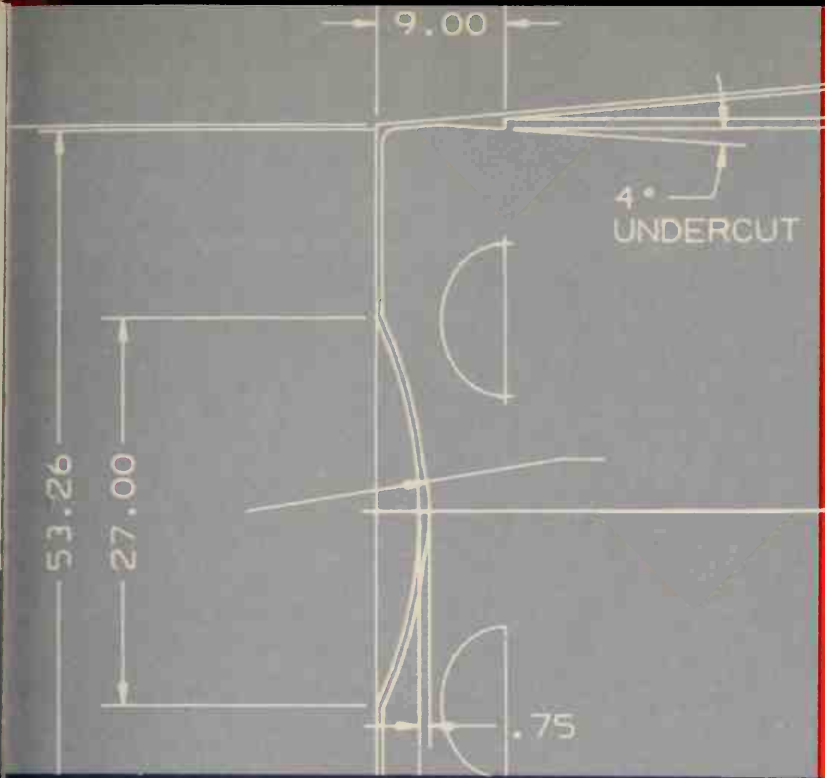
Problem 2-22



Problem 2-23



Problem 2-24



CHAPTER 3

The basic techniques associated with geometric construction must be thoroughly mastered. The various procedures discussed in this chapter will be used in solving all drawing problems throughout this book, as well as later on the job. By using these geometric construction techniques, drawings will be of professional quality and accomplished in the least amount of time. It is important for the beginning drafter to thoroughly know and understand these techniques and, more importantly, to know when and where to apply them.

GEOMETRIC CONSTRUCTION

To be truly proficient in the layout of both simple and complex drawings, the drafter must know and fully understand the many geometric construction methods used. These methods are illustrated in this chapter, and are basically simple principles of pure geometry. These simple principles are used to actually develop a drawing with complete accuracy, and in the fastest time possible, without wasted motion or any guesswork. Applying these geometric construction principles give drawings a finished, professional appearance.

In laying out the various geometric constructions, it is important to use a very sharp, 4-H lead and to be extremely accurate at all times. Always draw light construction lines that can hardly be seen when held at arm's length. These light construction lines should not be erased as this takes up valuable drawing time and they can also be reused to check layout work if necessary.

Geometric Nomenclature

Points in Space

A *point* is an exact location in space or on a drawing surface, Figure 3-1. A point is actually represented on the drawing by a crisscross at its exact location. The exact point in (drawing) space is where the two lines of the crisscross intersect. When a point is located on an existing line, a light, short dashed line or crossbar is placed on the line at the location of the exact point. Never represent a point on a drawing by a dot, except for sketching locations. This is not accurate enough, and is considered to be poor drafting practice.

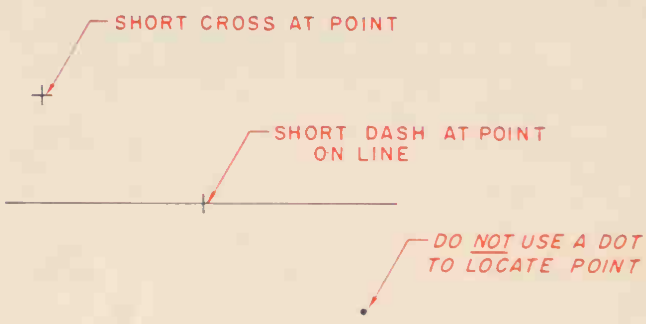


Figure 3-1 Points in space or on a surface

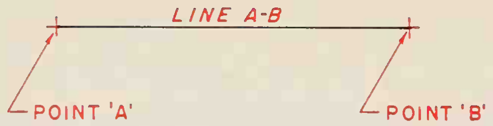


Figure 3-2 A straight line is the shortest distance between two points

Line

A straight line is the shortest distance between two points, Figure 3-2. It can be drawn in any direction. A *line* can be straight, an arc, a circle or a free curve, as illustrated in Figure 3-3. If a line is indefinite, and the ends are not fixed in length, the actual length is a matter of convenience. If the end points of a line are important, they must be marked by means of small, mechanically drawn crossbars, as described by a point in space.

Straight lines and curved lines are considered to be parallel if the shortest distance between them remains constant. The symbol used for parallel lines is //. Lines that are tangent and at 90° are considered perpendicular. The symbol for perpendicular lines is $\perp$ (singular), Figure 3-4, and $\perp$'s (plural). The symbol for an angle is $\angle$ (singular) and $\angle$'s (plural). To draw an angle, use the drafting machine, a triangle, or a protractor. For extra accuracy, use the vernier on the drafting machine or a vernier protractor.

Angle

An *angle* is formed by the intersection of two lines. There are three major kinds of angles: right angles, acute angles, and obtuse angles, Figure 3-5. The *right angle* is an angle of 90°. An *acute angle* is an angle at less than 90°, and an obtuse angle is an angle at more than 90°. Note that a straight line is 180°. Figure 3-5 also illustrates the complementary and supplementary angles of a given angle.

There are 360 degrees (360°) in a full circle. Each degree is divided into 60 minutes (60′). Each minute is divided into 60 seconds (60″). Example: 48°28′38″ is read as 48 degrees, 28 minutes, and 38 seconds.

To convert minutes and seconds to decimal degrees, divide minutes by 60 and seconds by 3600.

Example:

$$21°18'27'' = 21° + (18/60)° + (27/3600)° = 21.3075°$$

To convert decimal degrees to degrees, minutes, and seconds, multiply the degree decimal by 60 to obtain minutes, and the minute decimal by 60 to obtain seconds.

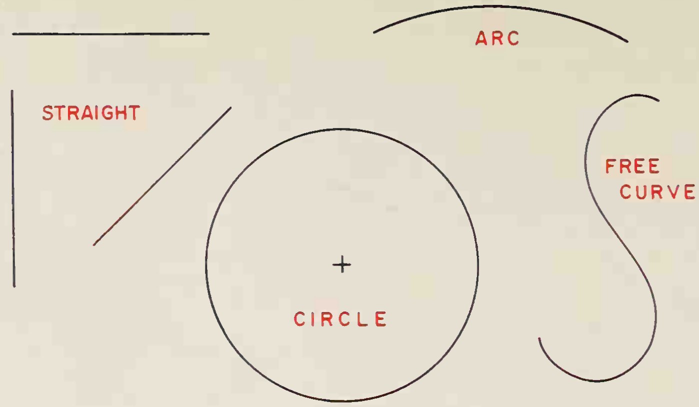


Figure 3-3 Kinds of lines

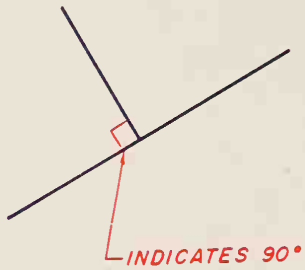


Figure 3-4 Perpendicular lines

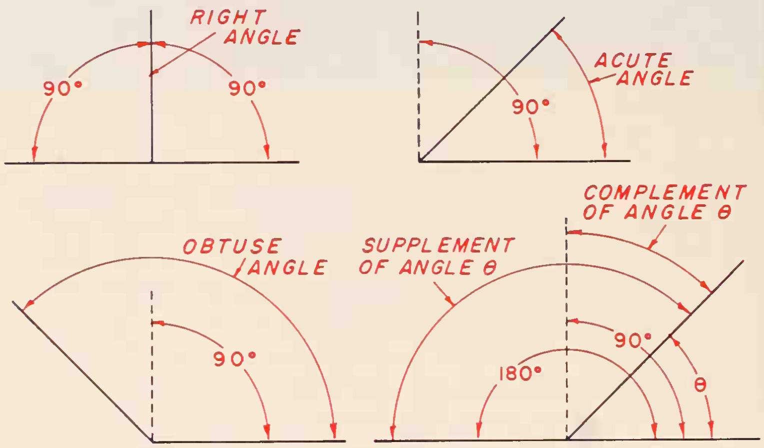


Figure 3-5 Kinds of angles

Example:

$$77.365° = 77° + (.365 \times 60)' = 77°21.9'$$
$$77°21.9' = 77°21' + (.9 \times 60)'' = 77°21'54''$$

A vernier may be used to measure and read off minutes and seconds of a degree. The vernier scale is discussed in Chapter 1.

Triangle

A *triangle* is a closed plane figure with three straight sides and three interior angles. The sum of the three

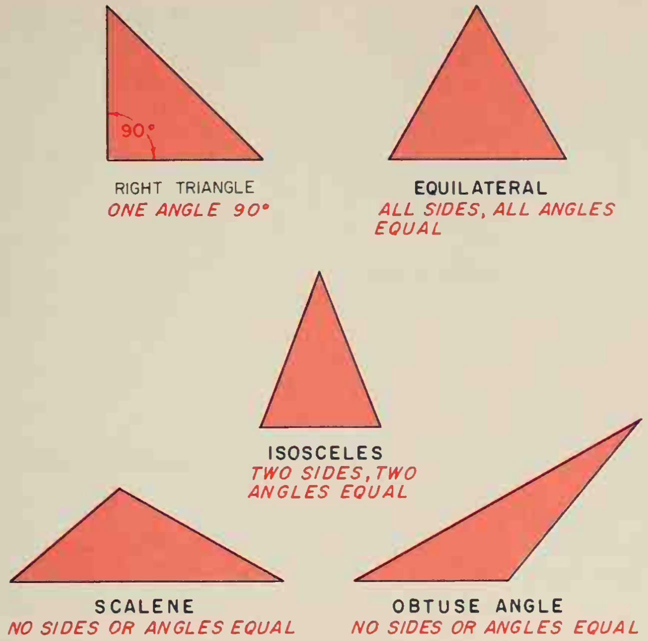


Figure 3-6 Kinds of triangles

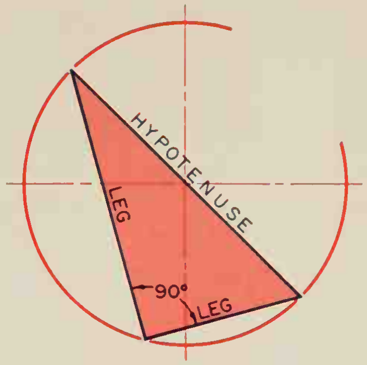


Figure 3-7 Any triangle inscribed within a semicircle is a right triangle

internal angles is always exactly 180°, half of the 360° in a full circle. Figure 3-6 shows the various kinds of triangles: a right triangle, an equilateral triangle, an isosceles triangle, a scalene triangle, and an obtuse angle triangle.

A *right triangle* is a triangle having a right angle or an angle of 90°. The two sides forming the right angle are called legs, and the third side (the longest) is the hypotenuse. Any triangle inscribed in a semicircle is a right triangle, Figure 3-7.

An *equilateral triangle*, as its name implies, is a triangle with all sides of equal length. All of its interior angles are also equal. An *isosceles triangle* has two sides of equal length and two equal interior angles. A *scalene triangle* has no equal sides or angles. An *obtuse angle triangle* is a triangle having an obtuse angle greater than 90°, with no equal sides.

Polygon

A *polygon* is a closed plane figure with three or more straight sides, Figure 3-8. More specifically, shown in the figure are regular polygons, meaning that all sides are equal in each of these examples. The most important of these polygons as they relate to drafting are probably the triangle with three sides, the square with four sides, the hexagon with six sides, and the octagon with eight sides.

Quadrilateral

A *quadrilateral* is a plane figure bounded by four straight sides. When opposite sides are parallel, the quadrilateral is also considered to be a *parallelogram*, Figure 3-9.

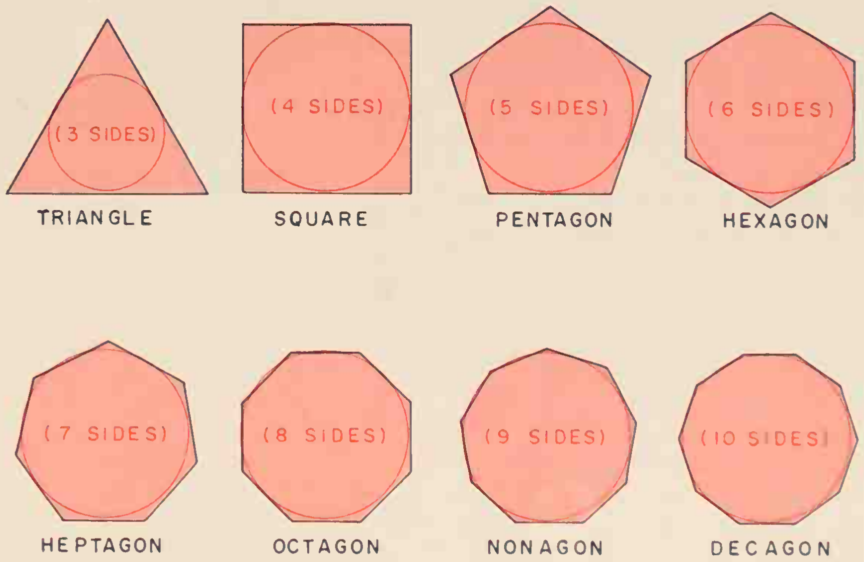


Figure 3-8 Examples of polygons

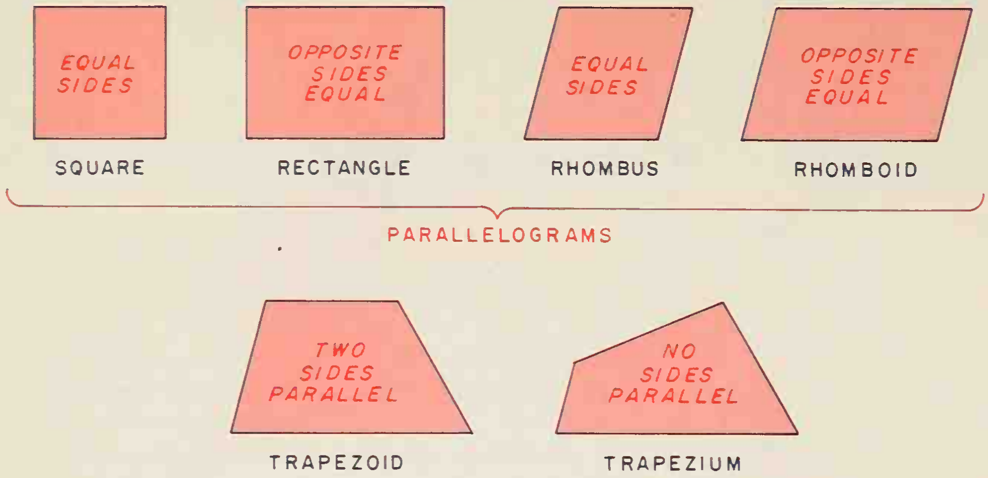


Figure 3-9 Quadrilaterals

Circle

A *circle* is a closed curve with all points on the circle at the same distance from the center point. The major components of a circle are the diameter, the radius, and the circumference, Figure 3-10.

The *diameter* of a circle is the straight distance from one outside curved surface through the center point to the opposite outside curved surface. The diameter of a circle is twice the size of the radius.

The *radius* of a circle is the distance from the center point to the outside curved surface. The radius is half the diameter, and is used to set the compass when drawing a diameter.

The *circumference* of a circle is the distance around the outer surface of the circle. To calculate the circumference of a circle, multiply the value of π (use the approximation 3.1416) by the diameter. A chart similar to the one found in the appendix of this text may be used.

Other important parts of a circle are the central angle, the sector, the quadrant, the chord, and the segment, Figure 3-11.

A *central angle* is an angle formed by two radial lines from the center of the circle.

A *sector* is the area of a circle lying between two radial lines and the circumference.

A *quadrant* is a sector with a central angle of 90°, and usually with one of the radial lines oriented horizontally.

A *chord* is any straight line whose opposite ends terminate on the circumference of the circle. (A diameter is a chord passing through the center of the circle.)

A *segment* is the smaller portion of a circle separated by a chord.

Concentric circles are two or more circles with a common center point, Figure 3-12.

Eccentric circles are two or more circles without a common center point, Figure 3-12.

A *semicircle* is half of a circle.

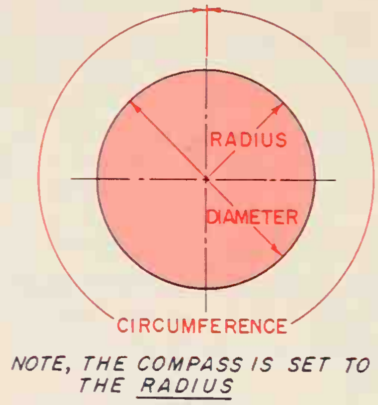


Figure 3-10 The major components of a circle

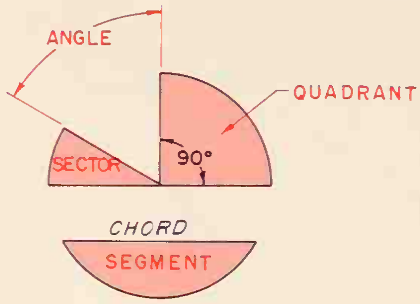


Figure 3-11 Other parts of a circle

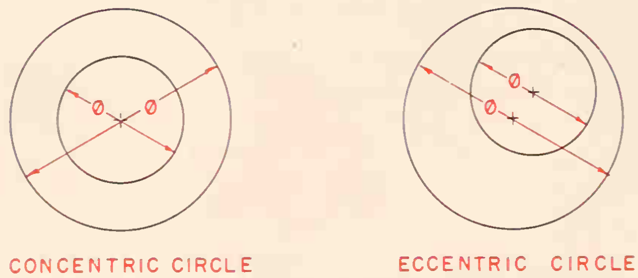
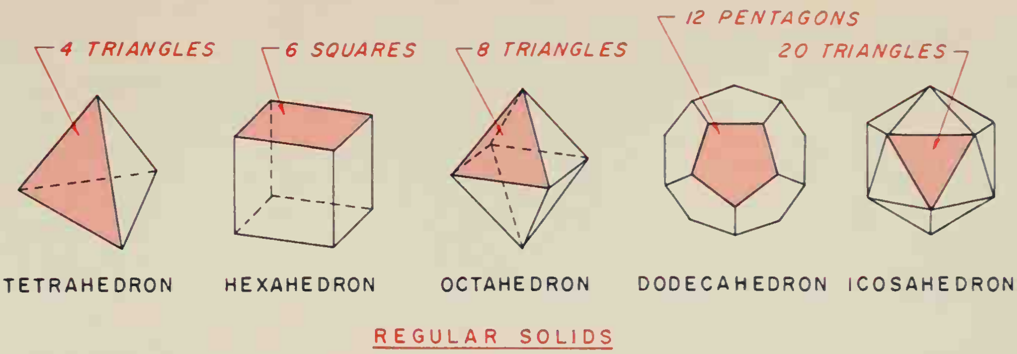


Figure 3-12 Concentric and eccentric circles

Figure 3-13 Polyhedrons (solids)



Polyhedron

A *polyhedron* is a solid object bounded by plane surfaces. Each surface is called a face. If the faces are equal, regular polygons, the solid figure is a regular polyhedron, Figure 3-13.

Prism

A *prism* is a solid having ends that are parallel matched polygons, and sides that are parallelograms, Figure 3-14. This definition also applies to round or circular objects, such as a cylinder. When the polygon on one end of a prism is not parallel to the other end, it is said to be *truncated*. The *altitude* of a prism is the perpendicular distance between its end polygons (or bases).

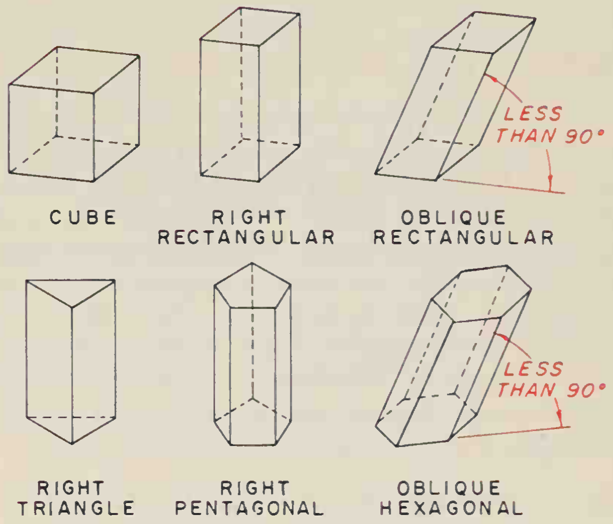


Figure 3-14 Prism

Pyramid and Cone

A *pyramid* is a polyhedron having a polygon as its base. Three or more triangles form its lateral sides which meet at a common vertex, Figure 3-15. A *cone* is a pyramid with a central axis, and an infinite number of sides which form a continuous curved lateral surface. When the vertex of a pyramid or cone has been removed by a plane that intersects all the lateral sides (which forms a new polygon), the pyramid or cone is said to be *truncated*, Figure 3-16.

Sphere

A *sphere* is a closed surface, every point on which is equal distant from a common point or center, Figure 3-17. If a sphere is cut into two equal parts, the parts are called *hemispheres*. *Poles* are two reference measuring positions on the surface of the sphere on opposite sides of its center.

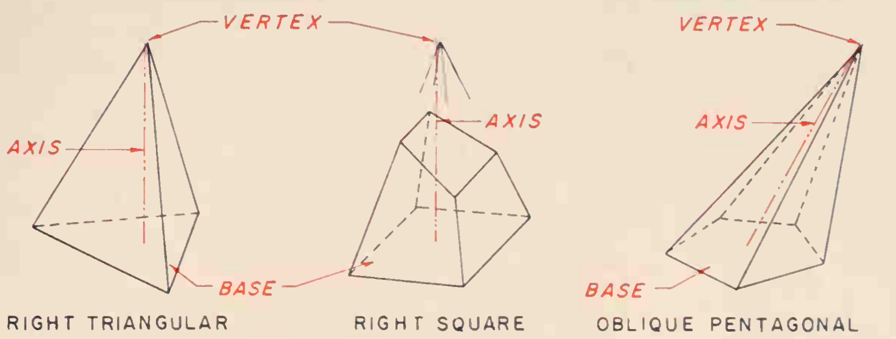


Figure 3-15 Pyramid

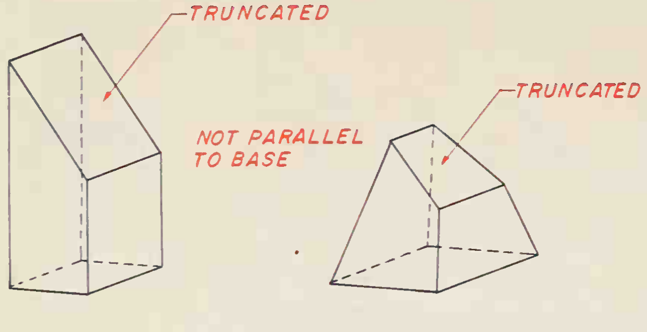


Figure 3-16 Truncated pyramid

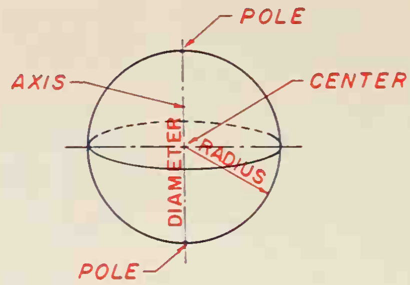


Figure 3-17 Sphere

Elemental Construction Principles

The remaining portion of this chapter is devoted to illustrating step-by-step the many geometric construction principles used by the drafter to develop various geometric forms. It is important that each step be fully understood and followed. As the beginning drafter uses these geometric construction principles, various shortcuts will become evident, thus reducing the drawing time and increasing accuracy even more. At the end of the chapter, each of these techniques is incorporated or used in some way to complete the various given problems.

How To Bisect a Line

To *bisect* a line means to divide it in half or to find its center point. In the given process, a line will also be constructed at the exact center point at exactly 90°.

Given: Line A-B, Figure 3-18A.

Step 1. Set the compass approximately two-thirds of the length of line A-B and swing an arc from point A, Figure 3-18B.

Step 2. Using the exact same compass setting, swing an arc from point B, Figure 3-18C.

Step 3. At the two intersections of these arcs, locate points X and Y, Figure 3-18D.

Step 4. Draw a straight line connecting point X with point Y. Where this line intersects line A-B is the bisect of line A-B, Figure 3-18E. Line X-Y is also perpendicular to line A-B at the exact center point.

Figure 3-18A How to bisect a line

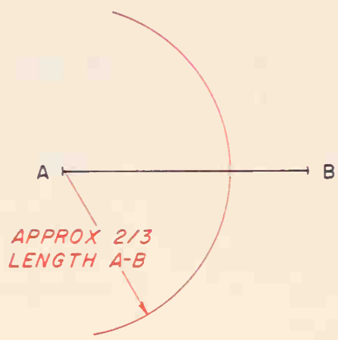


Figure 3-18B Step 1

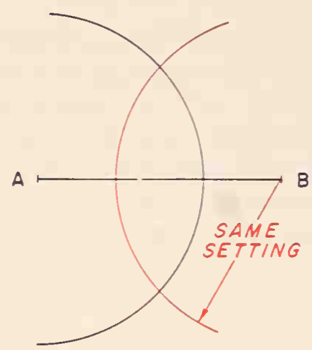


Figure 3-18C Step 2

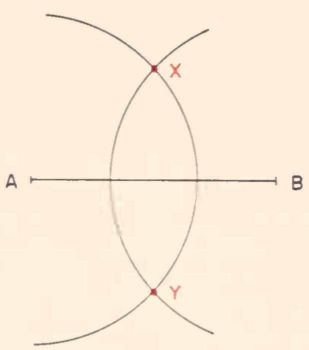


Figure 3-18D Step 3

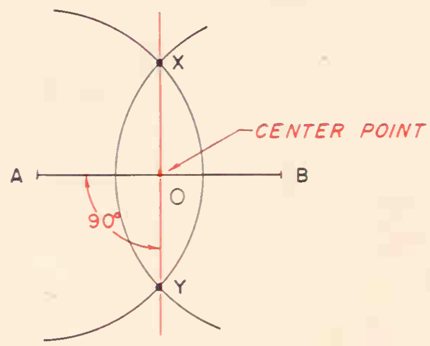


Figure 3-18E Step 4

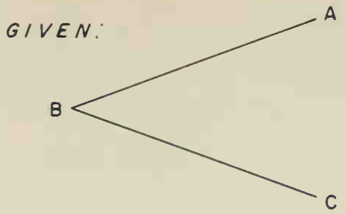


Figure 3-19A How to bisect an angle

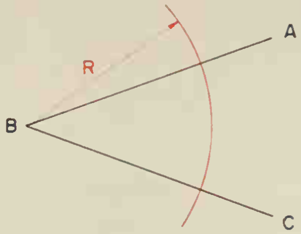


Figure 3-19B Step 1

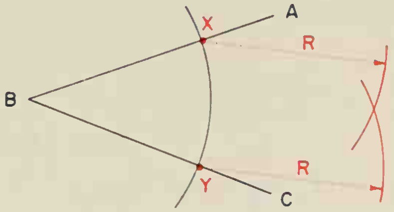


Figure 3-19C Step 2

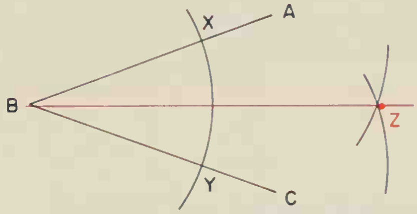


Figure 3-19D Step 3

How To Bisect an Angle

To *bisect* an angle means to divide it in half or to cut it into two equal angles.

Given: Angle ABC, Figure 3-19A.

Step 1. Set the compass at any convenient radius and swing an arc from point B, Figure 3-19B.

Step 2. Locate points X and Y on the legs of the angle, and swing two arcs of the same identical length from points X and Y, respectively, Figure 3-19C.

Step 3. Where these arcs intersect, locate point Z. Draw a straight line from B to Z. This line will bisect angle ABC and establish two equal angles: ABZ and ZBC, Figure 3-19D.

How To Draw an Arc or Circle (Radius) through Three Given Points

Given: Three points in space at random: A, B, and C, Figure 3-20A.

Step 1. With straight lines, lightly connect points A to B, and B to C, Figure 3-20B.

Step 2. Using the method outlined for bisecting a line, bisect lines A-B and B-C, Figure 3-20C.

Step 3. Locate point X where the two extended bisectors meet. Point X is the exact center of the arc or circle, Figure 3-20D.

Step 4. Place the point of the compass on point X and adjust the lead to any of the points A, B, or C (they are the same distance), and swing the circle. If all work is done correctly, the arc or circle should pass through each point, as shown in Figure 3-20E.

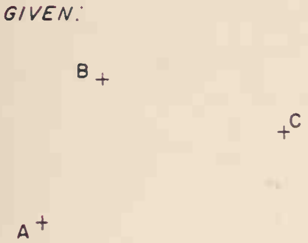


Figure 3-20A How to draw an arc or circle (radius) through three given points

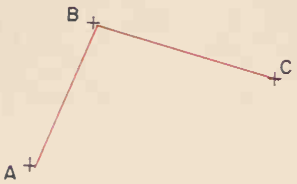


Figure 3-20B Step 1

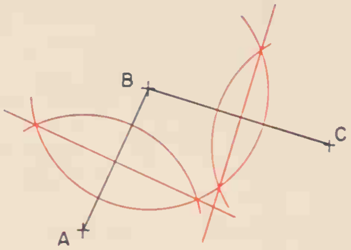


Figure 3-20C Step 2

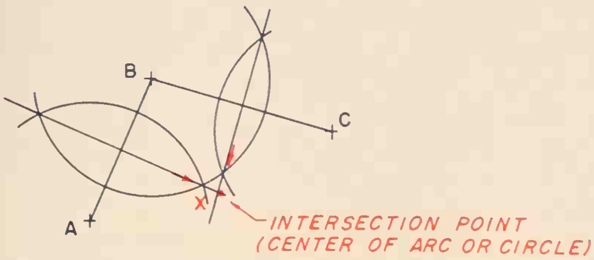


Figure 3-20D Step 3

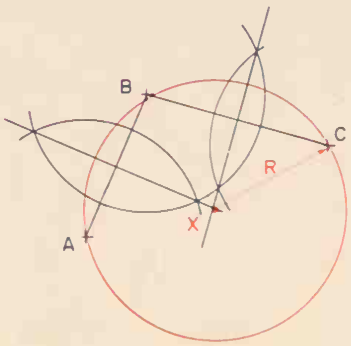


Figure 3-20E Step 4

Figure 3-21A How to draw a line parallel to a straight line at a given distance

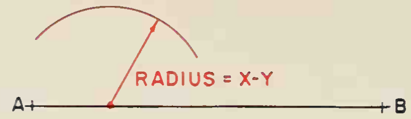


Figure 3-21B Step 1

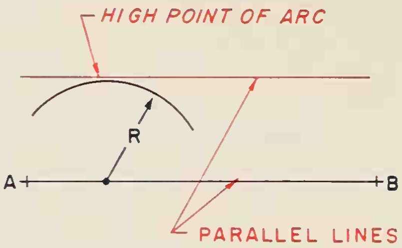


Figure 3-21C Step 2

How To Draw a Line Parallel to a Straight Line at a Given Distance

Given: Line A-B, and a required distance to the parallel line, Figure 3-21A.

Step 1. Set the compass at the required distance to the parallel line. Place the point of the compass at any location on the given line, and swing a light arc whose radius is the required distance, Figure 3-21B.

Step 2. Adjust the straightedge of either a drafting machine or an adjustable triangle so that it lines up with line A-B, slide the straightedge up or down to the extreme high point of the arc, then draw the parallel line, Figure 3-21C.

Note: The distance between parallel lines is measured on any line that is perpendicular to both.

How To Draw a Line Parallel to a Curved Line at a Given Distance

Given: Curved line A-B, and a required distance to the parallel line, Figure 3-22A.

Step 1. Set the compass at the required distance to the parallel line. Starting from either end of the curved line, place the point of the compass on the given line, and swing a series of light arcs along the given line, Figure 3-22B.

Step 2. Using an irregular curve, draw a line along the extreme high points of the arcs, Figure 3-22C.

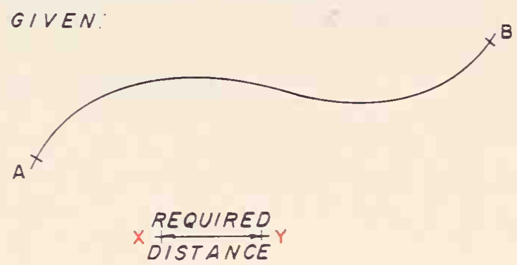


Figure 3-22A How to draw a line parallel to a curved line at a given distance

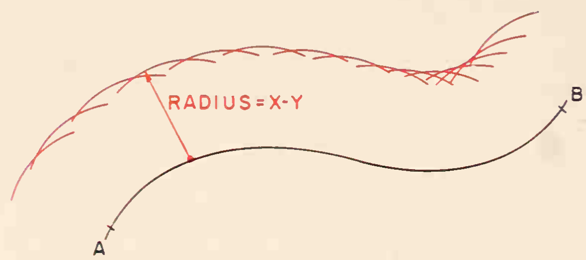


Figure 3-22B Step 1

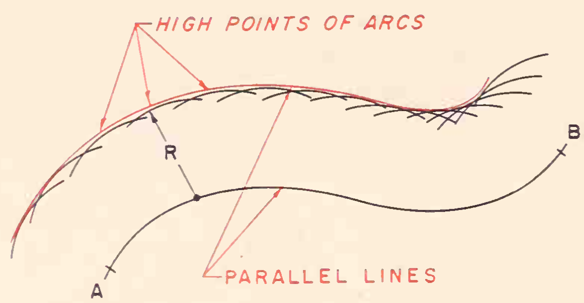


Figure 3-22C Step 2

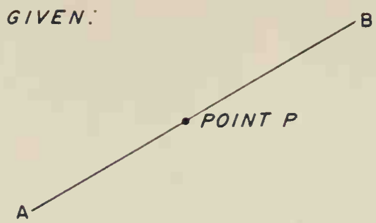


Figure 3-23A
How to draw a perpendicular to a line at a point (method 1)

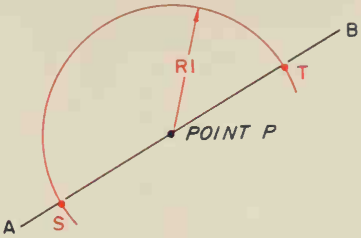


Figure 3-23B
Step 1

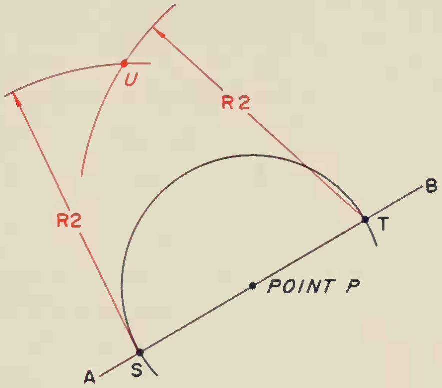


Figure 3-23C
Step 2

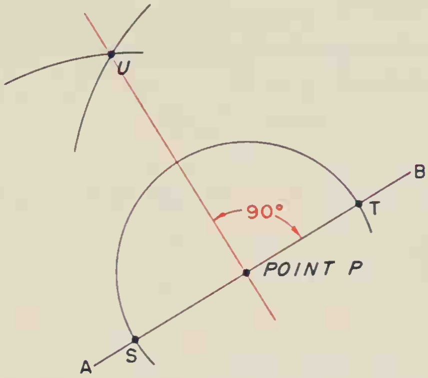


Figure 3-23D
Step 3

How To Draw a Perpendicular to a Line at a Point (Method 1)

Given: Line A-B with point P on the same line, Figure 3-23A.

Step 1. Using P as the center, make two arcs of equal radius or one continuous arc (R1) to intercept line A-B on either side of point P, at points S and T, Figure 3-23B.

Step 2. Swing larger but equal arcs (R2) from each of points S and T to cross each other at point U, Figure 3-23C.

Step 3. A line from U to P is perpendicular to line A-B at point P, Figure 3-23D.

How To Draw a Perpendicular to a Line at a Point (Method 2)

Given: Line A-B with point P on the line, Figure 3-24A.

Step 1. Swing an arc of any convenient radius whose center O is at any convenient location

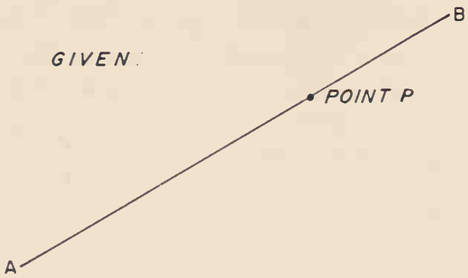


Figure 3-24A
How to draw a perpendicular to a line at a point (method 2)

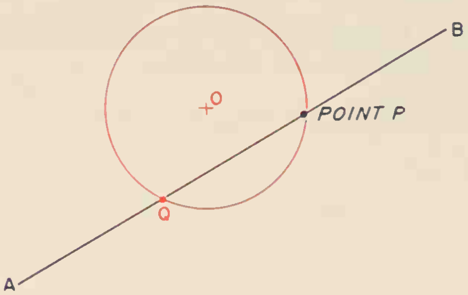


Figure 3-24B
Step 1

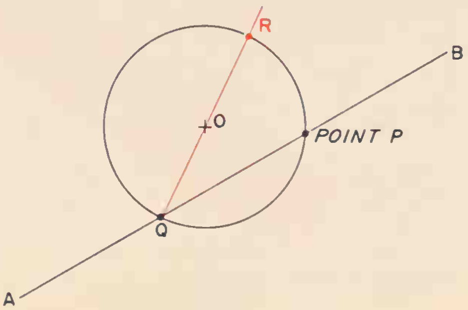


Figure 3-24C
Step 2

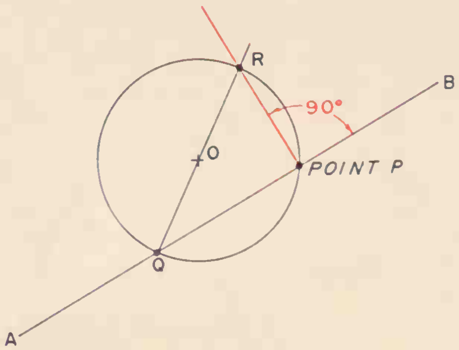


Figure 3-24D
Step 3

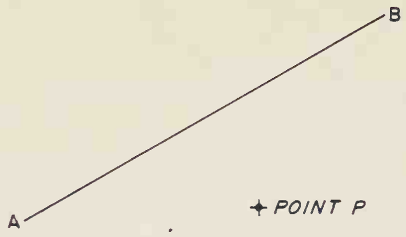


Figure 3-25A How to draw a perpendicular to a line from a point not on the line

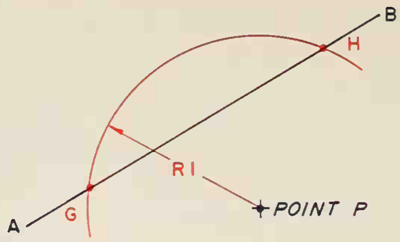


Figure 3-25B Step 1

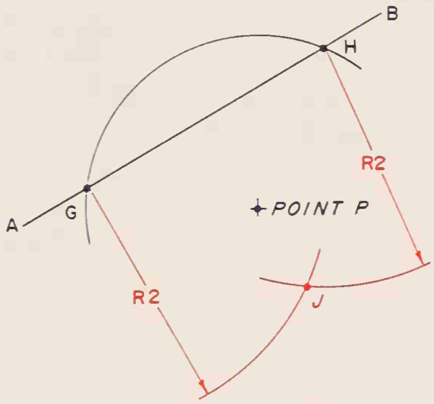


Figure 3-25C Step 2

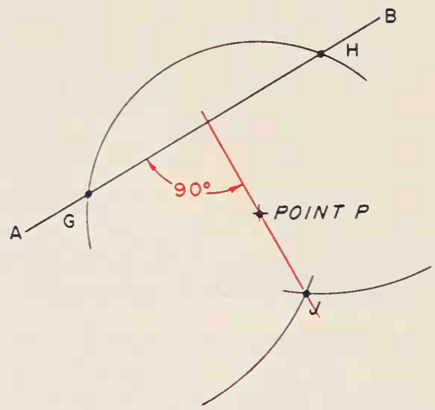


Figure 3-25D Step 3

NOT on line A-B, but positioned to make the arc cross line A-B at points P and Q, Figure 3-24B.

Step 2. A line from point Q through center O intercepts the opposite side of the arc at point R, Figure 3-24C.

Step 3. Line R-P is perpendicular to line A-B. (A right triangle has been inscribed in a semicircle.) See Figure 3-24D.

How To Draw a Perpendicular to a Line from a Point Not on the Line

Given: Line A-B and point P, Figure 3-25A.

Step 1. Using P as a center, swing an arc (R1) to intercept line A-B at points G and H, Figure 3-25B.

Step 2. Swing larger, but equal length arcs (R2) from each of the points G and H to intercept each other at point J, Figure 3-25C.

Step 3. Line P-J is perpendicular to line A-B, Figure 3-25D.

How To Divide a Line into Equal Parts

Given: Line A-B, Figure 3-26A.

Step 1. Draw a line 90° from either end of the given line. A 90° line from point B is illustrated in Figure 3-26B, but either end or either direction will work as well.

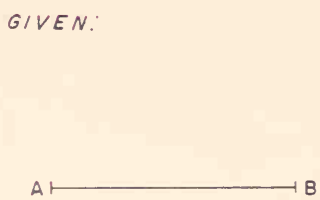


Figure 3-26A How to divide a line into equal parts

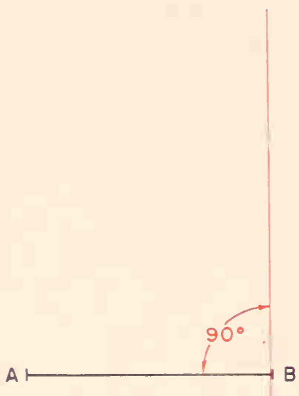


Figure 3-26B Step 1

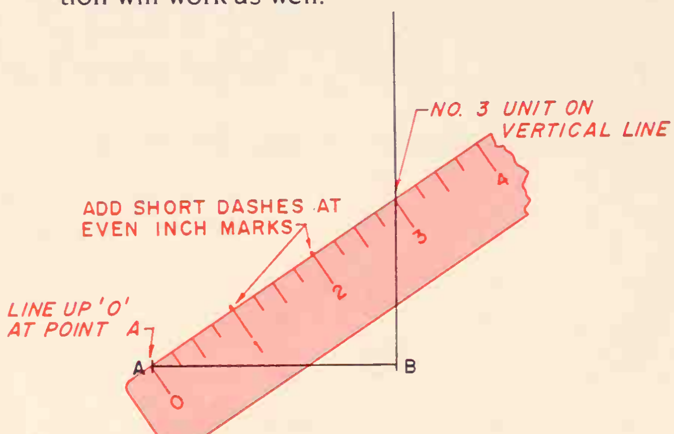
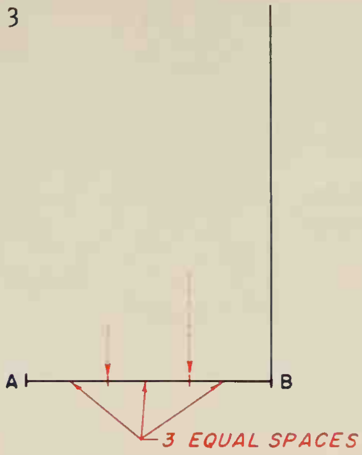


Figure 3-26C Step 2

Figure 3-26D Step 3



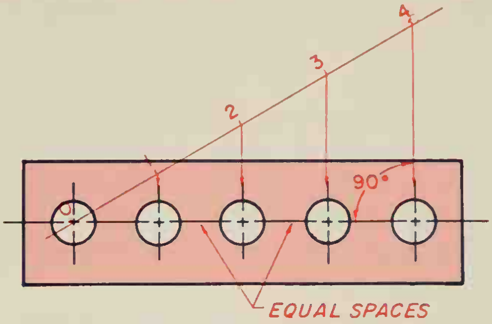


Figure 3-26E An example of equal spacing within a given length

Step 2. Place a scale with its zero at point A of the given line. If three equal parts are required, pivot the scale until the three-inch measurement (or any length representing three equal units of measure: 30, 60 and 90 mm, for example) is on the perpendicular line drawn in Step 1. Place a short dash at these points. The example in Figure 3-26C shows these dashes at the 1-inch and 2-inch marks.

Step 3. Project lines downward from these points and add short hash marks where these projected lines cross the original given line A-B. This divides the line A-B into three exact equal parts. Check all work, comparing your final step with Figure 3-26D. An example of equal spacing, where equally spaced holes are required within a given length, is illustrated in Figure 3-26E.

How To Divide a Line into Proportional Parts

Given: Line A-B, Figure 3-27A. *Problem*: Locate point X at 2/3 of the distance from point A to point B.

Step 1. Draw a line 90° from either end of the line. A 90° line from point B is illustrated in Figure 3-27B.

Step 2. Place a scale with its zero on point A of the given line. Because a 2/3 proportion is required, pivot the scale until any multiple of three units of measure intersects the perpendicular line drawn in Step 1. In this example, 6 is used, representing three 2-unit increments. The 2/3 position of this length is two 2-unit increments, or the 4 position, where a hash mark is made, as shown in Figure 3-27C. Projecting this point downward to line A-B, it becomes point X, which is 2/3 the overall distance from point A.

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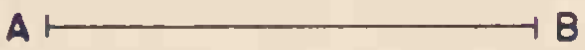


Figure 3-27A How to divide a line into proportional parts

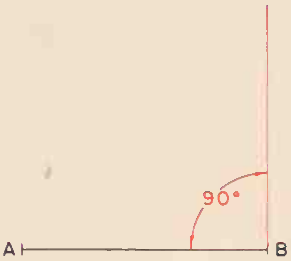


Figure 3-27B Step 1

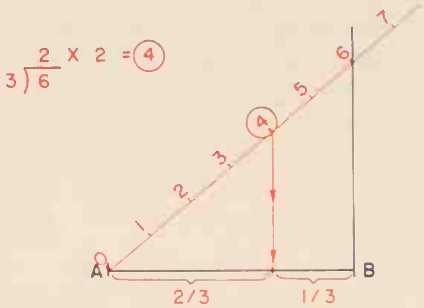


Figure 3-27C Step 2

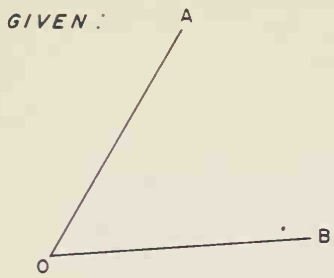


Figure 3-28A How to transfer an angle

Figure 3-28B Given: Point 0'

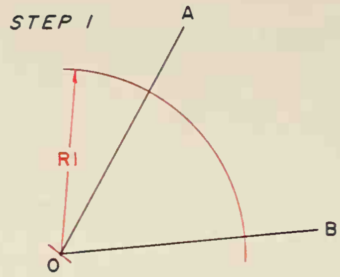


Figure 3-28C Step 1

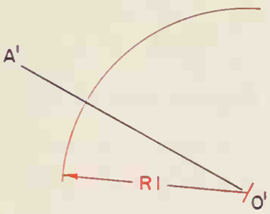


Figure 3-28D Transferred angle

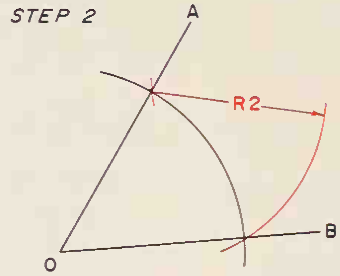


Figure 3-28E Step 2

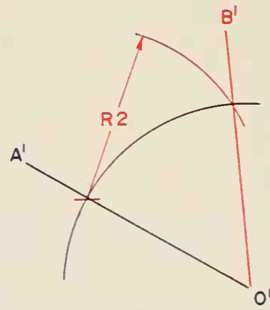


Figure 3-28F Step 3

How To Transfer an Angle

Given: An angle formed by two straight lines, 0A-0B, Figure 3-28A, and one location of where the transferred angle begins (point 0'), Figure 3-28B.

Step 1. Refer to Figure 3-28C. Draw an arc through both legs of a given angle (R1) and then duplicate this radius at the transferred angle location, Figure 3-28D.

Step 2. Transfer the chord length between the two angle legs at the intersection of the arc (R2) to the arc at the transfer angle location.

Step 3. A line from the arc center to the intersection of arc and chord length forms the second line, forming an angle equal to the original, Figures 3-28E and 3-28F.

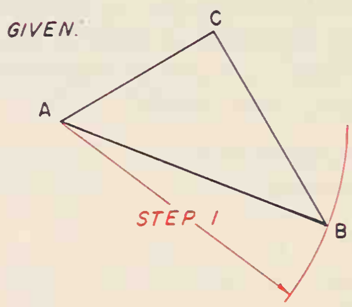


Figure 3-29A How to transfer an odd shape

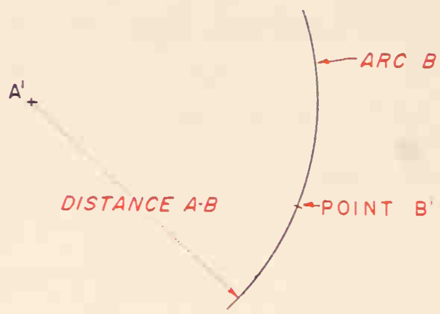


Figure 3-29B Step 1

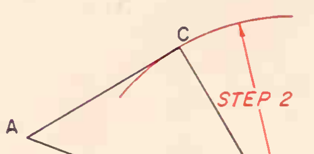


Figure 3-29C Step 2

How To Transfer an Odd Shape

Given: Triangle ABC, Figure 3-29A.

Step 1. Letter or number the various corners and point locations of the odd shape in counterclockwise order around its perimeter. In this example, place the compass point at point A of the original shape and extend the lead to point B. Refer back to Figure 3-29A. Swing a light arc at the new desired location, Figure 3-29B. Letter the center point as A' and add letter B' at any convenient location on the arc. It is a good habit to lightly letter each point as you proceed.

Step 2. Place the compass point at letter B of the original shape, Figure 3-29C, and extend the compass lead to letter C of the original shape.

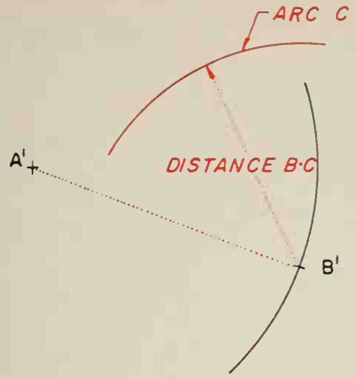


Figure 3-29D Step 3

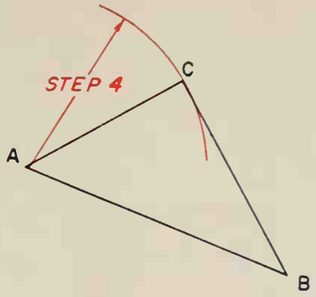


Figure 3-29E Step 4

Step 3. Transfer this distance, B-C, to the layout, Figure 3-29D.

Steps 4 *and* 5. Going back to the original object, place the compass point at letter A, Figure 3-29E, and extend the compass lead to letter C. Transfer the distance A-C as illustrated in Figure 3-29F. Locate and letter each point.

Step 6. Connect points A', B', and C' with light, straight lines. This completes the transfer of the object, Figure 3-29G. Recheck all work and, if correct, darken lines to the correct line weight.

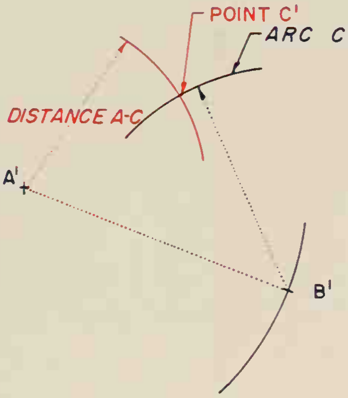


Figure 3-29F Step 5

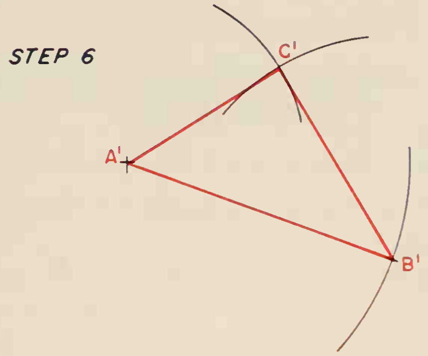


Figure 3-29G Step 6

How To Transfer Complex Shapes

A complex shape can be transferred in exactly the same way by reducing the shape into simple triangles and transferring each triangle using the foregoing method.

Given: An odd shape, A, B, C, D, E, F, G, Figure 3-30A. Letter or number the various corners and point locations of the odd shape in clockwise order around the perimeter, Figure 3-30A. Use the longest line or any convenient line as a starting point. Line A-B is chosen here as the example.

Step 1. Lightly divide the shape into triangle divisions, using the baseline if possible. Transfer each triangle in the manner described in Figures 3-29A through 3-29G. Suggested triangles to be used in example Figure 3-30A are ABC, ABD, ABE, ABF, and ABG, Figure 3-30B.

Step 2. This completes the transfer. Check all work and, if correct, darken in lines to correct line thickness. See Figure 3-30C.

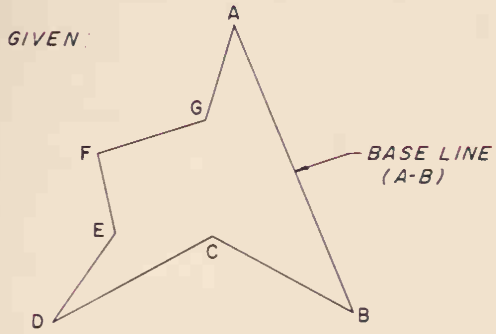


Figure 3-30A How to transfer complex shapes

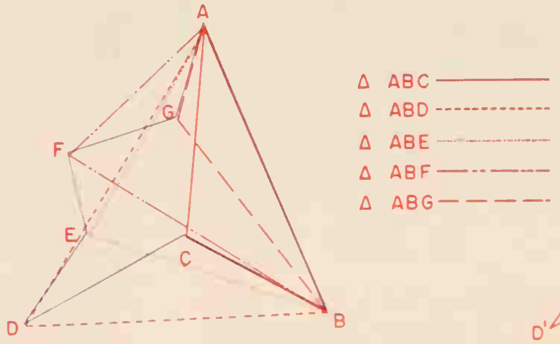


Figure 3-30B Step 1

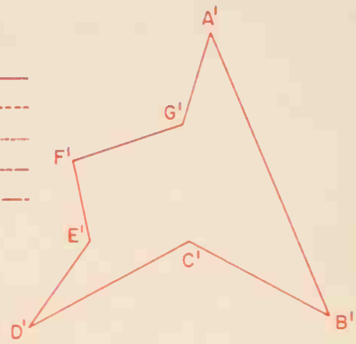


Figure 3-30C Step 2

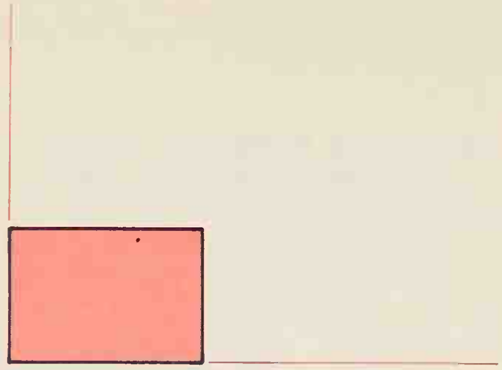


Figure 3-31A How to proportionately enlarge or reduce a shape

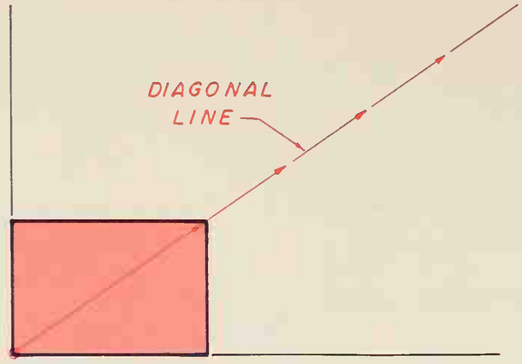


Figure 3-31B Step 1

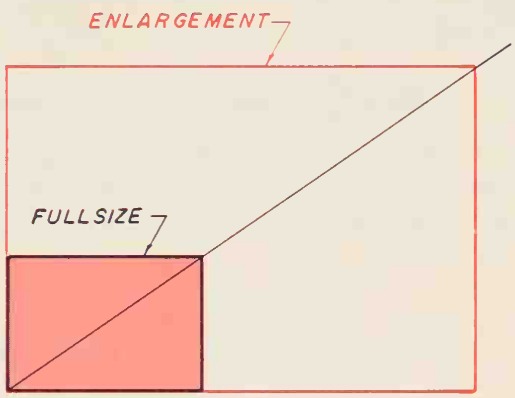


Figure 3-31C Step 2

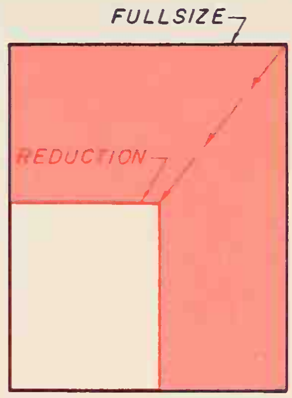


Figure 3-31D Step 1

How To Proportionately Enlarge or Reduce a Shape

Given: A rectangle, Figure 3-31A. *Problem*: To enlarge or reduce its size proportionately.

Step 1. Draw a line from corner to corner diagonally, and extend it as shown in Figure 3-31B.

Step 2. The rectangle is enlarged to any size proportionately if the vertical and horizontal sides are located from the extended diagonal line, Figure 3-31C.

Step 1. The rectangle is reduced proportionately if the vertical and horizontal lines are located on the unextended diagonal line, Figure 3-31D.

Polygon Construction

How To Draw a Triangle with Known Lengths of Sides

Given: Lengths 1, 2, and 3, Figure 3-32A.

Step 1. Draw the longest length line, in this example length 3, with endpoints A and B, Figure 3-32B. Swing an arc (R1) from point A whose radius is either length 1 or length 2; in this example, length 1.

Step 2. Using the radius length *not* used in Step 1, swing an arc (R2) from point B to intercept the arc swung from point A at point C, Figure 3-32C.

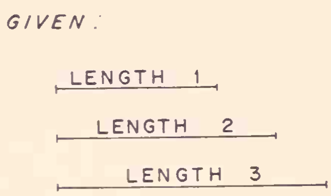


Figure 3-32A How to draw a triangle with known lengths of sides

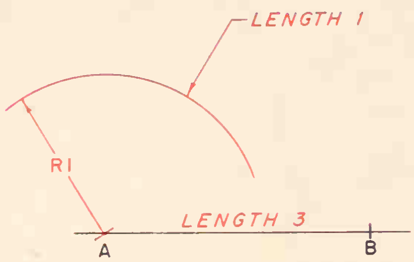


Figure 3-32B Step 1

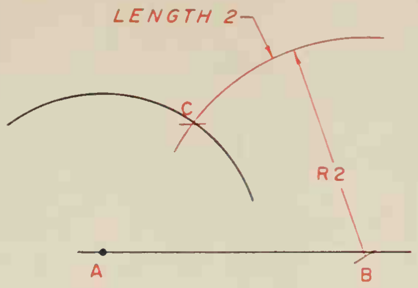


Figure 3-32C Step 2

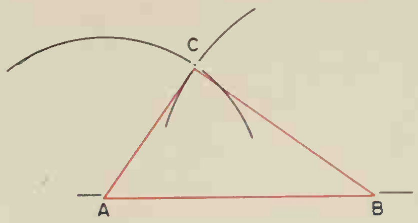


Figure 3-32D Step 3

Figure 3-33A How to draw an equilateral triangle

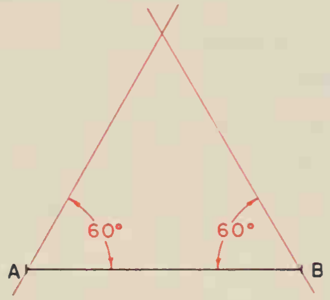


Figure 3-33B Step 1

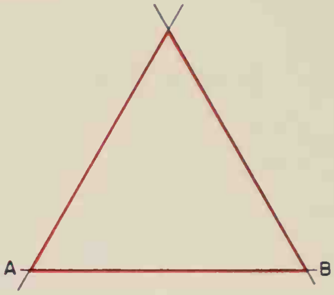


Figure 3-33C Step 2

Step 3. Connect A to C and B to C to complete the triangle, Figure 3-32D.

How To Draw an Equilateral Triangle

Given: A baseline and the given length of each side, Figure 3-33A.

Step 1. Either adjust the drafting machine angle to 60° or use a 30°-60° triangle and project from points A and B at 60° using light lines, Figure 3-33B. Allow light construction lines to cross as shown; do not erase them.

Step 2. Check to see that there are three equal sides and, if so, darken in the actual triangle using correct line thickness, Figure 3-33C. Care should be exercised in constructing the sharp corners. Again, do *not* erase the light construction lines.

How To Draw a Square

Given: The location of the center and the required distance across the "flats" of a square, Figure 3-34A.

Step 1. Lightly draw a circle with a diameter equal to the distance across the "flats" of the square. Set the compass at half the required diameter, Figure 3-34B.

Step 2. Using a triangle, lightly complete the square by constructing tangent lines to the circle. Allow the light construction lines to project from the square, as shown, without erasing them, Figure 3-34C.

Step 3. Check to see that there are four equal sides and, if so, darken in the actual square using the correct line thickness, Figure 3-34D. Care should be exercised in constructing the sharp corners. Again, do *not* erase the light construction lines.

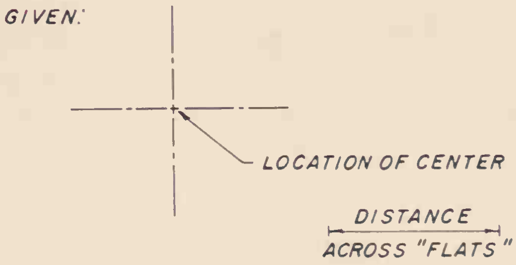


Figure 3-34A How to draw a square

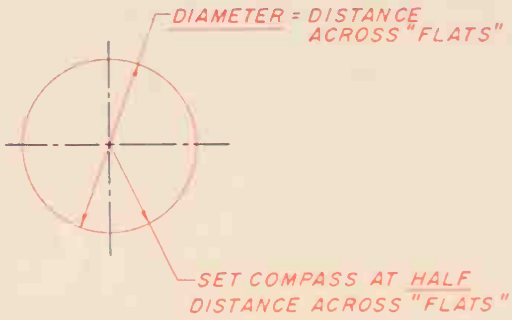


Figure 3-34B Step 1

Figure 3-34C Step 2

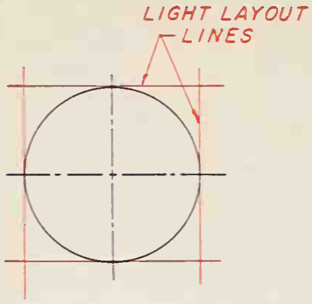
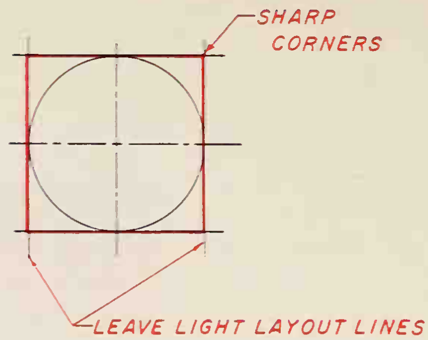


Figure 3-34D Step 3



How To Draw a Pentagon (5 Sides)

Given: The location of the pentagon center, and the diameter that will circumscribe the pentagon, Figure 3-35A.

Step 1. Locate point A at the top-center of the circle and, using a drafting machine, position an angle of 72° (360/5) from the horizontal (or 18° from the vertical) through point A to locate point B where the angle crosses the circumference of the circle, Figure 3-35B.

Step 2. Draw a horizontal line from point B to locate point C on the circumference of the circle on the opposite side, Figure 3-35C.

Step 3. Set the compass at the distance from point B to point C, and swing this distance from the points as illustrated in Figure 3-35D to locate points X and Y.

Step 4. Lightly connect the points. Check to see that there are five equal sides and, if correct, darken in the actual pentagon taking care to construct five sharp corners, Figure 3-35E.

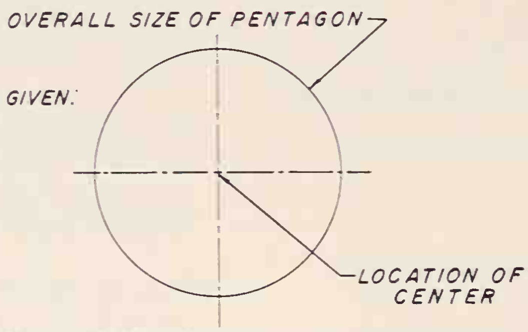
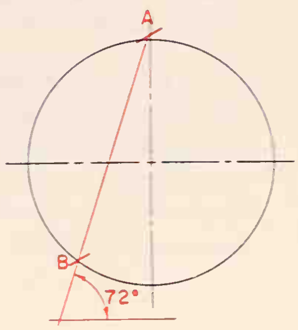


Figure 3-35A How to draw a pentagon

Figure 3-35B Step 1



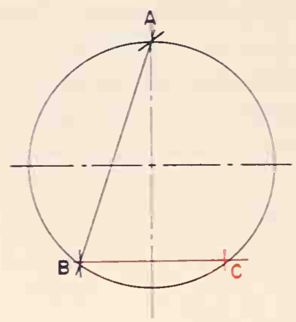


Figure 3-35C Step 2

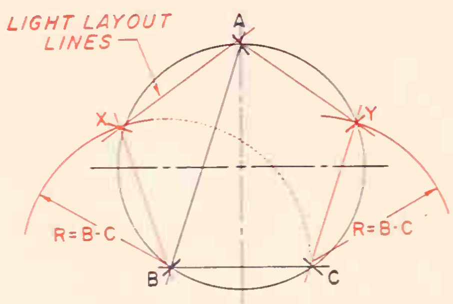


Figure 3-35D Step 3

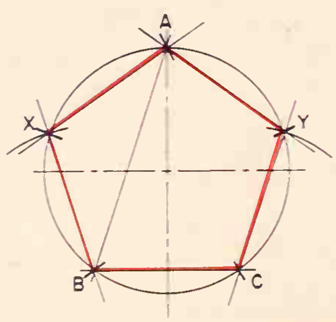


Figure 3-35E Step 4

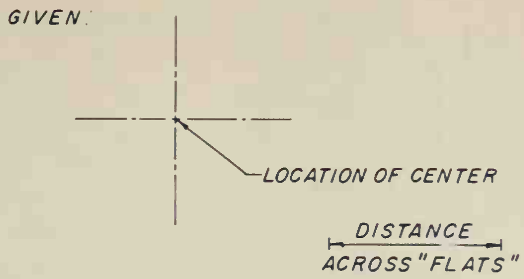


Figure 3-36A How to draw a hexagon

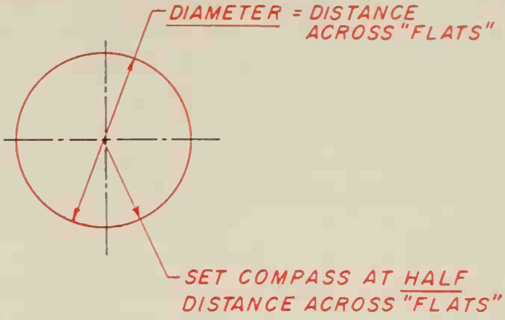


Figure 3-36B Step 1

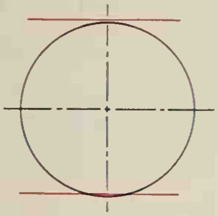


Figure 3-36C Step 2

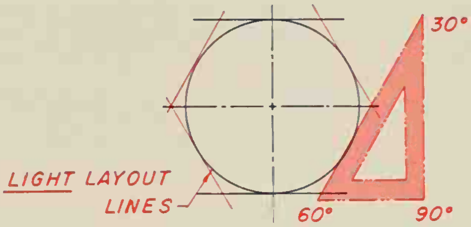


Figure 3-36D Step 3

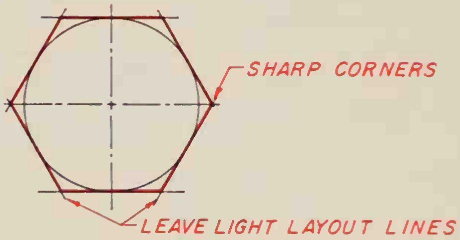


Figure 3-36E Step 4

How To Draw a Hexagon (6 Sides)

Given: The location of the required center and the required distance across the "flats" of a hexagon, Figure 3-36A.

Step 1. Lightly draw a circle with a diameter equal to the distance across the "flats" of the hexagon. Set the compass at half the required diameter, Figure 3-36B.

Step 2. Draw two horizontal lines tangent to the curve, or two vertical lines if the hexagon is to be oriented at 90° to the illustrated position, Figure 3-36C.

Step 3. Using a 30°-60° triangle, lightly complete the hexagon by constructing tangent lines to the circle, Figure 3-36D. Allow the light construction lines to extend as shown; do not erase them.

Step 4. Check to see that there are six equal sides and, if so, darken in the actual hexagon using correct line thickness and taking care to construct six sharp corners, Figure 3-36E. Again, do *not* erase the light construction lines.

How To Draw an Octagon (8 Sides)

Given: The location of the required center and the required distance across the "flats" of an octagon, Figure 3-37A.

Step 1. Lightly draw a circle with a diameter equal to the distance across the "flats" of the octagon. Set the compass at half the required diameter, Figure 3-37B.

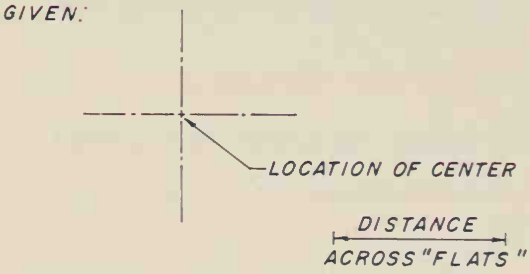


Figure 3-37A How to draw an octagon

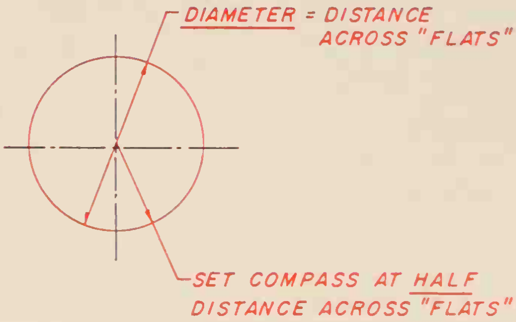


Figure 3-37B Step 1

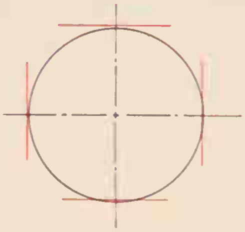


Figure 3-37C Step 2

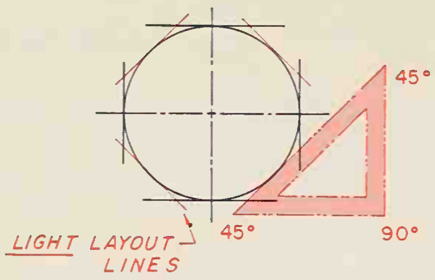


Figure 3-37D Step 3

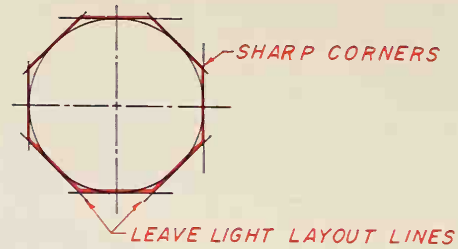


Figure 3-37E Step 4

Step 2. Lightly draw two horizontal lines and two vertical lines tangent to the circle, as illustrated in Figure 3-37C.

Step 3. Using a 45° triangle, lightly complete the octagon by constructing tangent lines to the circle, Figure 3-37D. Allow the light lines to extend.

Step 4. Check that there are eight equal sides and, if so, darken in the actual octagon using correct line thickness and taking care to construct eight sharp corners, Figure 3-37E. Again, do not erase the light construction lines.

Circular Construction

How To Locate the Center of a Given Circle

Given: A circle without a center point, Figure 3-38A.

Step 1. Using the drafting machine or T-square, draw a horizontal line across the circle approximately halfway between the *estimated* center of the given circle and the uppermost point on the circumference. Label the end points of the chord thus formed as A and B, Figure 3-38B.

Step 2. Draw perpendicular lines (90°) downward from points A and B. Locate points C and D where these two lines pass through the circle, Figure 3-38C.

Step 3. Carefully draw a straight line from point A to point D and from point C to point B. Where these lines cross is the exact center of the given circle. Place a compass point on the center point; adjust the lead to the edge of the circle and swing an arc to check that the center is accurate, Figure 3-38D.

Alternatively, the intersection of perpendicular bisectors of any two nonparallel chords serve to locate the center. This is a modification of the previous construction for passing a circle through any three nonaligned points.

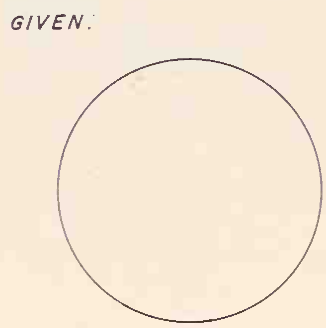


Figure 3-38A How to locate the center of a given circle

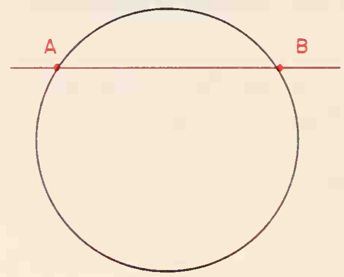


Figure 3-38B Step 1

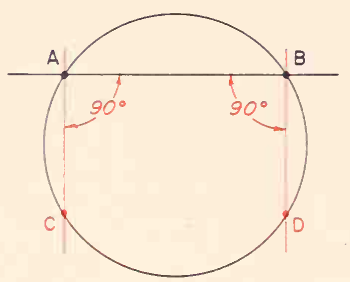


Figure 3-38C Step 2

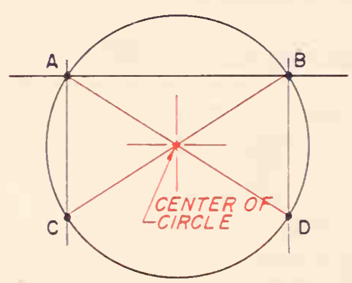


Figure 3-38D Step 3

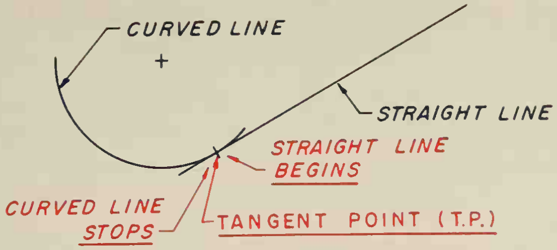


Figure 3-39 Tangent points

Tangent Points

A *tangent point* is the exact location or point where one line stops and another line begins. Tangent also means to "touch." As an example, a tangent point is the exact point where a curved line stops and a straight line begins, Figure 3-39.

How To Locate Tangent Points

The tangent point is a point 90° from the straight line to the swing point of the curved line. Place a light hash mark at each tangent point. It is a good habit to always find *all* tangent points on the object in all views before darkening in the drawing.

The tangent points for a right angle bend are illustrated in Figure 3-40A. The tangent points for an acute angle bend are illustrated in Figure 3-40B. The tangent points for an obtuse angle bend are illustrated in Figure 3-40C.

In each preceding example, a light line is constructed 90° from the straight line to the exact swing point of the radius. Find all the tangent points before darkening in the final work. Always darken in all compass work first, followed by the straight lines.

The tangent point between two arcs or circles is the exact point where one arc or circle ends and the next arc or circle begins. The tangent point could also be where one arc or circle touches another arc or circle, Figure 3-40D.

The tangent point is found by drawing a straight line from the swing point of the first arc or circle to the swing point of the second arc or circle, Figure 3-40E. Place a short light dash at the exact tangent point.

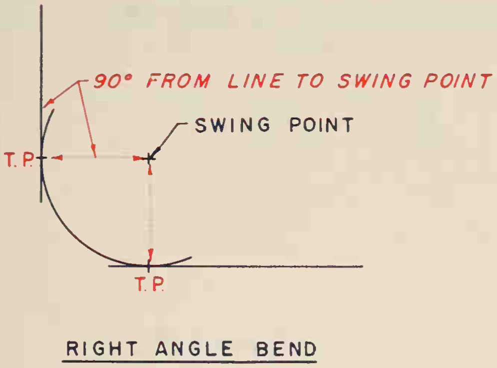


Figure 3-40A How to locate tangent points on a right angle

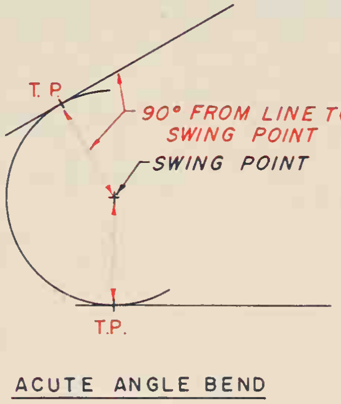


Figure 3-40B How to locate tangent points on an acute angle

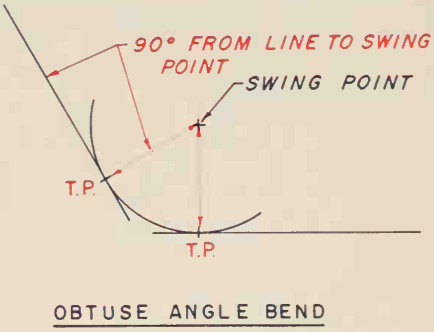


Figure 3-40C How to locate tangent points on an obtuse angle

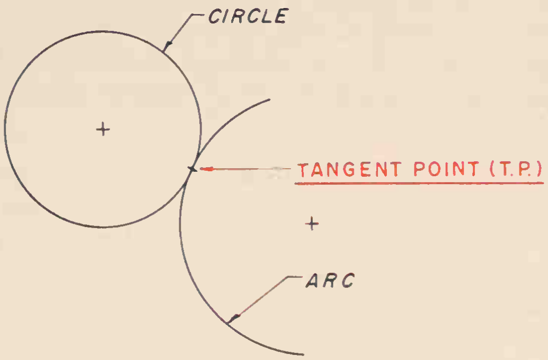


Figure 3-40D How to locate tangent points between arcs or circles

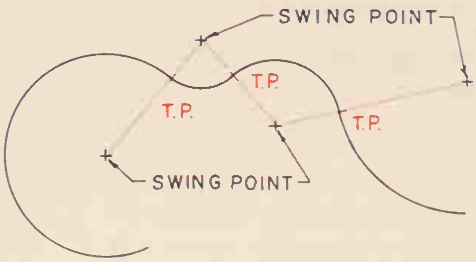


Figure 3-40E Tangent points between arcs or circles

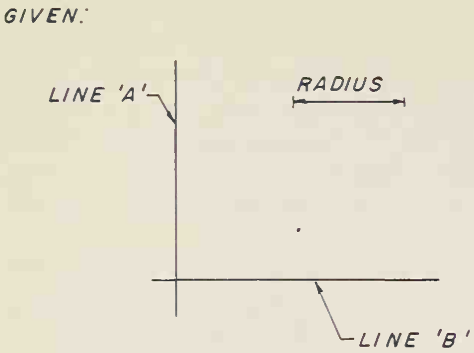


Figure 3-41A How to construct an arc tangent to a right angle

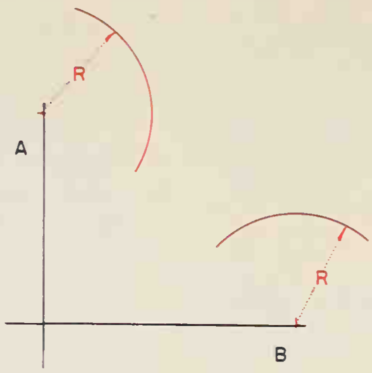


Figure 3-41B Step 1

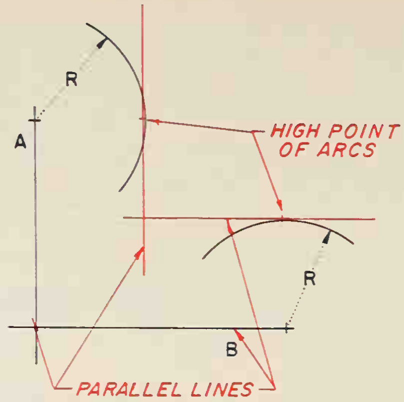


Figure 3-41C Step 2

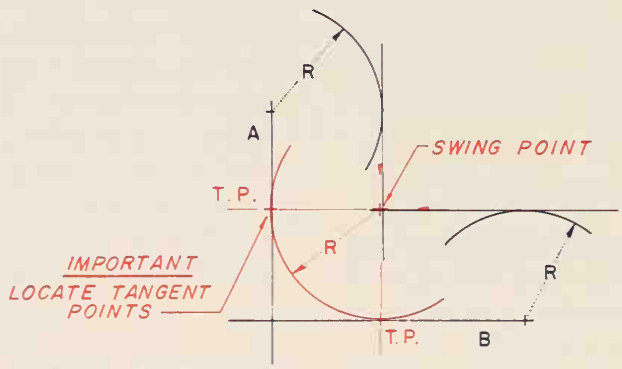


Figure 3-41D Step 3

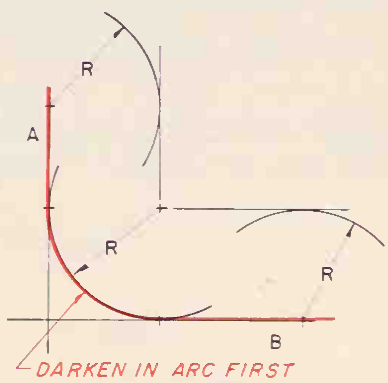
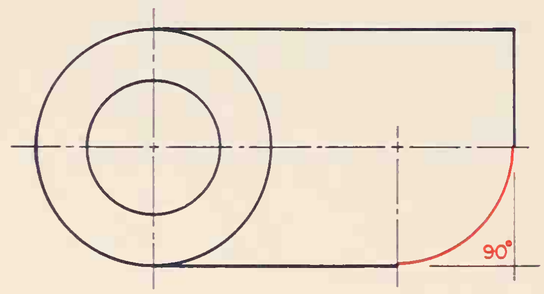


Figure 3-41E Step 4



EXAMPLE

Figure 3-41F Example of an arc tangent to two lines at a right angle

How To Construct an Arc Tangent to a Right Angle (90°)

Given: A right angle (90°), lines A and B and a required radius, Figure 3-41A.

Step 1. Set the compass at the required radius and, out of the way, swing a radius from line A and one from line B, as illustrated in Figure 3-41B.

Step 2. From the extreme high points of each radius, construct a light line parallel to line A and another line parallel to line B, Figure 3-41C.

Step 3. Where these lines intersect is the exact location of the required swing point. Set the compass point on the swing point and lightly construct the required radius, Figure 3-41D. Allow the radius swing to extend past the required area, as shown in the figure. It is important to locate all tangent points (T.P.) before darkening in.

Step 4. Check all work, and darken in the radius using the correct line thickness. Darken in connecting straight lines as required. Always construct compass work first, followed by straight lines. Leave all light construction lines. See Figure 3-41E.

An example of an arc tangent to two lines at a right angle (90°) is illustrated in Figure 3-41F.

How To Construct an Arc Tangent to an Acute Angle (Less Than 90°)

Given: An acute angle, lines A and B, and a required radius, Figure 3-42A. Follow the exact same procedure as outlined in the preceding example.

Step 1. Set the compass at the required radius and, out of the way, swing a radius from line A and one from line B, as illustrated in Figure 3-42B.

Step 2. From the extreme high points of each radius, construct a light line parallel to line A and another line parallel to line B, Figure 3-42C.

Step 3. Where these lines intersect is the exact location of the required swing point. Set the compass point on the swing point and lightly construct the required radius, Figure 3-42D. Allow the radius swing to extend past the required area, as shown in Figure 3-42D.

Step 4. Check all work, and darken in the radius using the correct line thickness. Darken in connecting straight lines as required. Always construct compass work first, followed by straight lines. Leave all light construction lines. See Figure 3-42E.

An example of an arc tangent to two lines at an acute angle (22°) is illustrated in Figure 3-42F.

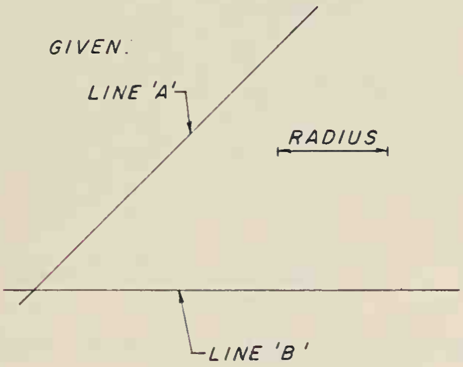


Figure 3-42A How to construct an arc tangent to an acute angle

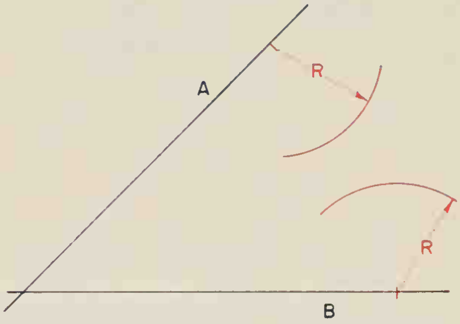


Figure 3-42B Step 1

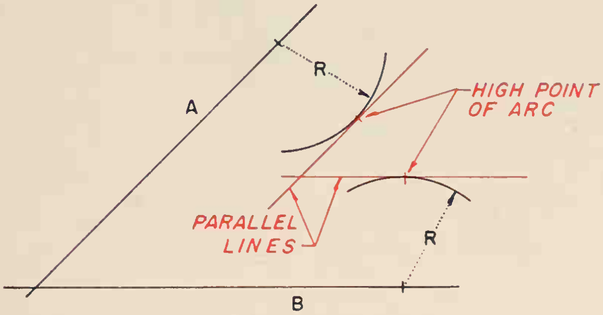


Figure 3-42C Step 2

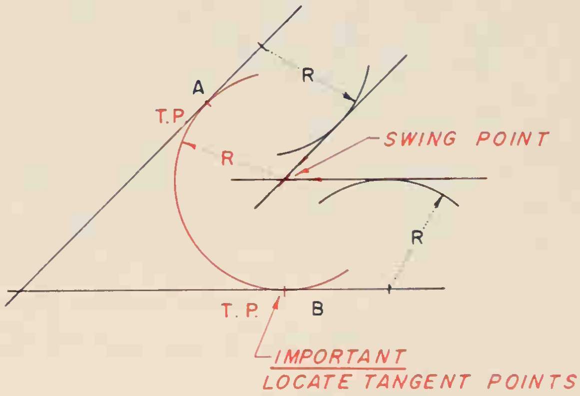


Figure 3-42D Step 3

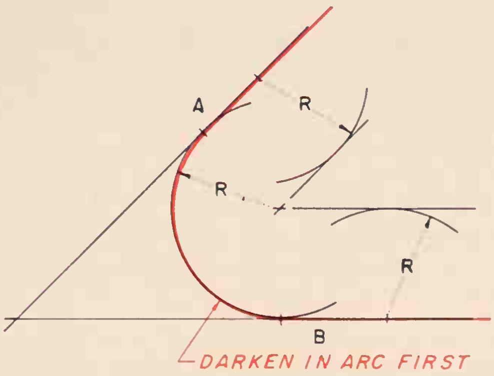


Figure 3-42E Step 4

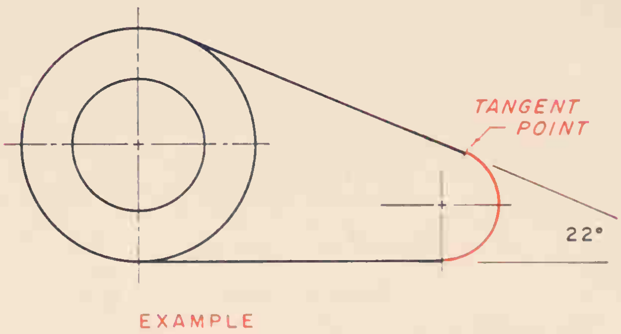


Figure 3-42F Example of an arc tangent to two lines at an acute angle

How To Construct an Arc Tangent to an Obtuse Angle (More Than 90°)

Given: An obtuse angle between lines A and B, and a required radius, Figure 3-43A. Follow the exact same procedure as outlined in the two preceding examples.

Step 1. Set the compass at the required radius and, out of the way, swing a radius from line A and one from line B, as illustrated in Figure 3-43B.

Step 2. From the extreme high points of each radius, construct a light line parallel to line A and one parallel to line B, Figure 3-43C.

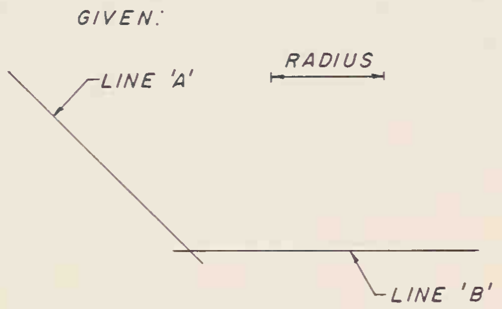


Figure 3-43A How to construct an arc tangent to an obtuse angle

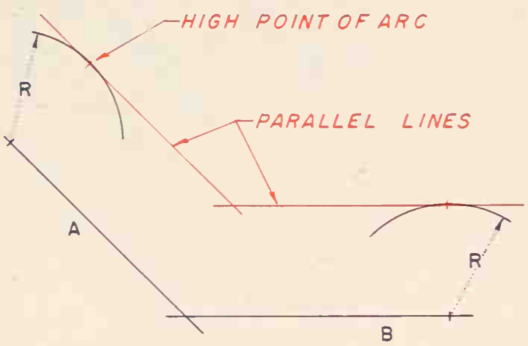


Figure 3-43C Step 2

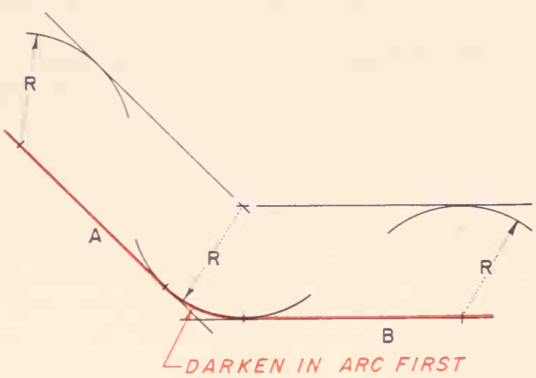


Figure 3-43E Step 4

Step 3. Where these lines intersect is the exact location of the required swing point. Set the compass point on the swing point and lightly construct the required radius. Allow the radius swing to extend past the required area, as shown in Figure 3-43D.

Step 4. Check all work, darken in the radius using the correct line thickness. Darken in connecting straight lines as required. Always construct compass work first, followed by straight lines. Leave all light construction lines. See Figure 3-43E.

An example of an arc tangent to two lines at an obtuse angle (120°) is illustrated in Figure 3-43F.

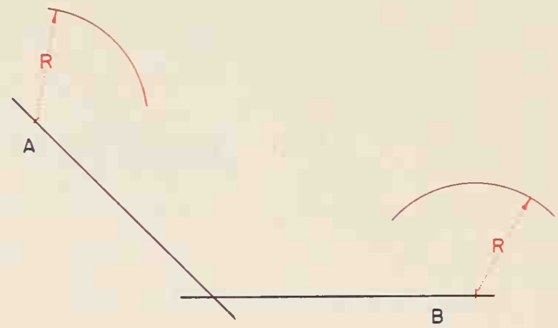


Figure 3-43B Step 1

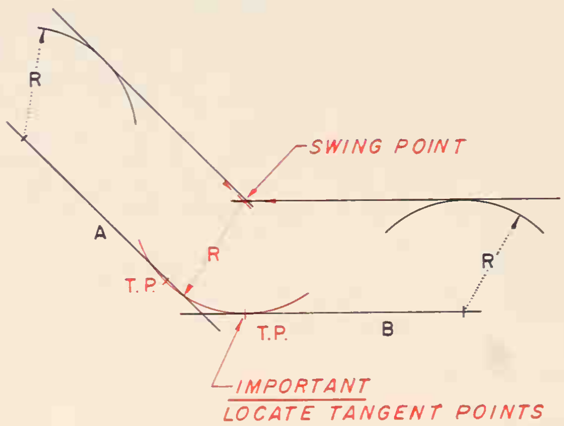


Figure 3-43D Step 3

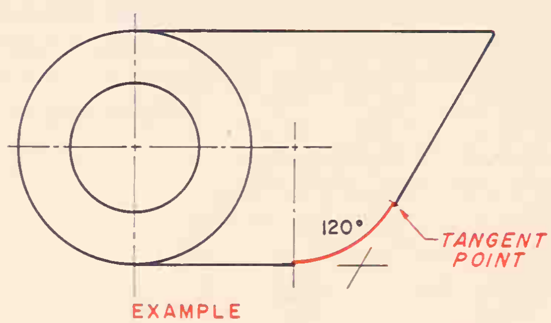


Figure 3-43F Example of an arc tangent to two lines at an obtuse angle

How To Construct an Arc Tangent to a Straight Line and a Curve

Given: Straight line A, an arc B with a center point, and a required radius, Figure 3-44A.

Step 1. Set the compass at the required radius and, out of the way, swing a radius from the given arc B and one from the given straight line A, Figure 3-44B.

Step 2. From the extreme high points of each radius, construct a light straight line parallel to line A, and construct a radius outside the given arc B equal to the required radius, as illustrated in Figure 3-44C.

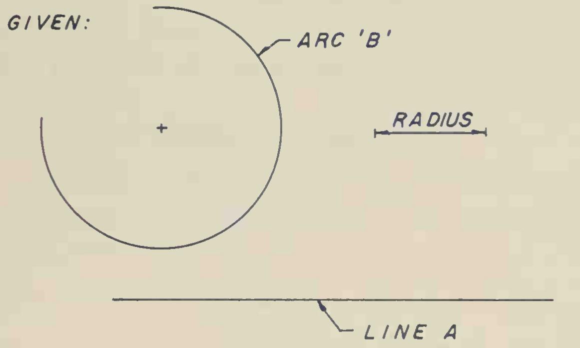


Figure 3-44A How to construct an arc tangent to a straight line and a curve

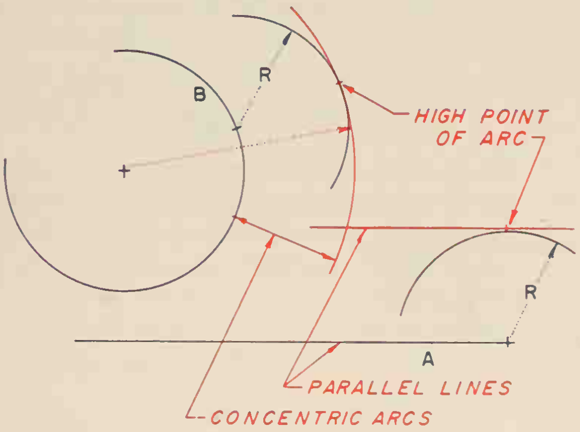


Figure 3-44C Step 2

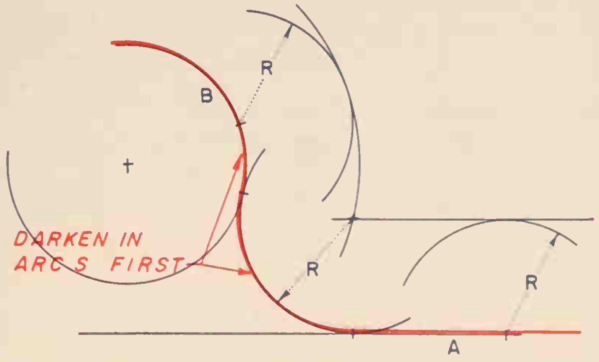


Figure 3-44E Step 4

Step 3. Where these lines intersect is the exact location of the required swing point. Set the compass point on the swing point and lightly construct the required radius, Figure 3-44D. Allow the radius swing to extend past the required area as shown. Locate all tangent points (T.P.) before darkening in.

Step 4. Check all work, darken in the radius using the correct line thickness. Darken in the arcs first and the straight line last, Figure 3-44E.

An example of an arc tangent to a straight line and a curve is illustrated in Figure 3-44F.

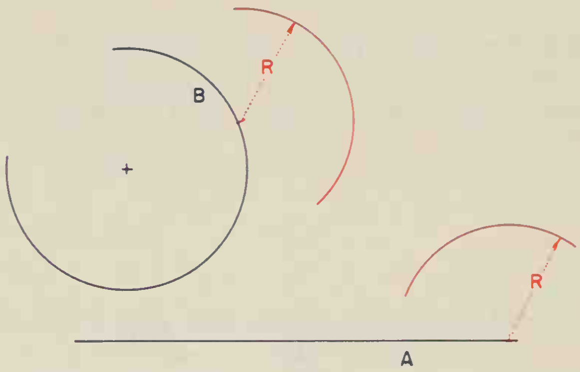


Figure 3-44B Step 1

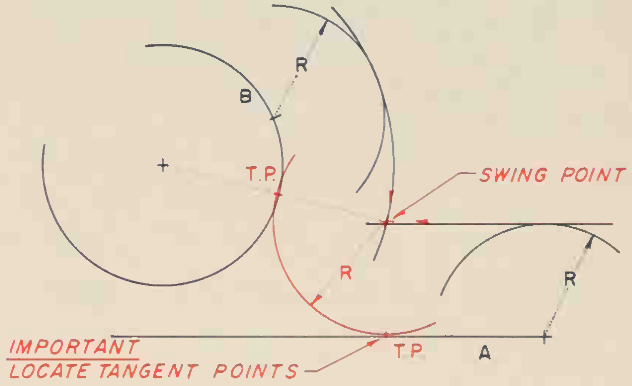


Figure 3-44D Step 3

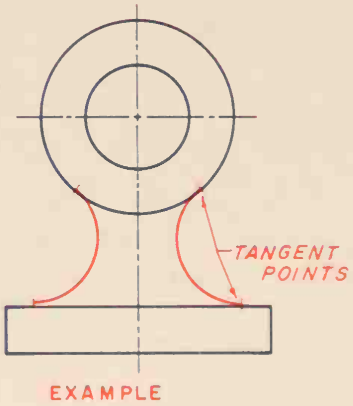


Figure 3-44F Example of an arc tangent to a straight line and a curve

How To Construct an Arc Tangent to Two Radii or Diameters

Given: Diameter A and arc B with center points located, and the required radius, Figure 3-45A.

Step 1. Set the compass at the required radius and, out of the way, swing a radius of the required length from a point on the circumference of given diameter A. Out of the way, swing a required radius from a point on the circumference of given arc B, Figure 3-45B.

Step 2. From the extreme high points of each radius, construct a light radius outside of the given radii A and B, as illustrated in Figure 3-45C.

Step 3. Where these arcs intersect is the exact location of the required swing point. Set the compass point on the swing point and lightly construct the required radius, Figure 3-45D. Allow the radius swing to extend past the required area as shown. Before darkening in, it is important to locate all tangent points (T.P.), Figure 3-45D.

Step 4. Check all work, darken in the radii using the correct line thickness. Darken in the arcs or radii in consecutive order from left to right or from right to left, thus constructing a smooth connecting line having no apparent change in direction, Figure 3-45E.

An example of an arc tangent to two radii is illustrated in Figure 3-45F.

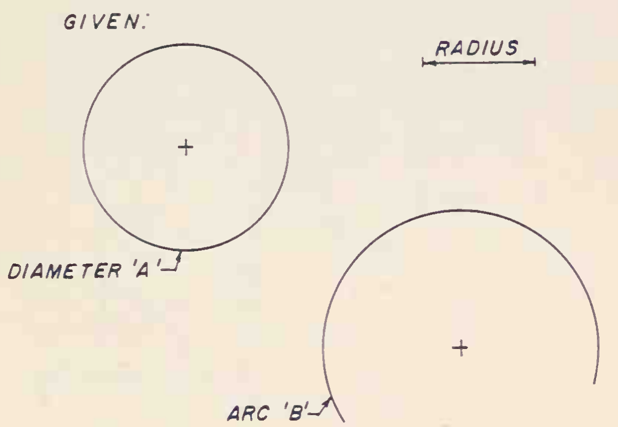


Figure 3-45A How to construct an arc tangent to two radii or diameters

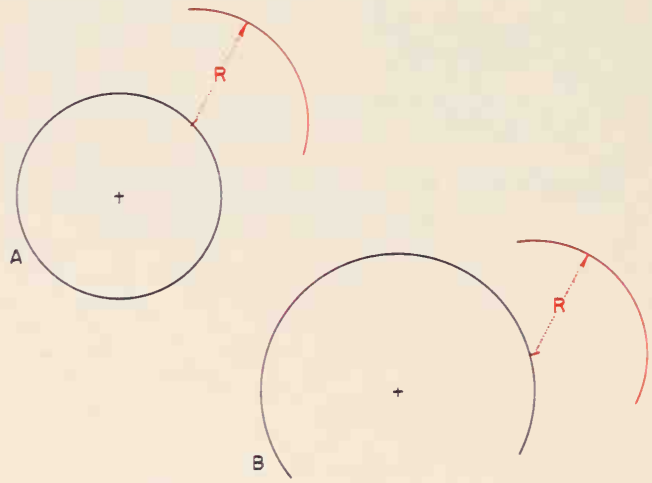


Figure 3-45B Step 1

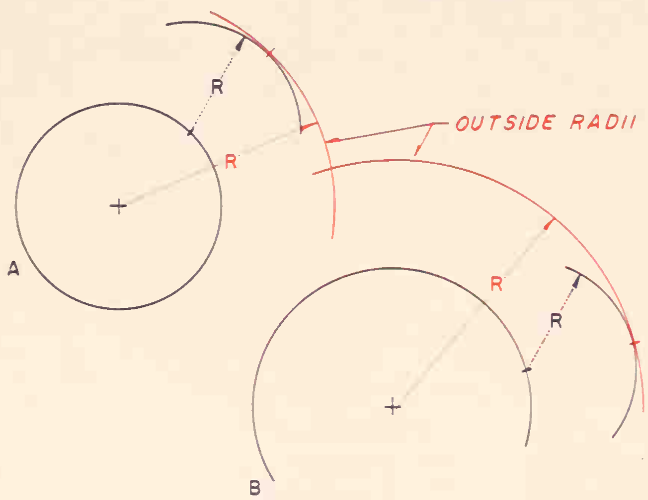


Figure 3-45C Step 2

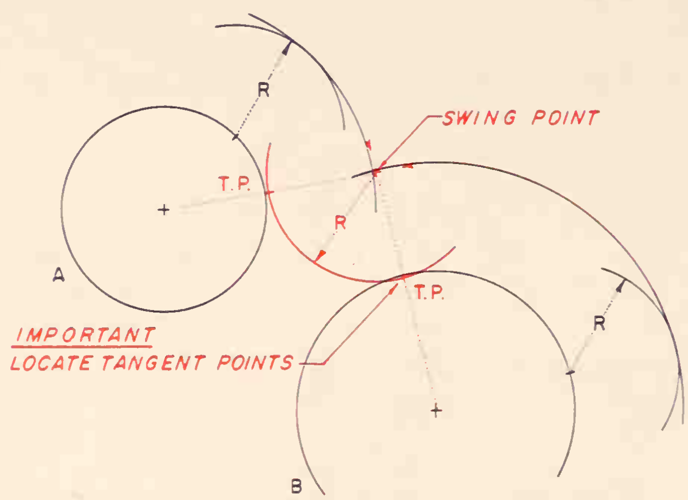


Figure 3-45D Step 3

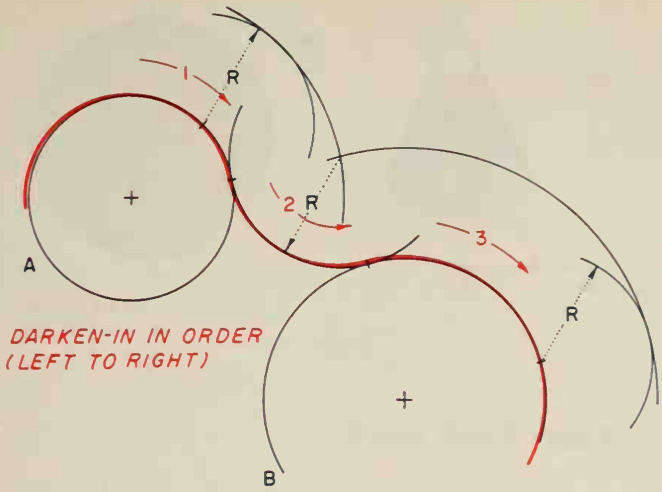


Figure 3-45E Step 4

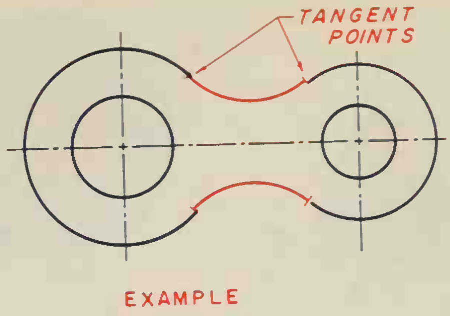


Figure 3-45F Example of an arc tangent to two radii

How To Draw an Ogee Curve

An *ogee curve* is used to join two parallel lines. It forms a gentle curve that reverses itself in a neat symmetrical geometric form.

Given: Parallel lines A-B and C-D, Figure 3-46A.

Step 1. Draw a straight line connecting the space between the parallel lines. In this example, from point B to point C, Figure 3-46B.

Step 2. Make a perpendicular bisector to line B-C to establish point X, Figure 3-46C.

Step 3. Make perpendicular bisectors to the lines B-X and X-C, Figure 3-46D.

Step 4. Draw a perpendicular from line A-B at point B to intersect the perpendicular bisector of B-X, which locates the first required swing center. Draw a perpendicular from line C-D at point C to intersect the perpendicular bisector of C-X which locates the second required swing center, Figure 3-46E.

Step 5. Place the compass point on the first swing point and adjust the compass lead to point B, and swing an arc from B to X. Place the compass point on the second swing point and swing an arc from X to C, Figure 3-46F. This completes the ogee curve.

Note: point X is the tangent point between arcs. Check and, if correct, darken in all work.

An example of an ogee curve is illustrated in Figure 3-46G.

Figure 3-46A How to draw an ogee curve

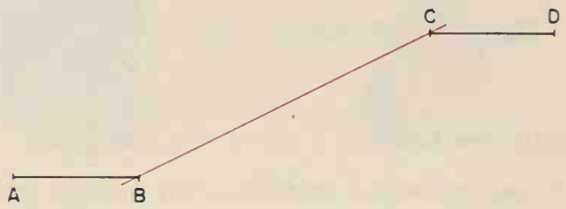


Figure 3-46B Step 1

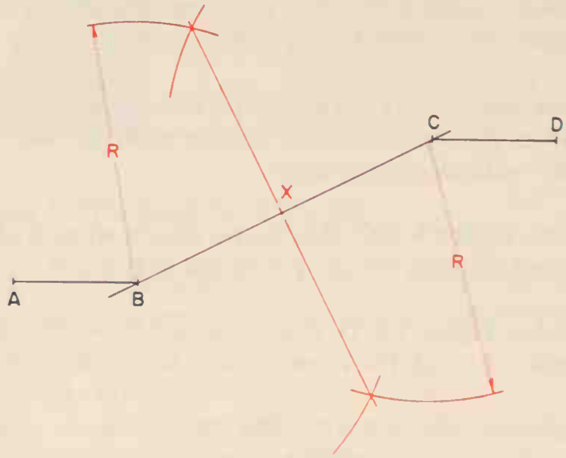


Figure 3-46C Step 2

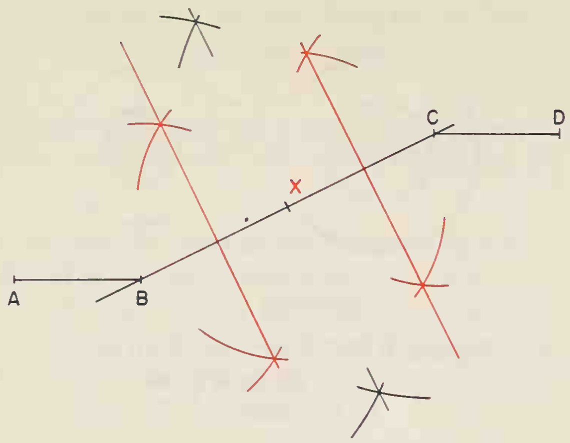


Figure 3-46D Step 3

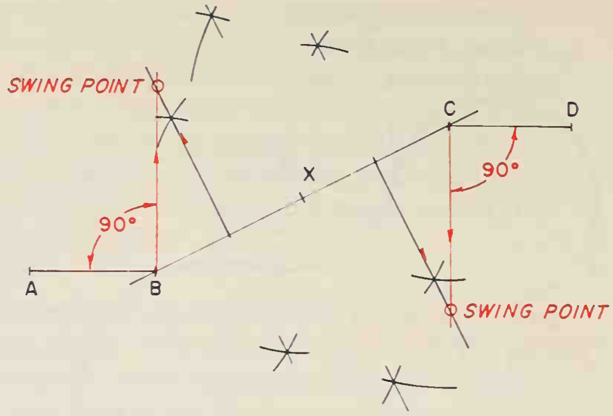


Figure 3-46E Step 4

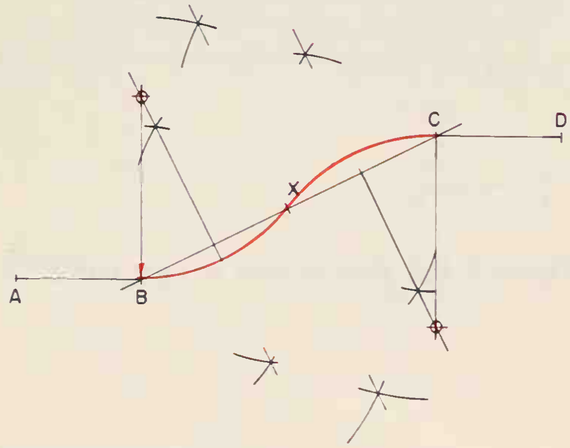


Figure 3-46F Step 5

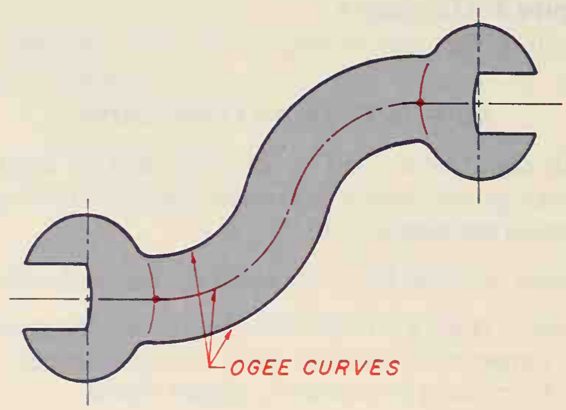


Figure 3-46G Step 6

Conic Sections

A *conic section* is a section cut by a plane passing through a cone. These sections are bounded by various kinds of shapes. Depending upon where the section is cut, the various shapes can be a triangle, a circle, an ellipse, a parabola or a hyperbola, Figures 3-47A through 3-47E.

Triangle, Figure 3-47A. This shape results when a plane passes through the apex of the cone.

Circle, Figure 3-47B. This shape results when a plane passes through the cone, parallel with the base and perpendicular to the axis.

Ellipse, Figure 3-47C. This shape results when a plane passes through the cone inclined to the axis.

Parabola, Figure 3-47D. This shape results when a plane passes through the cone parallel to one element.

Hyperbola, Figure 3-47E. This shape results when a plane passes through the cone parallel with the axis of the cone.

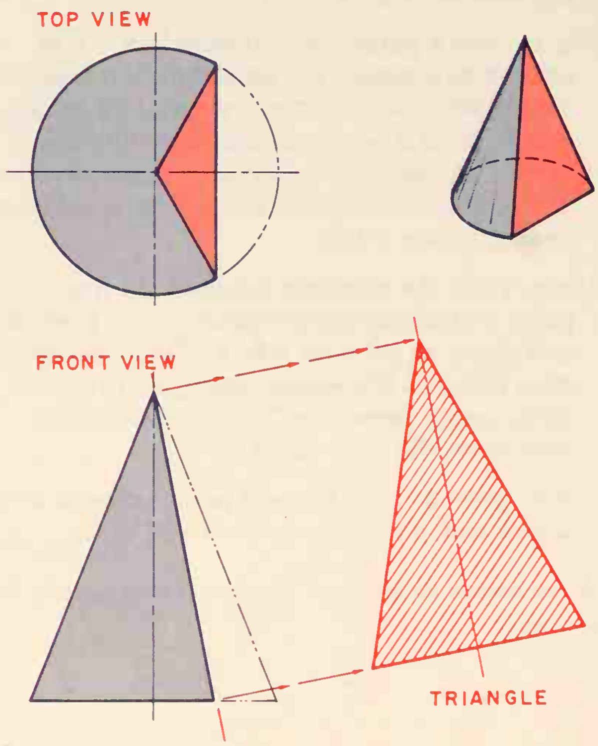


Figure 3-47A Triangle section

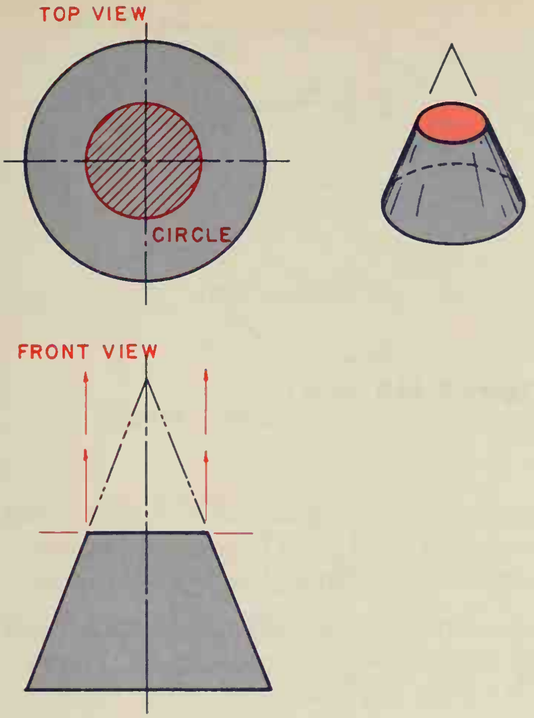


Figure 3-47B Circle section

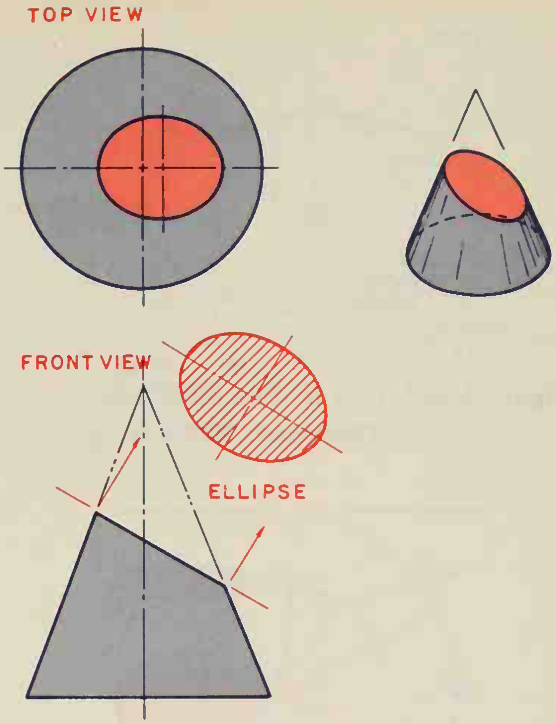


Figure 3-47C Ellipse section

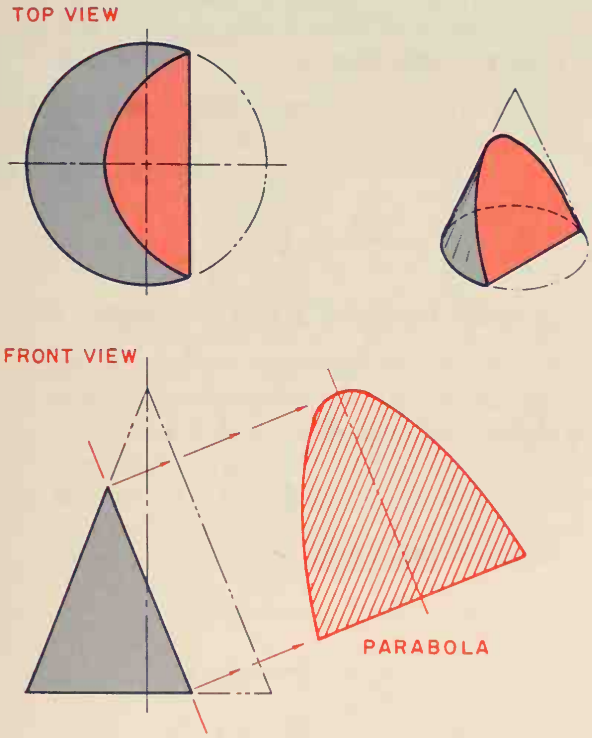


Figure 3-47D Parabola section

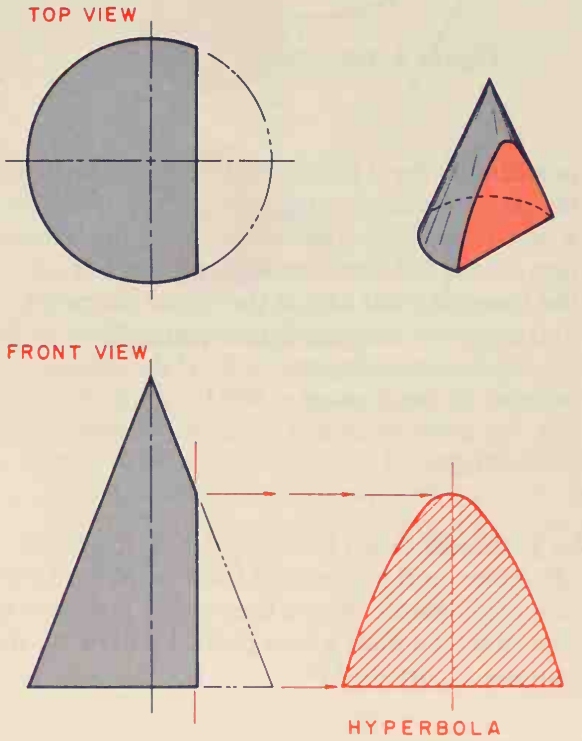


Figure 3-47E Hyperbola section

How To Draw an Ellipse, Concentric Circle Method

Given: The location of the center point, the major diameter, and the minor diameter, Figure 3-48A.

Step 1. Lightly draw one circle equal to the major diameter and another circle equal to the minor diameter, Figure 3-48B.

Step 2. Divide both circles into 12 equal divisions by passing lines through the center at every 30 degrees. Number points 1 through 5 in clockwise consecutive order on the major diameter,

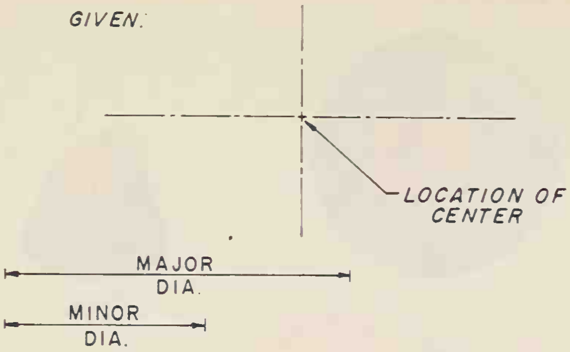


Figure 3-48A How to draw an ellipse (concentric method)

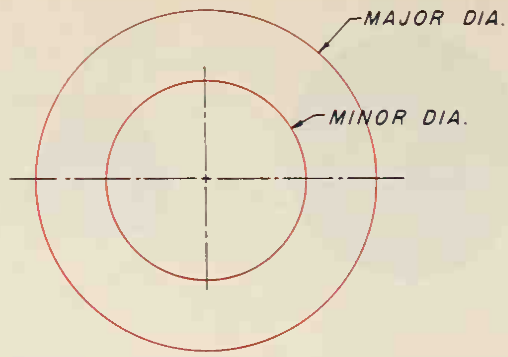


Figure 3-48B Step 1

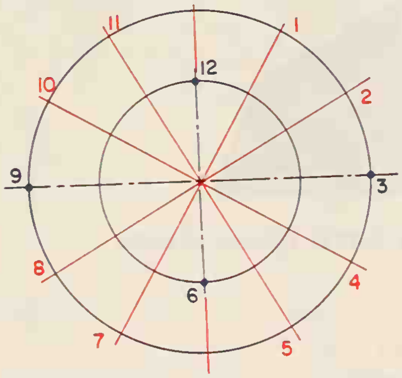


Figure 3-48C Step 2

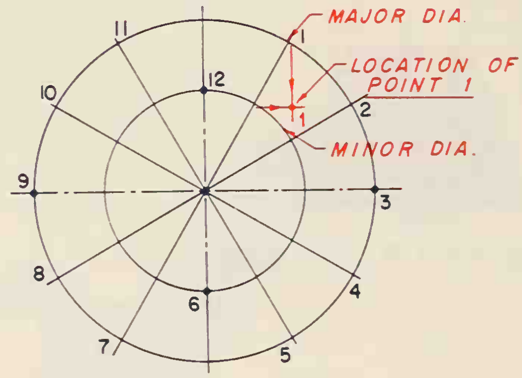


Figure 3-48D Step 3

positioning the 3 location on the right horizontal axis. Number points 7 through 11 in clockwise consecutive order, positioning the 9 location on the left horizontal axis. Point 6 is on the lower vertical axis at the minor diameter, and point 12 is on the upper vertical axis at the minor diameter, Figure 3-48C. If the ellipse were to be positioned at 90° from this example, the point locations would be rotated accordingly.

Step 3. Project down from point 1 on the major diameter, and to the right from point 1 on the minor diameter. Where these lines intersect is the exact location where point 1 will be on the ellipse, Figure 3-48D.

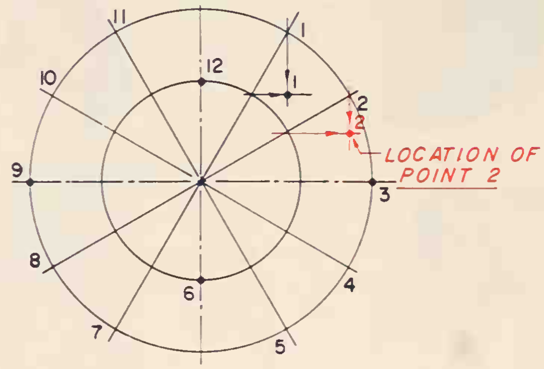


Figure 3-48E Step 4

Step 4. Project down from point 2 on the major diameter, and to the right from point 2 on the minor diameter. Where these lines intersect is the exact location where point 2 will be on the ellipse, Figure 3-48E.

Step 5. This completes the first quadrant of the ellipse. Continue around the circle to locate points 4, 5, 6, 7, 8, 9, 10, and 11 in the same manner except in reverse, Figure 3-48F.

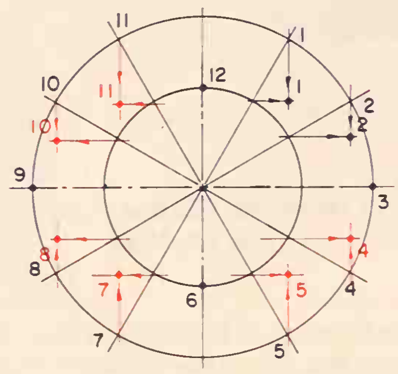


Figure 3-48F Step 5

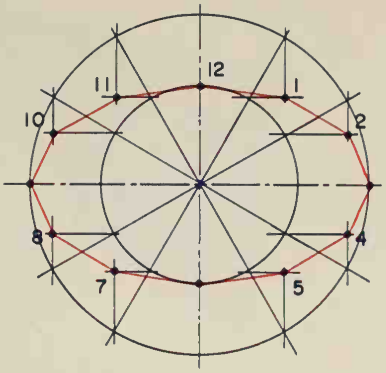


Figure 3-48G Step 6

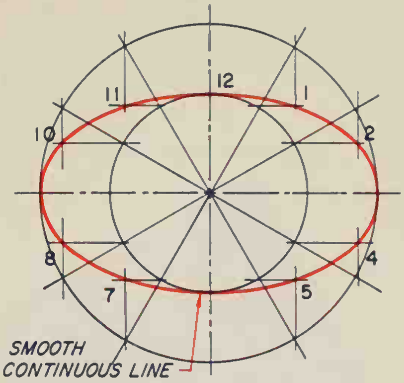


Figure 3-48H Step 7

Step 6. Lightly draw straight lines connecting points 1 through 12 in order to get a general idea of the ellipse outline, Figure 3-48G.

Step 7. Darken in the ellipse using an irregular curve. Carefully connect all the points with a smooth continuous line of the correct thickness, Figure 3-48H. It is sometimes helpful to divide into 10° or 15° spaces the two ends where the ellipse curves the fastest in order to have more points around the extreme ends. In this example, this is done between points 2-4 and 8-10.

Examples of ellipses are illustrated in Figure 3-48I, showing how a rotated circle would look at 0°, 15°, 45°, 60°, and 90°.

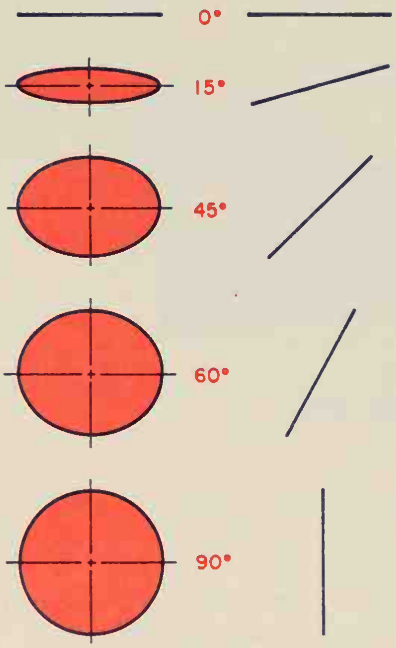


Figure 3-48I Example of ellipses at various degrees

How To Draw a Trammel Ellipse

Given: A major or minor axis of a required ellipse, and any located point through which the ellipse must pass, Figure 3-49A. If a major axis is given, mark the end points A and B. If the minor axis is given, as is shown in the figure, mark the end points C and D. Mark as P the known location of where the ellipse must pass.

Step 1. Draw a perpendicular bisector of the given axis to locate the unknown axis position, crossing the known axis at a point that will become 0, Figure 3-49B.

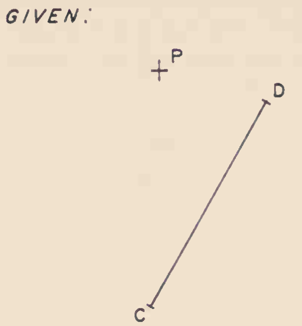


Figure 3-49A Trammel ellipse

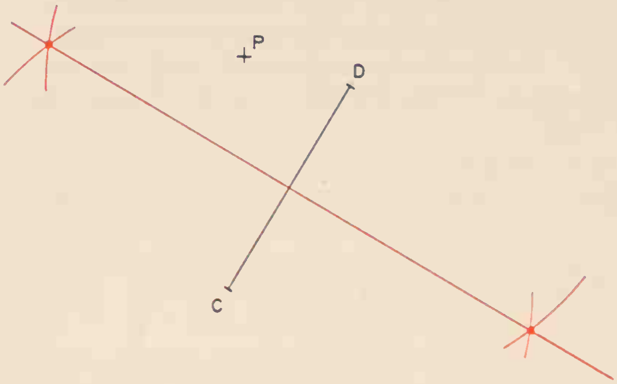


Figure 3-49B Step 1

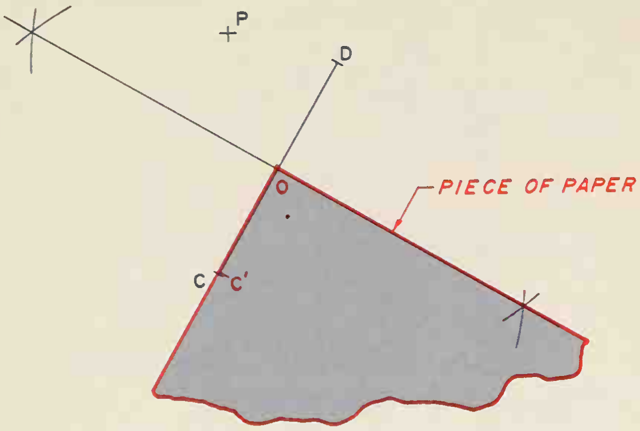


Figure 3-49C Step 2

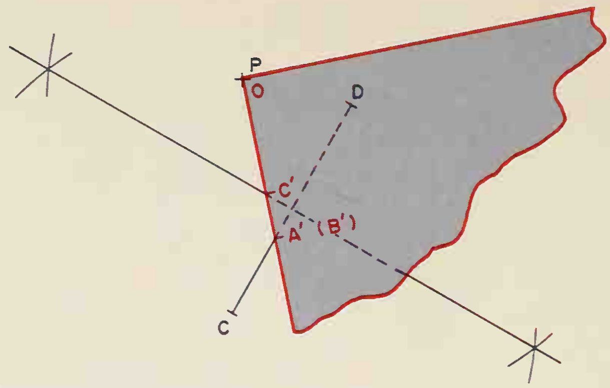


Figure 3-49D Step 3

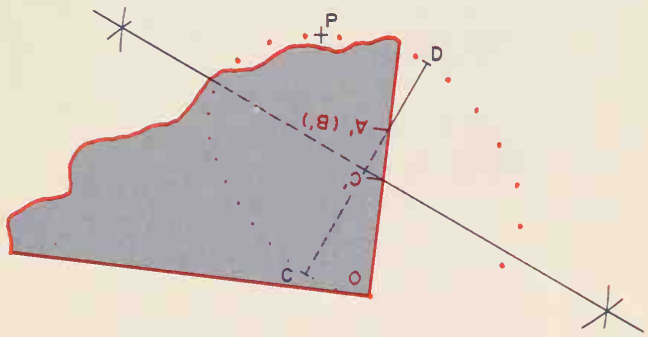


Figure 3-49E Step 4

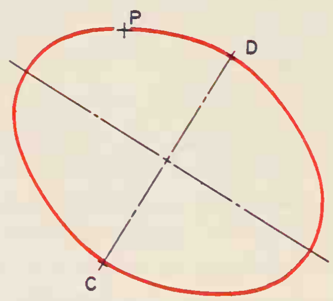


Figure 3-49F Step 5

Step 2. Mark an end corner of a separate strip of paper as point 0, and mark along the edge of the strip one-half of the distance A-B or C-D, whichever is known. Mark this point on the strip as A' or C' to correspond to the known axis, Figure 3-49C. Position the strip so that point 0 lies on the known point through which the ellipse must pass. Position the other strip mark on the axis that is not represented by the half-length on the strip, at the position (of two possible positions) that is nearest to the ellipse center.

Step 3. With the strip positioned as specified in Step 2, mark the strip at the location of where it crosses the other axis. The length of end point 0 to this new position represents one-half of the unknown axis length, and should correspondingly be labeled as A' or C', Figure 3-49D.

Step 4. Using the two marked strip locations, reposition the strip so that the mark representing one-half of the major axis always lies on the minor axis, and the mark representing one-half of the minor axis always lies on the major axis. Repeat as needed to establish enough points for constructing the ellipse, Figure 3-49E.

Step 5. Using a French curve, pass a smooth line through each of these established points, Figure 3-49F.

How To Draw a Foci Ellipse

Given: Major and minor axes of a required ellipse. The end points of the major axis are labeled A and B, the end points of the minor axis are labeled C and D, and the ellipse center is labeled 0, Figure 3-50A.

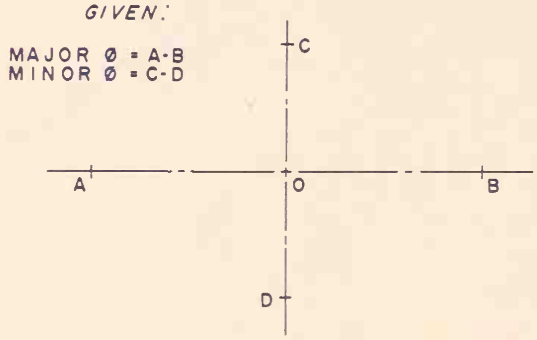


Figure 3-50A How to draw a foci ellipse

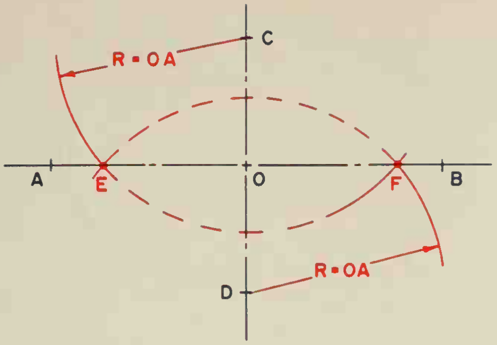


Figure 3-50B Step 1

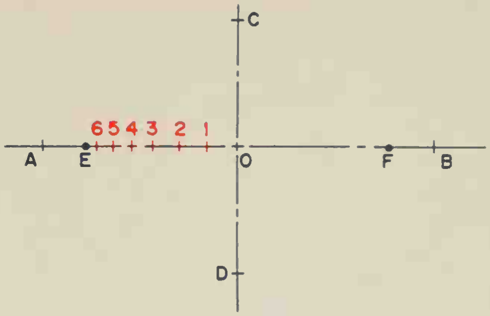


Figure 3-50C Step 2

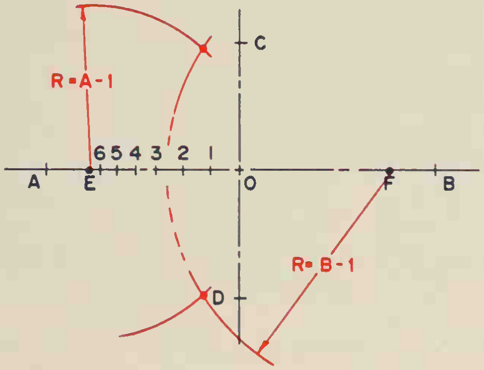


Figure 3-50D Step 3

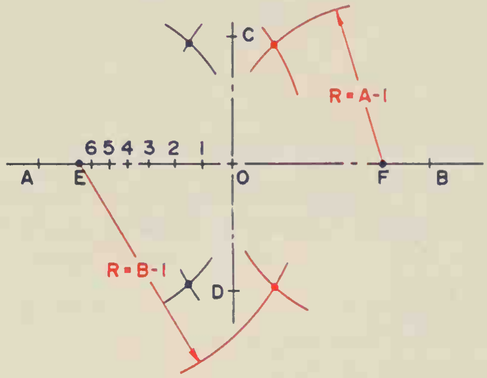


Figure 3-50E Step 4

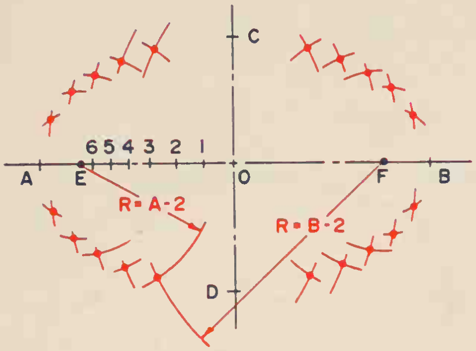


Figure 3-50F Step 5

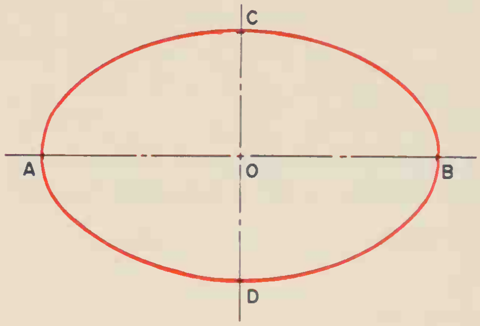


Figure 3-50G Step 6

Step 1. Swing a radius of one-half of the major axis (OA) from the end point of the minor axis (C or D) to locate the focal points E and F at the points where the arc crosses the major axis Figure 3-50B.

Step 2. Select a random array of points on the major axis between one focal point and the ellipse center (space those at the ends more closely). Number these in consecutive order, Figure 3-50C.

Step 3. Swing an arc whose radius is the distance from point B to number 1. Swing this distance from focal point F. Intersect this arc with an arc whose radius is the distance from point A to the same numbered point, number 1 in this example, but whose center is at focal point E, Figure 3-50D.

Step 4. Repeat Step 3, but reverse the focal point positions of the arc centers, Figure 3-50E.

Step 5. Repeat Steps 3 and 4 for each point selected in Step 2, Figure 3-50F.

Step 6. Connect the points into a smooth curve, using a French curve, Figure 3-50G.

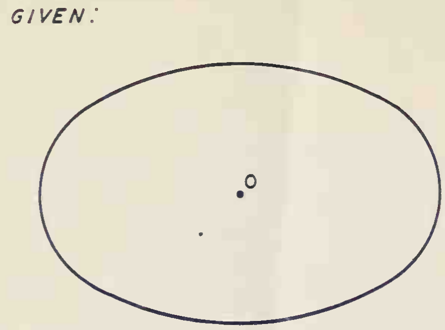


Figure 3-51A How to locate the major and minor axes of a given ellipse

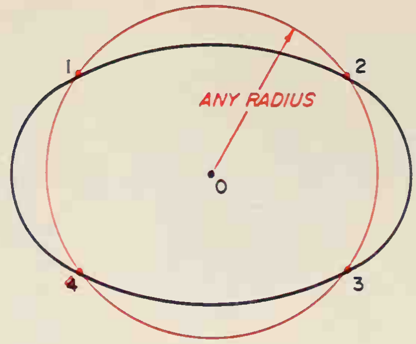


Figure 3-51B Step 1

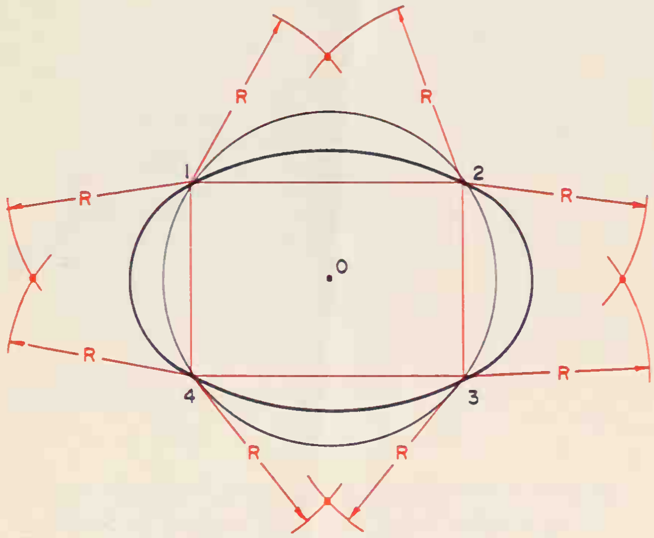


Figure 3-51C Step 2

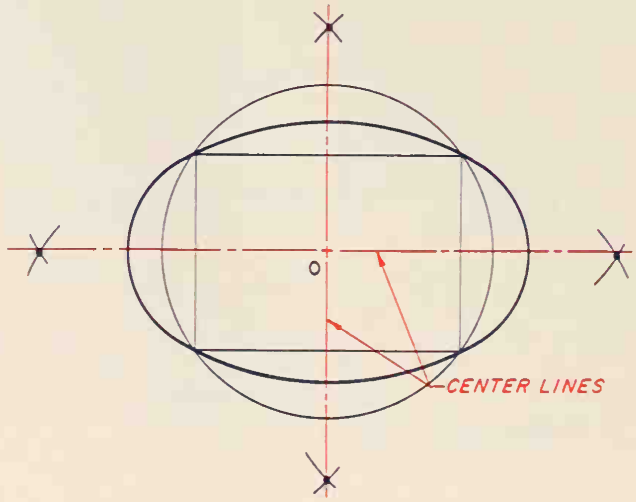


Figure 3-51D Step 3

How To Locate the Major and Minor Axes of a Given Ellipse with a Located Center

Given: An ellipse, with center 0 located, Figure 3-51A.

Step 1. From the ellipse center 0, draw a circle at a radius that allows intersecting the ellipse at any four locations. Label these points in successive order 1, 2, 3, and 4, moving clockwise around the ellipse center, Figure 3-51B.

Step 2. Draw a rectangle by connecting each of the labeled points in successive order. As shown in Figure 3-51C, the major and minor axes are parallel to these sides, found by drawing perpendicular bisectors of two consecutive sides.

Step 3. Draw the major and minor axes parallel to sides 1-2 and 2-3 through point 0, Figure 3-51D.

How To Draw a Tangent to an Ellipse at a Point on the Ellipse

Given: An ellipse, and a point P on its perimeter, Figure 3-52A. If not provided, locate the major

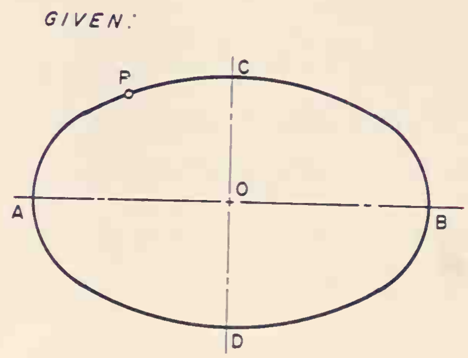


Figure 3-52A How to draw a tangent to an ellipse at a point on the ellipse

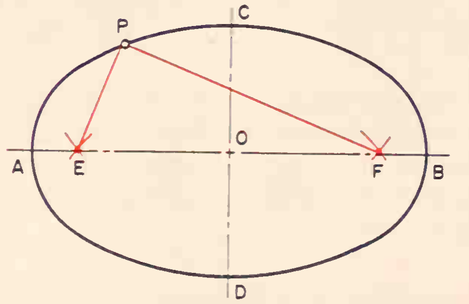


Figure 3-52B Step 1

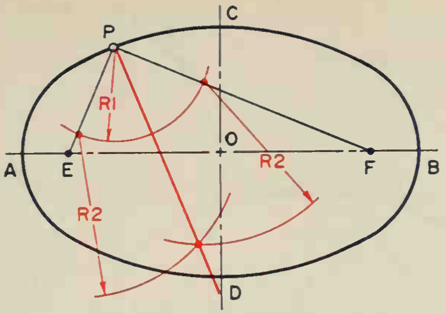


Figure 3-52C Step 2

axis A-B and minor axis C-D, and the focal points E and F.

Step 1. Draw E-P and F-P, Figure 3-52B.

Step 2. Bisect the angle EPF, Figure 3-52C.

Step 3. Draw a perpendicular to the angle bisector of angle EPF at point P. This is the required tangent, Figure 3-52D.

How To Draw a Tangent to an Ellipse from a Distant Point

Given: An ellipse and a distant point P, Figure 3-53A.

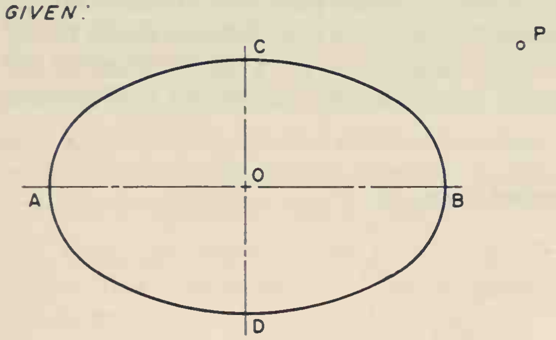


Figure 3-53A How to draw a tangent to an ellipse from a distant point

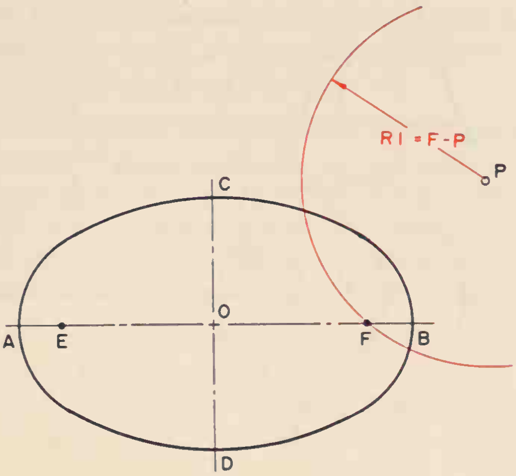


Figure 3-53C Step 2

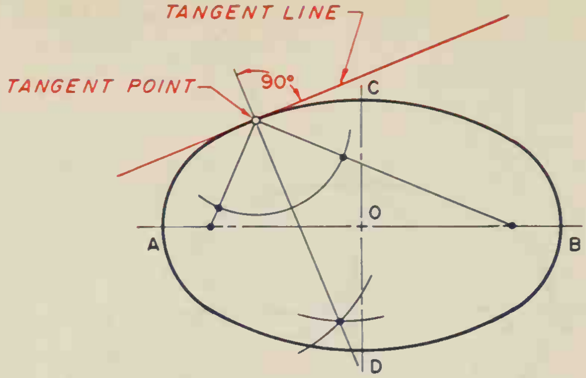


Figure 3-52D Step 3

Step 1. If not provided, locate the major axis A-B and focal points E and F, Figure 3-53B.

Step 2. Swing an arc R1 from point P to pass through either focal point. F is selected for this example, Figure 3-53C.

Step 3. Swing an arc whose radius is equal to the major axis, from the other focal point (E in this example). Intersect the arc from Step 2 at points R and S, Figure 3-53D.

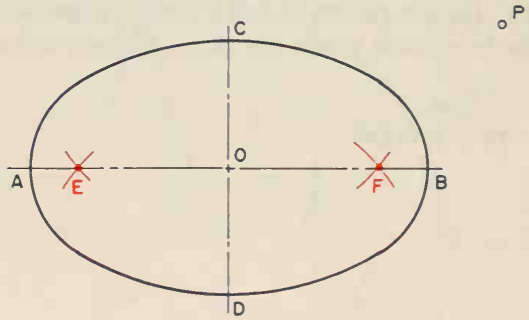


Figure 3-53B Step 1

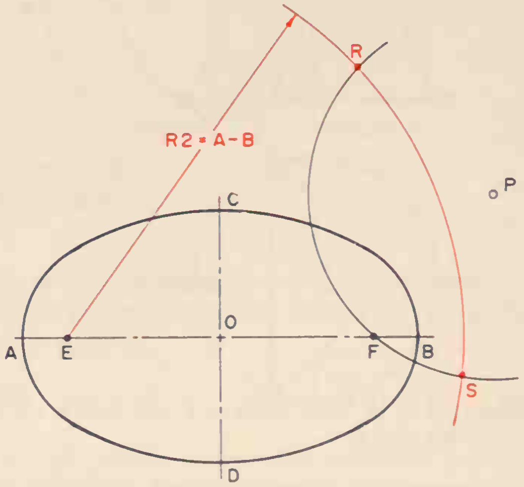


Figure 3-53D Step 3

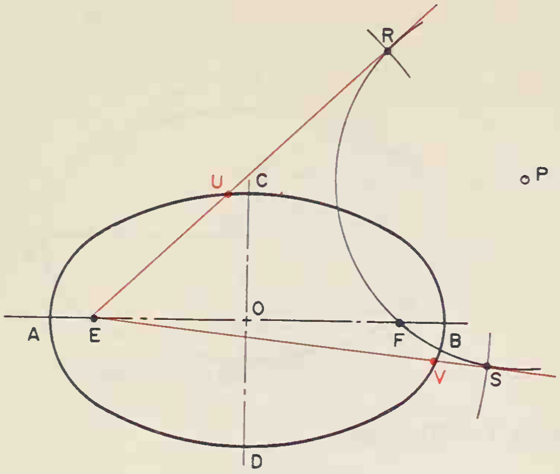


Figure 3-53E Step 4

Step 4. Extend the lines from E to each of points R and S, to cross the ellipse at U and V, Figure 3-53E.

Step 5. The two possible points of tangency of the two possible lines from point P are U and V. Select and draw either, or both, Figure 3-53F.

How To Draw a Parabola (Method 1)

Given: The front view and plan view of cone ABC with cutting plane X-Y, Figure 3-54A.

Step 1. Locate points Y' and Y" in the plan view. In the front view, place the point of the compass

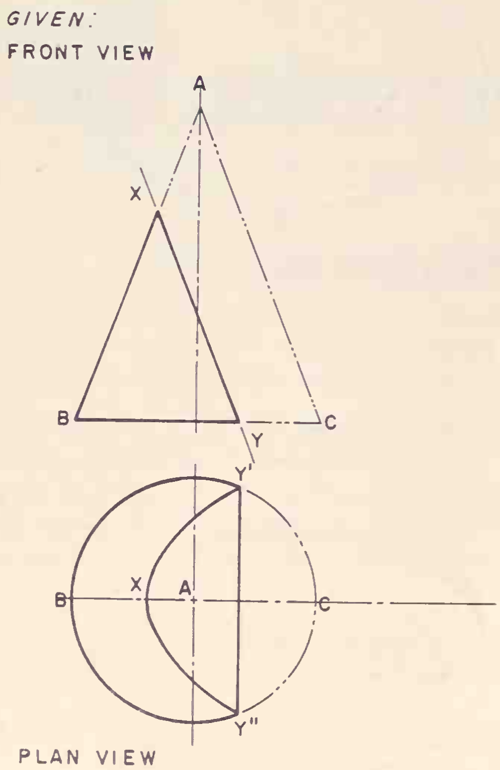


Figure 3-54A How to draw a parabola (method 1)

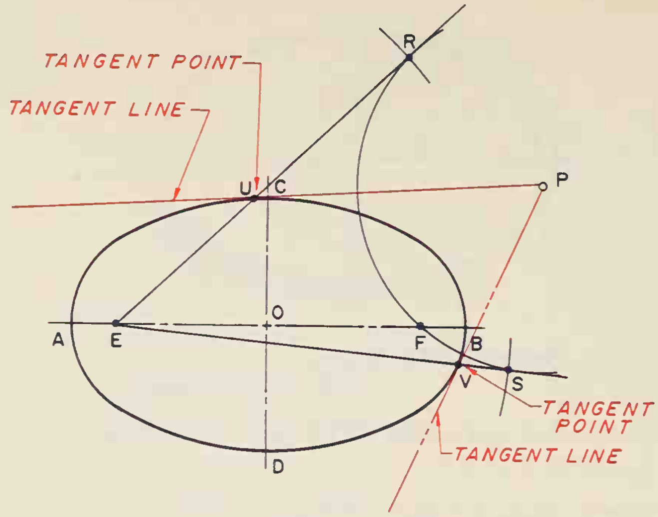


Figure 3-53F Step 5

on point Y and position the lead on point X. Swing point X to the extended baseline and down into the plan view, as illustrated in Figure 3-54B.

Step 2. Locate a point along line X-Y (in this example, point D) and, using point Y as a swing point, swing point D to the extended baseline and down into the plan view. In the front view, reset the compass to a distance equal to the horizontal distance from the cone axis to the outer edge (identified as length 1), illustrated

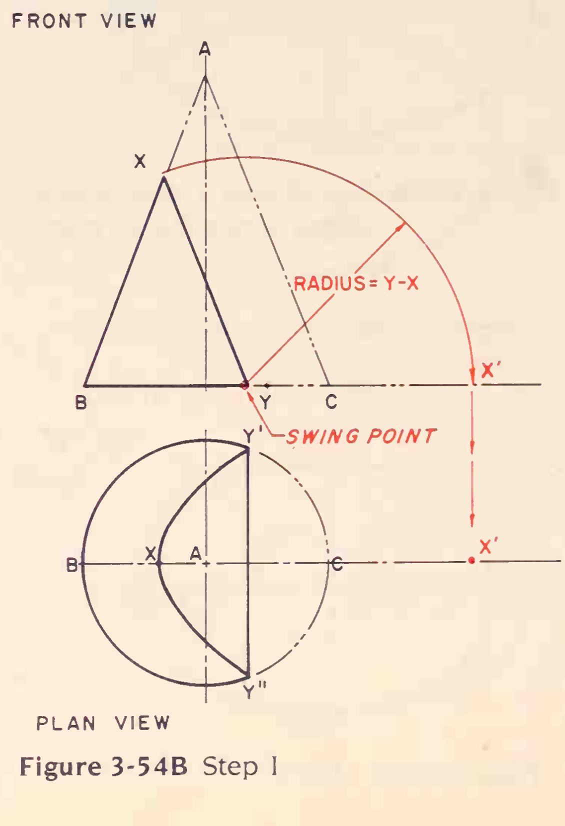


Figure 3-54B Step 1

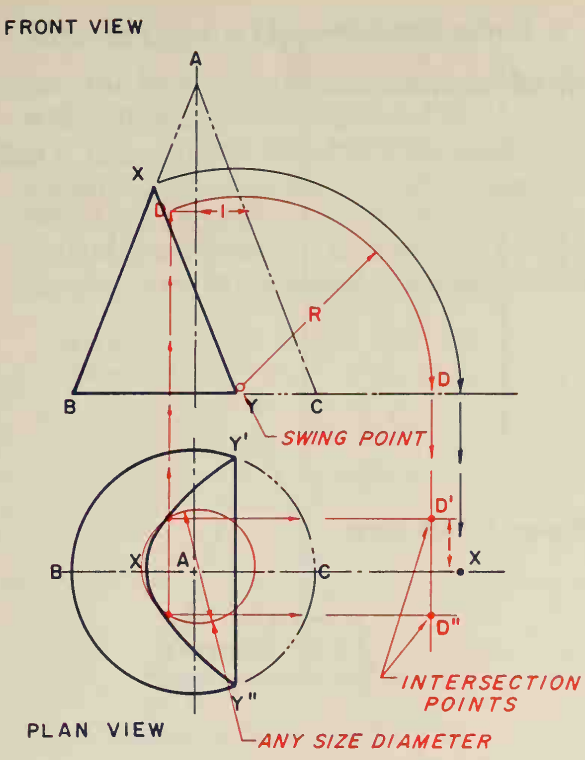


Figure 3-54C Step 2

in Figure 3-54C. Transfer this distance to the plan view. Project point D down into the plan view and, where point D intersects the arc, locate points D′ and D″. Project these points to the right, intersecting with point D from above at the actual intersection points D′ and D″.

Step 3. Choose other various points along line X-Y in the front view, and project them over and down as described in Step 2, Figure 3-54D.

Step 4. Using an irregular curve, connect all points. This completes the parabola, Figure 3-54E.

How To Draw a Parabola (Method 2)

Given: Required rise A-B, and required span A-C. *Problem*: Construct a parabola within the required rise and span, Figure 3-55A.

Step 1. Divide half the span distance A-0 into any number of equal parts. (In this example, 4 equal parts are used.) See Figure 3-55B. Divide half the rise A-B into equal parts amounting to the square of the equal parts in Step 1 (in this example, $4^2 = 16$ equal parts).

Step 2. From line A-0, each point on the parabola is offset by a number of units equal to the square of the numbers of units from point 0, see Figure 3-55C. For example, point 1 projects 1 unit; point 2 projects 4 units; point 3 projects 9 units, and so forth.

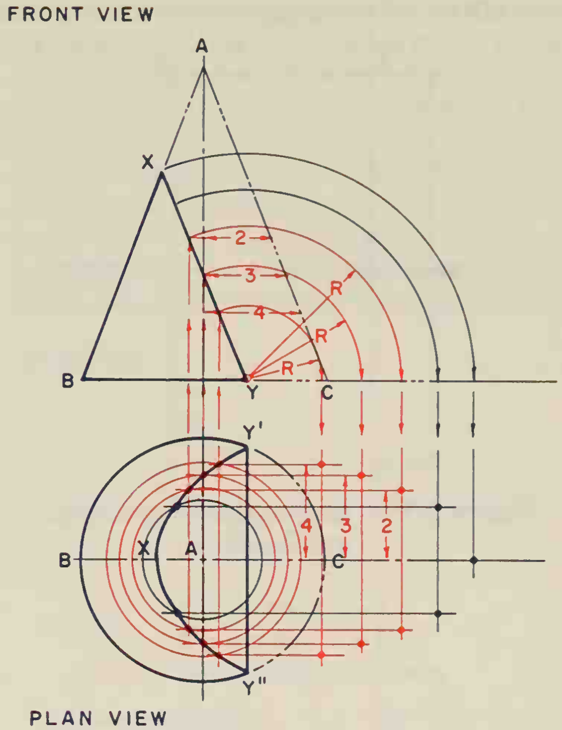


Figure 3-54D Step 3

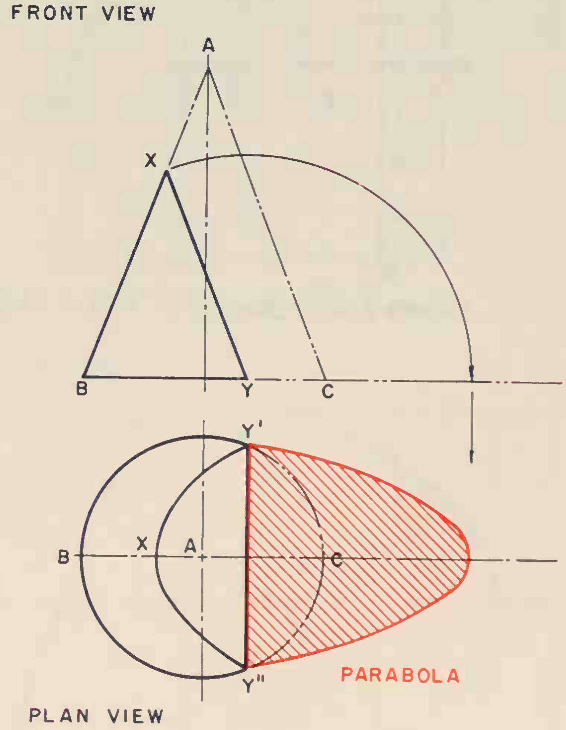


Figure 3-54E Step 4

Step 3. Using an irregular curve, connect the points to form a smooth parabolic curve, Figure 3-55D.

How To Find the Focus Point of a Parabola

Given: A parabolic curve with points A, 0, and B, Figure 3-56A. *Problem*: Find the focus point of the parabola A0B.

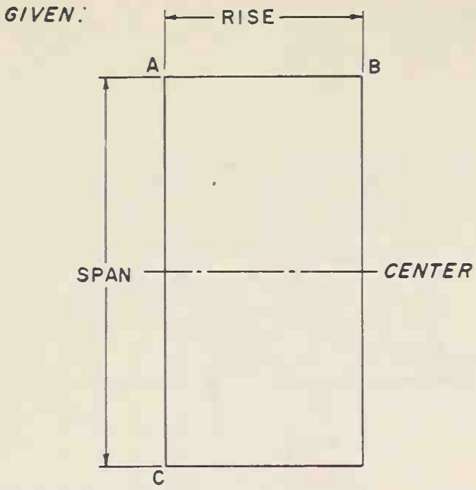


Figure 3-55A How to draw a parabola (method 2)

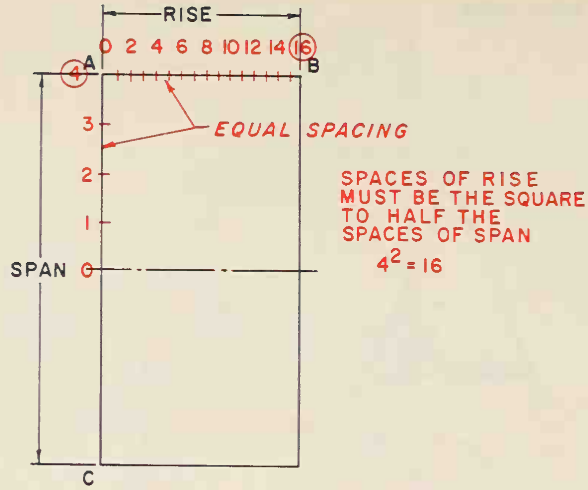


Figure 3-55B Step 1

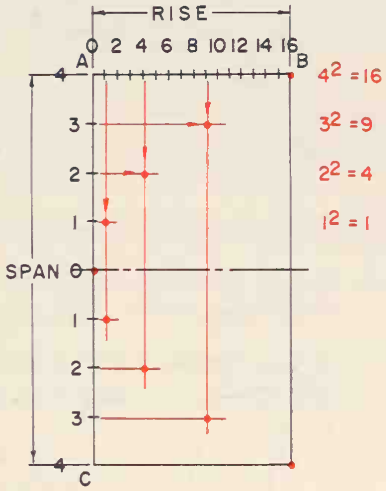


Figure 3-55C Step 2

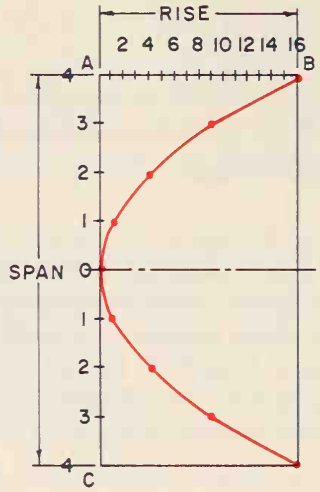


Figure 3-55D Step 3

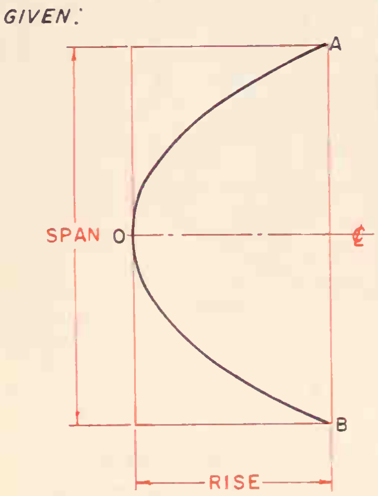


Figure 3-56A How to find a focus point of a parabola

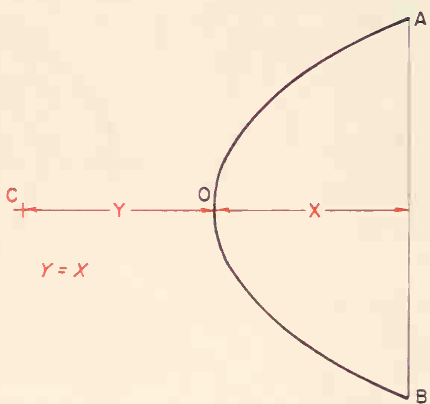


Figure 3-56B Step 1

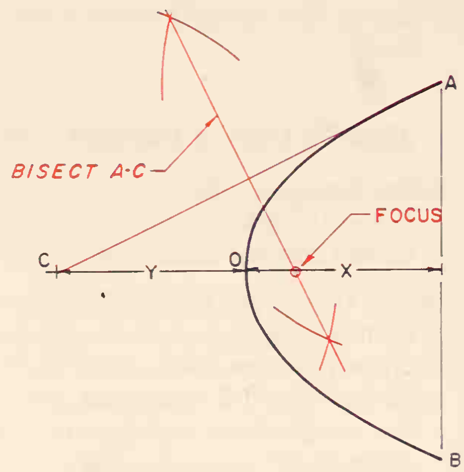


Figure 3-56C Step 2

Step 1. Draw a line from point A to point B. Continue the center line to a point equal to length X, distance Y, to find point C, Figure 3-56B.

Step 2. Draw a line from point C to point A and bisect it. The intersection of the bisect line and the axis is the focus of the parabola, Figure 3-56C.

How To Draw a Hyperbola (Method 1)

Given: The front view and plan view of cone ABC with cutting plane X-Y, Figure 3-57A.

Step 1. Locate points Y' and Y'' in the plan view. In the front view, place the point of the compass on point Y and set the lead to point X. Swing point X to the extended baseline and down to the plan view, as illustrated in Figure 3-57B.

Step 2. Locate a point along line X-Y (in this example, point D). Using Y as a swing point, swing point D to the extended baseline and down into the plan view. In the front view, reset the compass to a distance equal to the horizontal distance from the cone axis to the outer edge (length 1), as illustrated in Figure 3-57C. Transfer the arc to the plan view; where the arc intersects with the cutting plane line X-Y, project to the right, and where these points inter-

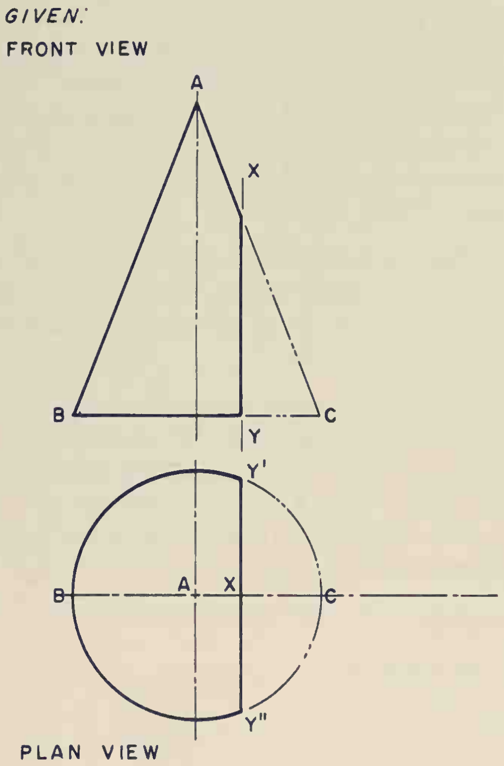


Figure 3-57A How to draw a hyperbola (method 1)

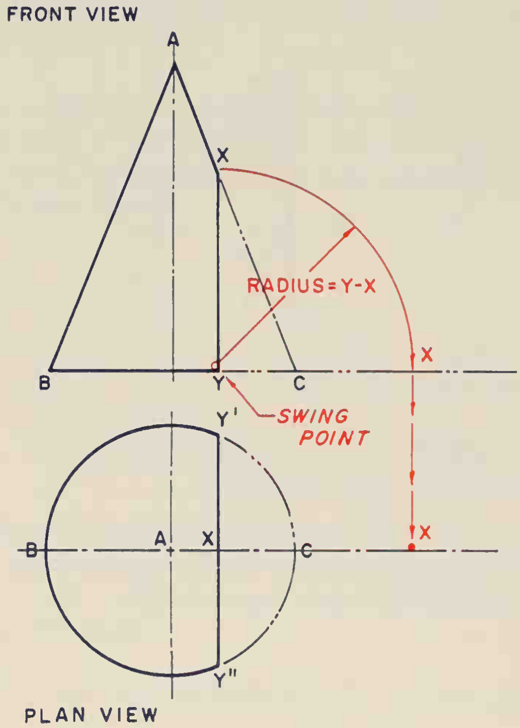


Figure 3-57B Step 1

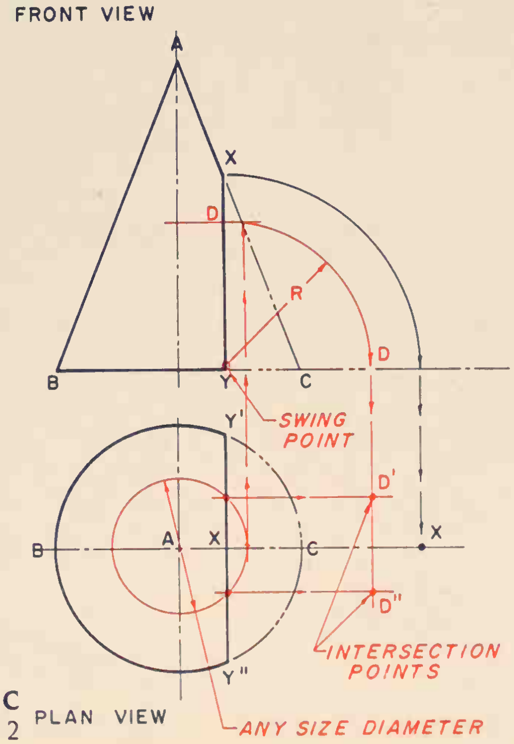


Figure 3-57C
Step 2

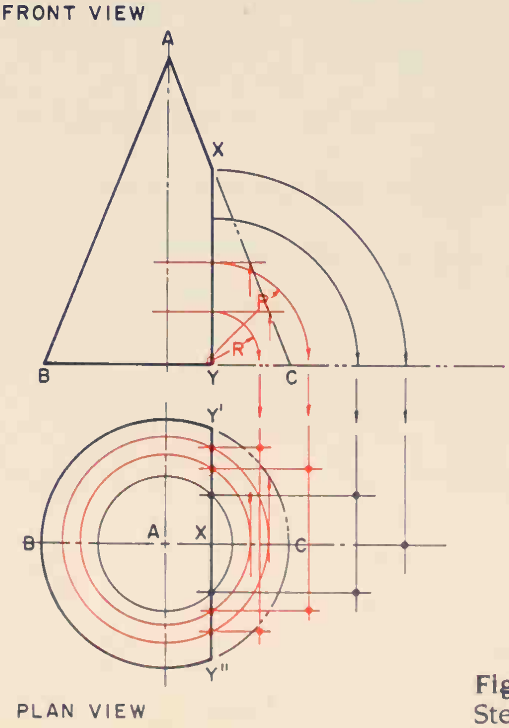


Figure 3-57D
Step 3

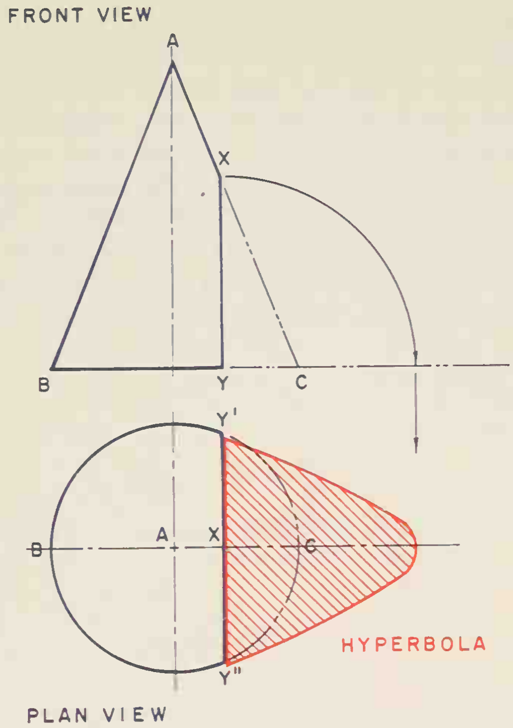


Figure 3-57E Step 4

sect with point D from above is the actual location of points D′ and D″.

Step 3. Choose other points along line X-Y in the front view and project them over and down as described in Step 2, Figure 3-57D.

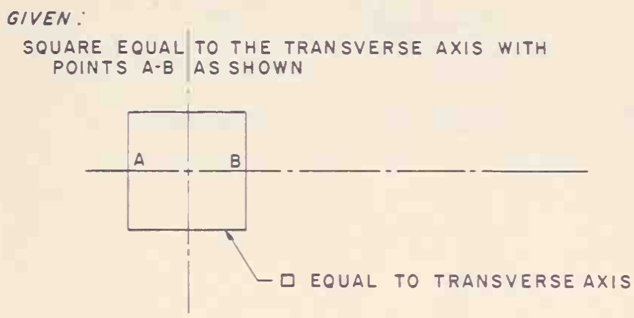


Figure 3-58A How to draw a hyperbola (method 2)

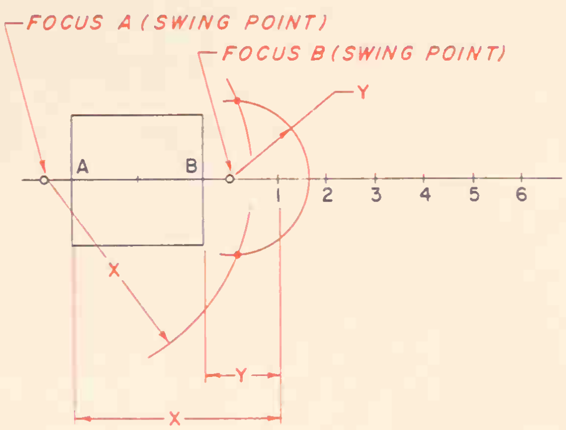


Figure 3-58C Step 2

Step 4. Using an irregular curve, connect all points. This completes the parabola, Figure 3-57E.

How To Draw a Hyperbola (Method 2)

Given: Coordinates, a square whose sides equal the transverse axis, and points A and B, Figure 3-58A.

Step 1. With the center at the intersection of the diagonal lines from opposite corners of the square, place the compass lead at the corner of the given square and swing arcs to intersect the horizontal line through the center. This locates focus A and focus B. Progressing outward along the horizontal line, mark off equal spaces of arbitrary length from the focus points, Figure 3-58B.

Step 2. Set the compass at dimension X (A-1) and swing an arc from focus A. Set the compass at dimension Y (B-1) and swing an arc from focus B. See Figure 3-58C.

Step 3. Follow the same procedure for as many points as are required (in this example, 6 points). Set the compass at distance A-2 and swing from focus A. Set the compass at distance B-2 and swing from focus B, and so on, Figure 3-58D.

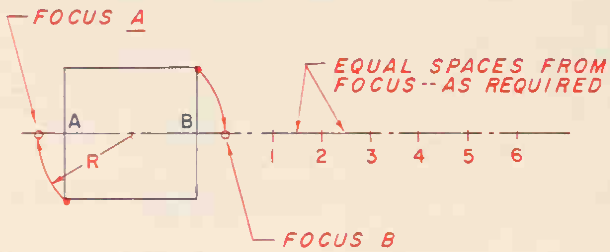


Figure 3-58B Step 1

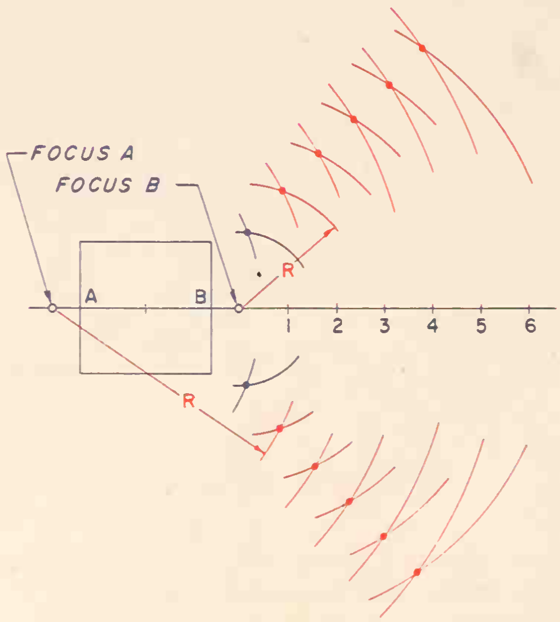


Figure 3-58D Step 3

Step 4. Using an irregular curve, carefully complete the hyperbola curve, Figure 3-58E.

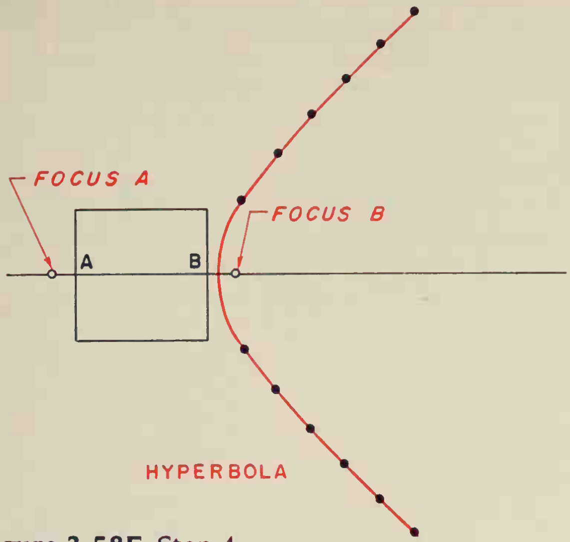


Figure 3-58E Step 4

How To Join Two Points by a Parabolic Curve

Given: Points X and Y with 0 an assumed point of tangency, Figures 3-59A, 3-59B, and 3-59C.

Step 1. Divide line X-0 into an equal number of parts; divide 0-Y into the exact same number of equal parts. See Figures 3-59D, 3-59E, and 3-59F.

Step 2. Connect corresponding points, Figures 3-59G, 3-59H, and 3-59I. Using an irregular curve, draw the parabolic curve as a smooth flowing curve.

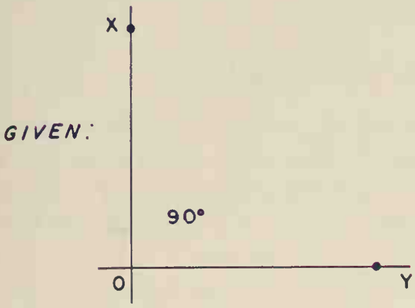


Figure 3-59A How to join two points by a parabolic curve (given: 90° angle)

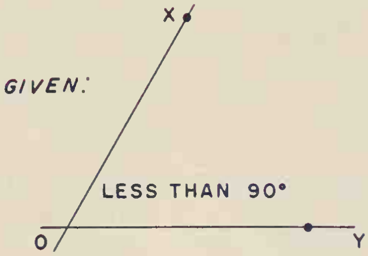


Figure 3-59B Given: Less than 90° angle

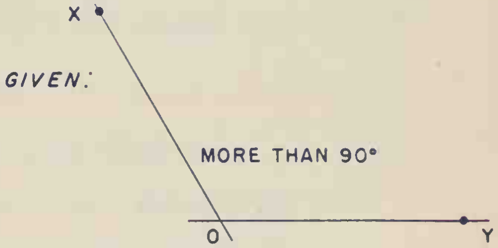


Figure 3-59C Given: More than 90° angle

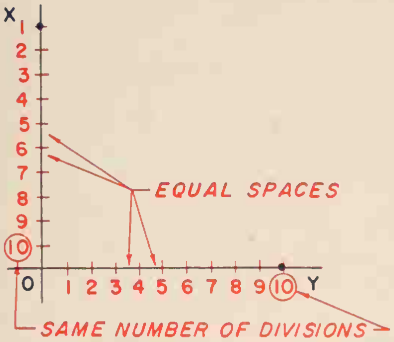


Figure 3-59D Step 1

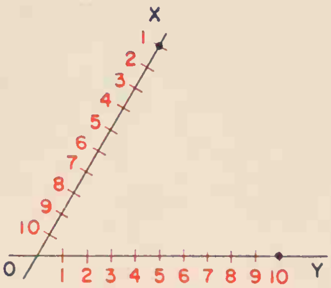


Figure 3-59E Step 1

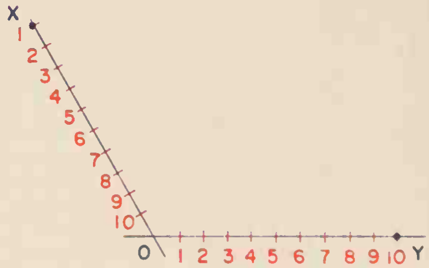


Figure 3-59F Step 1

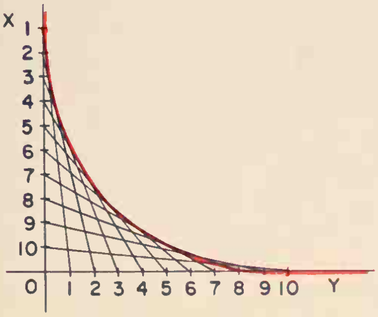


Figure 3-59G Step 2

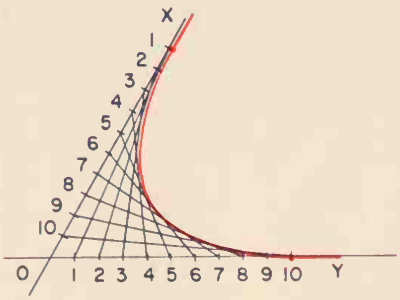


Figure 3-59H Step 2

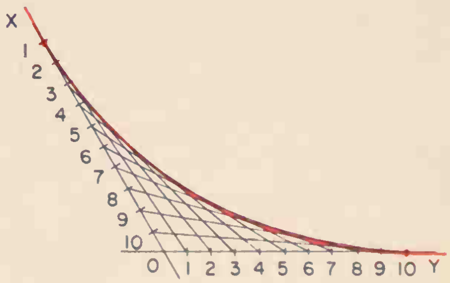


Figure 3-59I Step 2

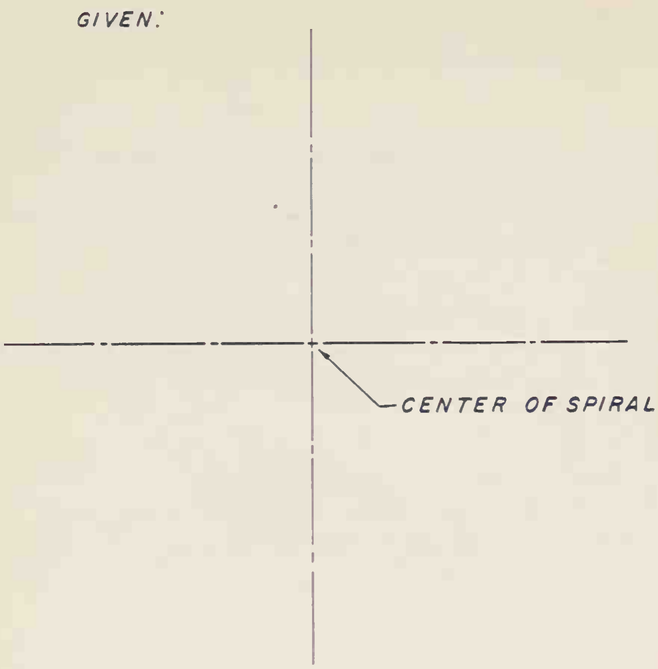


Figure 3-60A How to draw a spiral

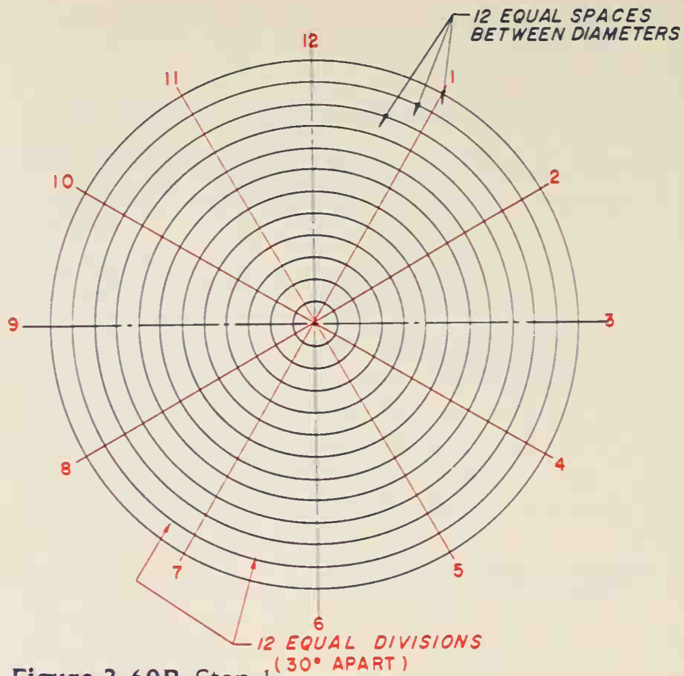


Figure 3-60B Step 1

Supplementary Construction

How To Draw a Spiral

Given: Crossed axes, Figure 3-60A.

Step 1. Divide the circle into equal angles (in this example, 30°). Set the compass at a required radius and draw various diameters to suit, evenly spaced, as illustrated in Figure 3-60B.

Step 2. Starting any place along the angles, step over one angle and up one diameter until the required spiral is completed, Figure 3-60C.

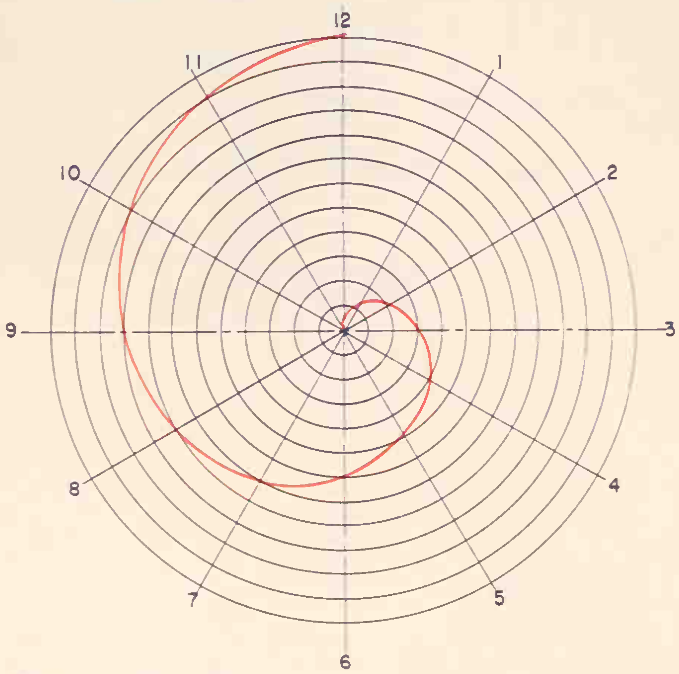


Figure 3-60C Step 2

How To Draw a Helix

A *helix*, a form of spiral, is used in screw threads, worm gears, and spiral stairways, to mention but a few uses. A helix is generated by moving a point around and along the surface of a cylinder with uniform angular velocity about its axis. A *cylindrical helix* is simply known as a helix, and the distance measured parallel to the axis traversed by a point in one revolution is called the *lead*.

Given: The top and front views of a cylinder with a required lead, Figure 3-61A.

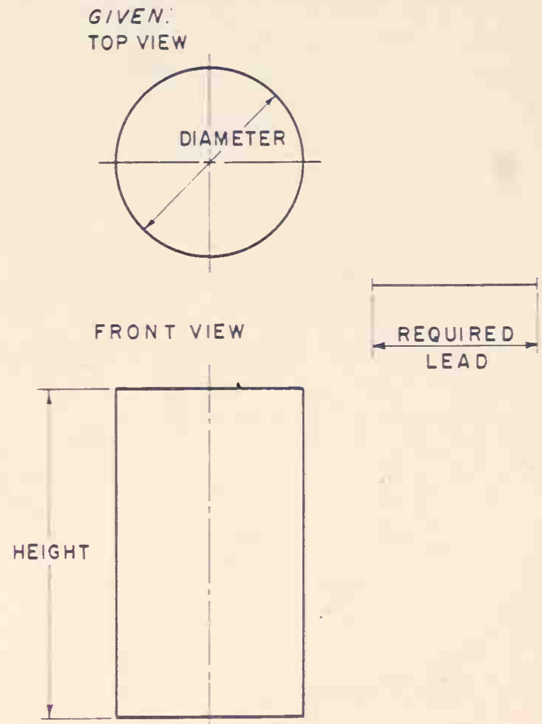


Figure 3-61A How to draw a helix

Step 1. Divide the top view into an equal number of spaces (12 in this example). Draw a line equal to one revolution and/or circumference, project the lead distance from the end, and label all points per illustration 3-61B.

Step 2. Divide the circumference into the same amount of equal spaces, and project each from the inclined line to the corresponding point projected from the front view, Figure 3-61C.

Step 3. Connect all points of the helix, and draw as hidden lines the lines that would disappear from view on an actual helix form, Figure 3-61D.

Notice that a right-hand helix is illustrated. To construct a left-hand helix, simply project all the points in the opposite direction, Figure 3-61E.

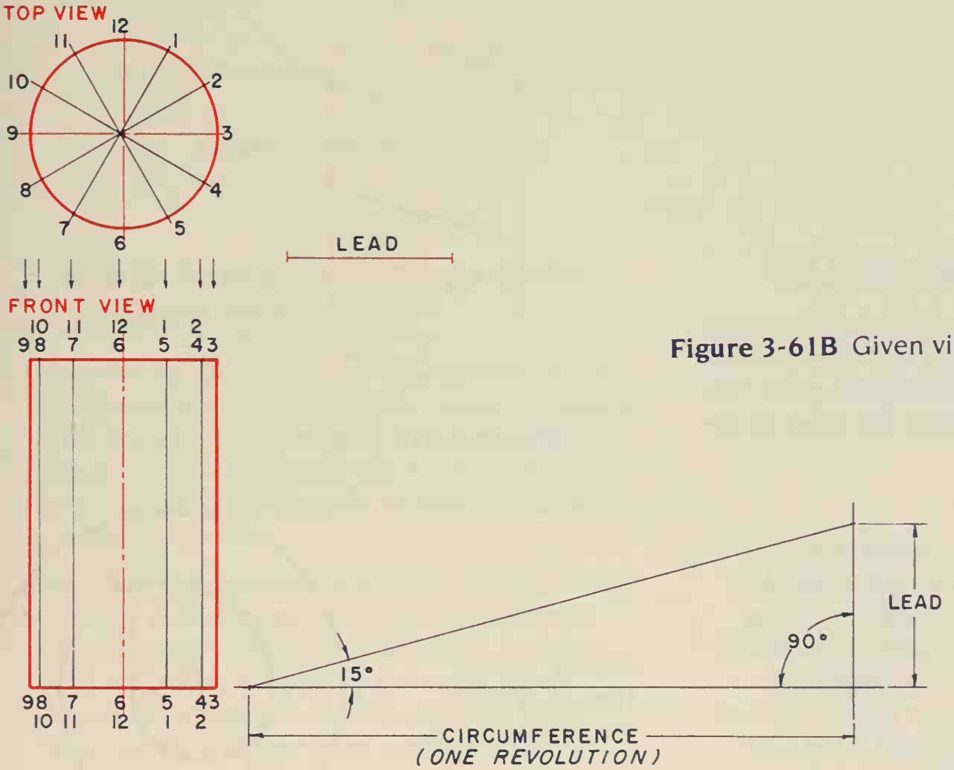


Figure 3-61B Given views

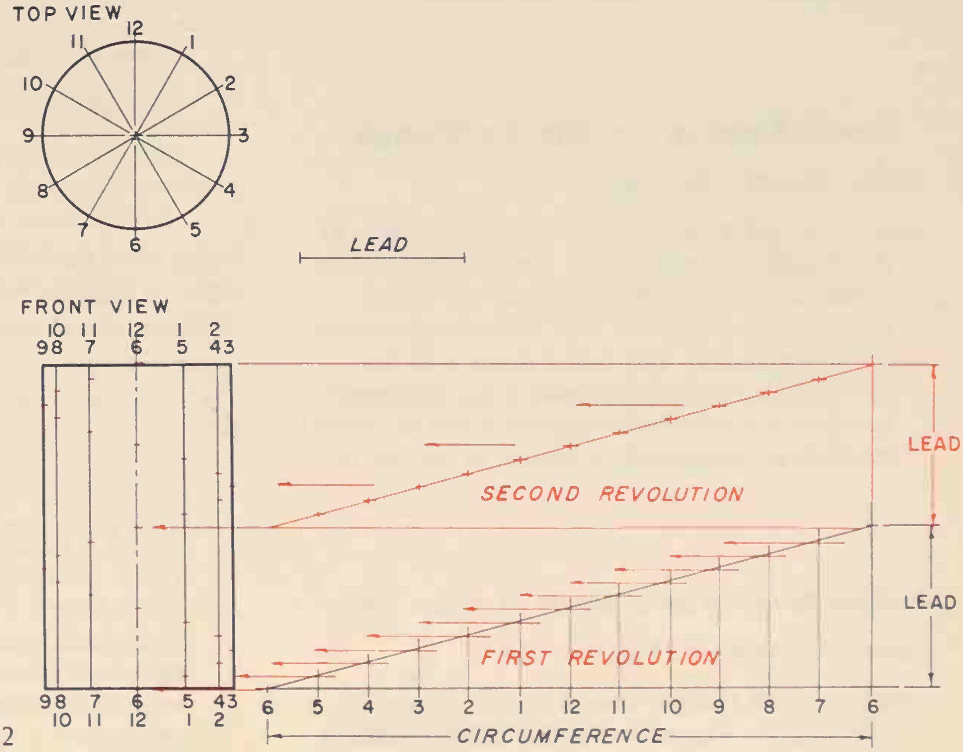


Figure 3-61C Steps 1 and 2

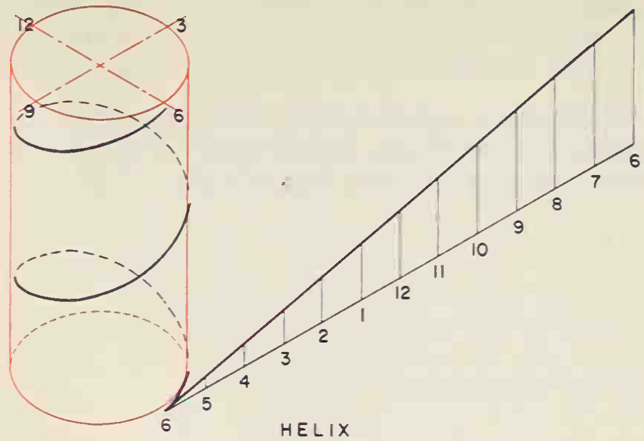


Figure 3-61D Step 3

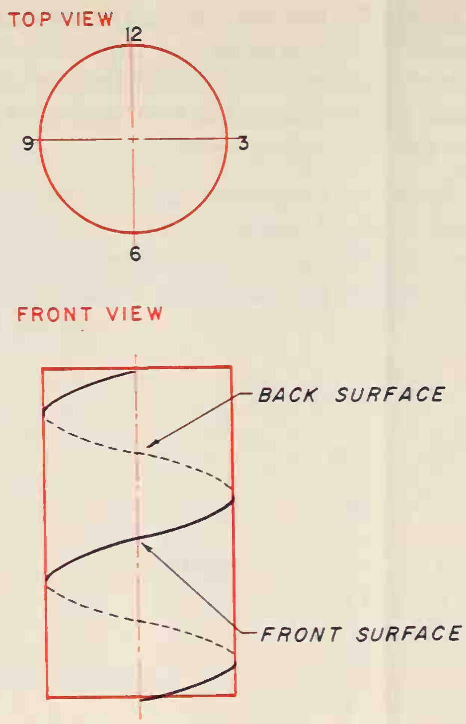


Figure 3-61E Step 4

How To Draw an Involute of a Line

The curved path of a point on a string as it unwinds from a line, a triangle, a square or a circle is an *involute*. The involute is used to construct involute gears. The involute forms the face and part of the flank of the teeth of the gear.

Given: Line A-B, Figure 3-62A.

Step 1. Extend line A-B, as illustrated in Figure 3-62B. Set the compass at the length A-B, and, using point B as the swing point, swing semicircle A-C. With the compass set at length A-C, and, using point A as the swing point, swing semicircle A-D. Continue in this manner, alternating between points A and B until the required involute is completed, as shown in the figure.

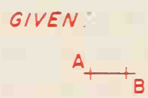


Figure 3-62A
How to draw an involute of a line

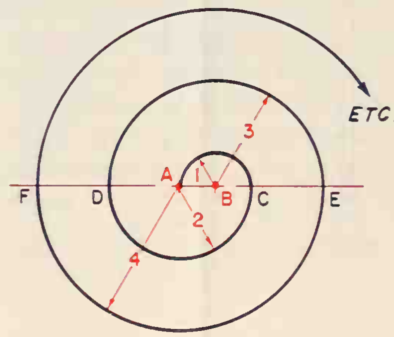


Figure 3-62B Step 1

How To Draw an Involute of a Triangle

Given: Triangle ABC, Figure 3-63A.

Step 1. Extend straight lines from the triangle, as illustrated in Figure 3-63B. Set the compass at length A-C, and, using point A as the swing point, swing semicircle A-C. With the compass set at length B-D, and, using point B as the swing point, swing semicircle B-E. Continue similarly around the triangle until the required involute is completed, as shown in the figure.

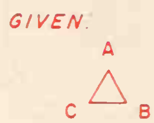


Figure 3-63A
How to draw an involute of a triangle

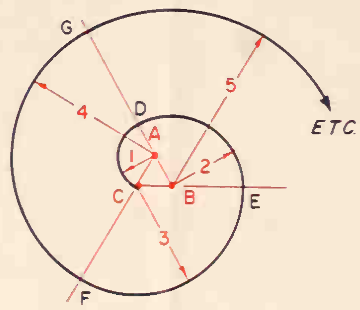


Figure 3-63B Step 1

How To Draw an Involute of a Square

Given: Square ABCD, Figure 3-64A.

Step 1. Extend straight lines from the square, as illustrated in Figure 3-64B. Set the compass at length A-B, and using point A as the swing point, swing semicircle A-E. With the compass set at length B-E, and, using point B as the swing point, swing semicircle B-F. Continue in the same manner around the square until the required involute is completed, as shown in the figure.

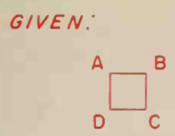


Figure 3-64A How to draw an involute of a square

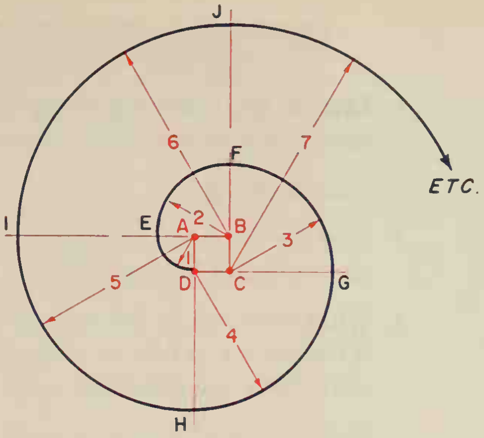


Figure 3-64B Step 1

Figure 3-65A How to draw an involute of a circle

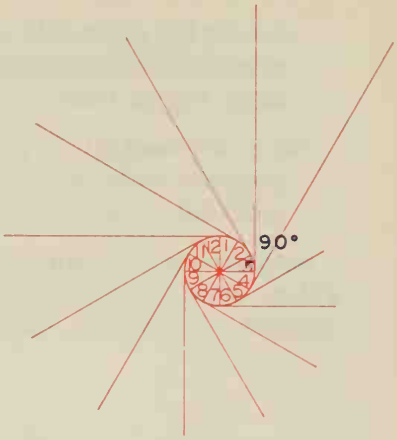


Figure 3-65B Step 1

How To Draw an Involute of a Circle

Given: Circle A, Figure 3-65A.

Step 1. Divide the circle into a number of equal parts and number each point clockwise around the circle (in this example, 12 equal parts). Project a line perpendicular to the radius at each point in a clockwise direction, Figure 3-65B.

Step 2. Set the compass at length 1-2, and, using point 2 as the swing point, swing semicircle 1-2. With the compass set at length 1-2 plus 2-3, and, using point 3 as the swing point, swing semicircle 1-3. Continue in the same manner around the circle until the required involute is completed, as shown in Figure 3-65C.

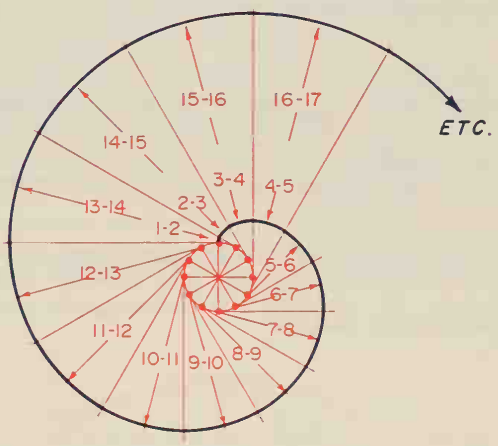


Figure 3-65C Step 2

How To Draw a Cycloidal Curve

Given: A required span of a cycloid.

Step 1. As the span represents the rolling distance of one revolution of a diameter, divide the span length by pi to find the required diameter. Divide the span into an equal number of divisions. Twelve is a convenient number, Figure 3-66A.

Step 2. Draw the rolling diameter tangent to the given span at point 0/12. Divide this diameter into the same number of equal spaces as done in the Step 1 span division. Consecutively number the radial end points of these divisions to make them meet their corresponding number of the span divisions as the diameter rolls along the span, Figure 3-66B.

Step 3. At each span division draw the rolling diameter tangent to the span in the rolled position, with the division numbers of span and diameter matching at their contact point.

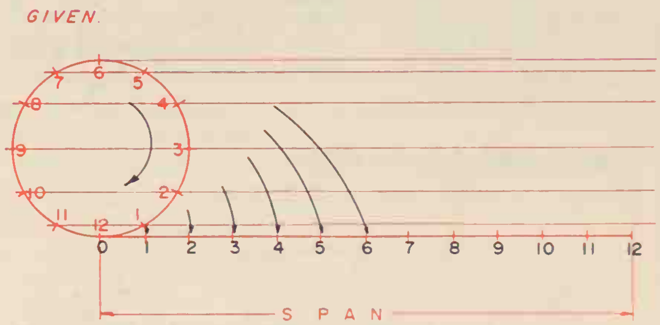


Figure 3-66A How to draw a cycloidal curve (Step 1)

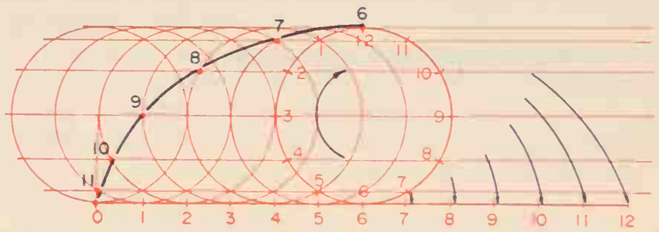


Figure 3-66B Step 2

Locate the point 0/12 position on the diameter at each of these locations, marked with a small cross, Figure 3-66C.

Step 4. Connect all the point 1 diameter division positions with a smooth curve to complete the cycloidal curve, Figure 3-66D.

Note: If the given span is a concave arc, a *hypocycloid* will be drawn, Figure 3-67. If the span is convex, an *epicycloid* will be drawn, Figure 3-68.

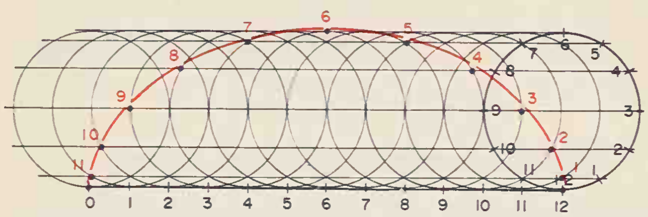


Figure 3-66C Step 3

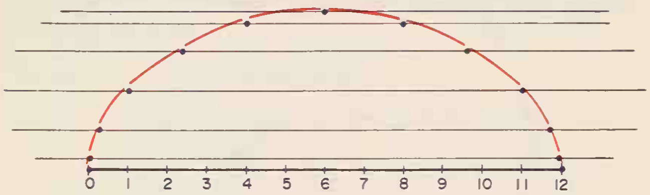


Figure 3-66D Step 4

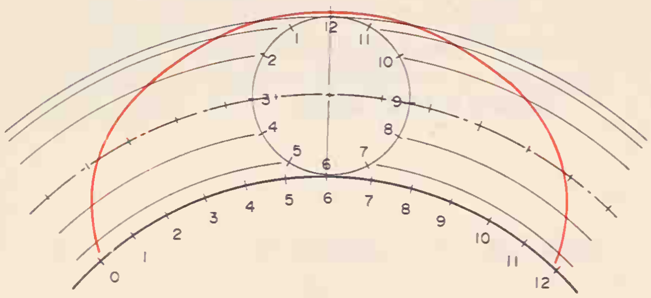


Figure 3-67 A hypocycloid

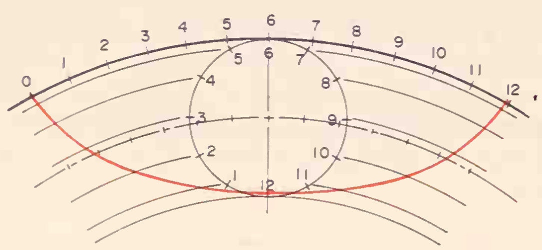


Figure 3-68 An epicycloid

Review

1. Explain the following terms:
   right angle, acute angle, obtuse angle
2. List six polygons.
3. Why are geometric construction procedures so important to the drafter?
4. What is meant by the term *tangent*, and why is it important to find all tangent points before darkening in a drawing?
5. Explain the following parts of a circle:
   central angle, sector, quadrant, segment
6. Explain the difference between a concentric circle and an eccentric circle.
7. How is an actual point in space represented on a drawing?
8. Completely describe an angle.
9. List five kinds of triangles.
10. What is meant by the circumference of a circle, and how is it calculated?
11. What is the sum of the three internal angles of a triangle?
12. Define a *line*.

Chapter Three Problems

The following problems are intended to give the beginning drafter practice in using the many geometric construction techniques used to develop drawings. Accuracy, line work, neatness, speed, and centering are stressed. It is recommended that dimensions not be added to problems at this time. The beginning drafter should practice using drafting instruments and correct line thicknesses, and should concentrate on developing good drafting habits.

The steps to follow in laying out all drawings throughout this book are:

Step 1. All geometric construction work should be made very accurately using a sharp 4-H lead.

Step 2. All geometric construction work must be laid out very lightly.

Step 3. Do not erase construction lines. If constructed lightly, they will not be seen on the whiteprint copy.

Step 4. Make a rough sketch of each problem before beginning to calculate the overall shape.

Step 5. Lightly draw each problem completely, first.

Step 6. Locate *all* tangent points as you proceed. Make short light dashes at each tangent point.

Step 7. Try to center the problem in the work area.

Step 8. Check each dimension for accuracy.

Step 9. Darken in the drawing using the correct line thickness and the following steps:

- Locate and draw all center lines with a thin black line.
- Darken in all diameters using a compass.
- Darken in all radii using either a compass or a circle template.
- Darken in all horizontal lines, either from right to left or from left to right.
- Recheck all dimensions.
- Check all lines for correct thickness.
  Fill out the title block using light guidelines and neat lettering.

Problem 3-1

Divide the work area into four equal spaces. In the upper left-hand space, draw an inclined line 3.25 long. Bisect this line. Show all construction lines lightly.

In the upper right-hand space, draw an acute angle with intersecting lines, each approximately 2.75 long. Bisect this angle. Show all light construction lines.

In the lower left-hand space, draw an inclined line 2.88 long. Divide this line into 5 spaces. Show all light construction lines.

In the lower right-hand space, draw an inclined line 3.125 long. Divide this line into three proportional parts 2, 3, and 4. Show all light construction lines.

Problem 3-2

Divide the work area into four equal spaces. In the center of the upper left-hand space, draw an equilateral triangle having sides of 2.0. Bisect the interior angles. Show all light construction lines.

In the center of the upper right-hand space, draw a square having sides of 2.0. Show all light construction lines.

In the center of the lower left-hand space, draw a hexagon having the distance of 2.0 across the flats. Show all light construction lines.

In the center of the lower right-hand space, draw an octagon having the distance of 2.0 across the flats. Show all light construction lines.

Problem 3-3

Divide the work area into four equal spaces. In the upper left-hand space, draw two lines intersecting at 60° and draw an arc with a .88 radius tangent to the two lines. Show all light construction lines.

In the upper right-hand space, draw two lines intersecting at 120° and draw an arc with a .625 radius tangent to the two lines. Show all light construction lines.

In the lower left-hand space, draw two lines intersecting at 90° and draw an arc with 1.25 radius tangent to the two lines. Show all light construction lines.

In the lower right-hand space, draw an ellipse with a major diameter of 3.00 and a minor diameter of 1.75.

Problem 3-4

Divide the work area into four equal spaces. In the upper left-hand space, center a line 10 mm long and label it line A-B. Construct a straight line involute with five arcs.

In the upper right-hand space, center a triangle with sides equal to .25 and label the triangle ABC. Construct a triangular involute with five arcs.

In the lower left-hand space, center a square with sides equal to 10 mm and label the square ABCD. Construct a square involute with five arcs.

In the lower right-hand space, center a circle with a diameter of 1.00. Construct a circle involute with as many arcs as space will allow.

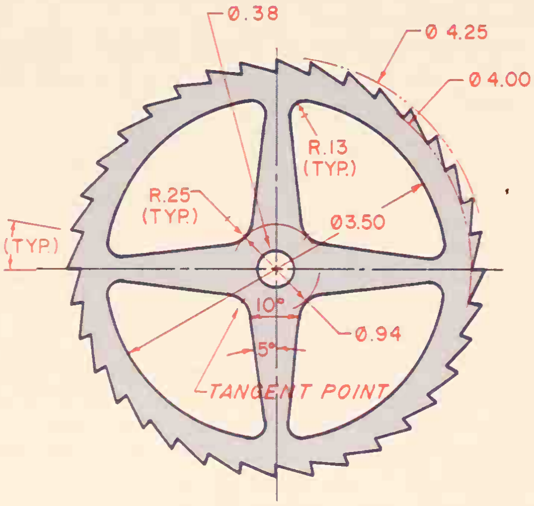
Problem 3-5

Divide the work area into four equal spaces. In the center of the upper left-hand space draw a spiral with 30° spaces, at 4 mm increments, for one 360° rotation.

In the center of the upper right-hand space, draw two lines at right angles intersecting a point 0. One line is to be 3.5 long, and the other 2.5 long. Draw a parabolic curve between these two lines.

In the center of the lower left-hand space, draw a rectangle 2.0 x 4.50 in size. Label the 2.0 side as the rise, and the 4.50 as the span. Construct a parabola (Method 2), and locate the focus point.

In the center of the lower right-hand space, draw a line 80 mm long, and label its end points as A and B. Locate a point on line A-B at 5/8 of the line's length from point A. Label the point X.



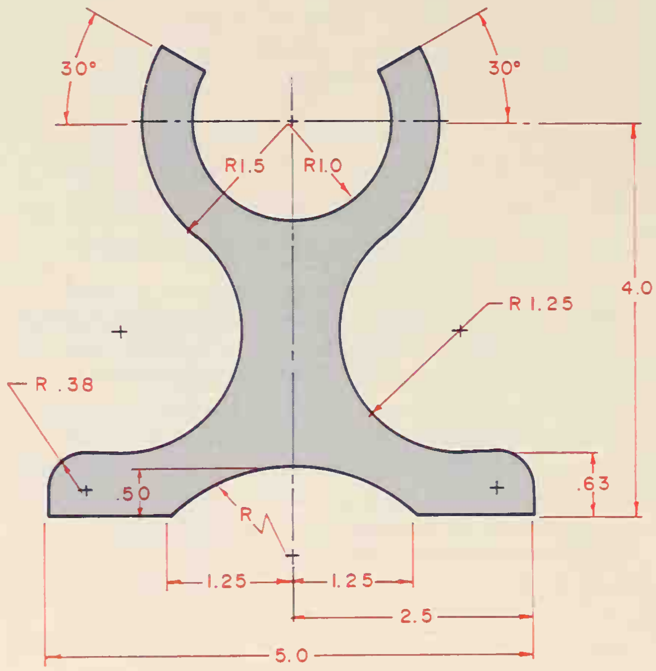
Problem 3-6

Problems 3-6 through 3-19

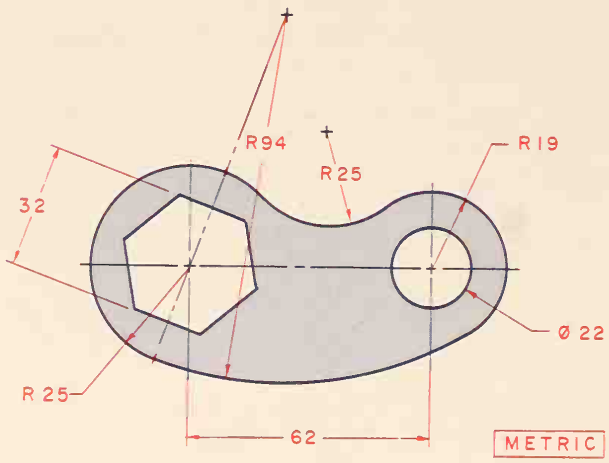
Using the art for problems 3-6 through 3-19, center each object within the work area using correct line thickness. Do not erase all light construction lines.

Locate and draw a light short dash at all tangent points.

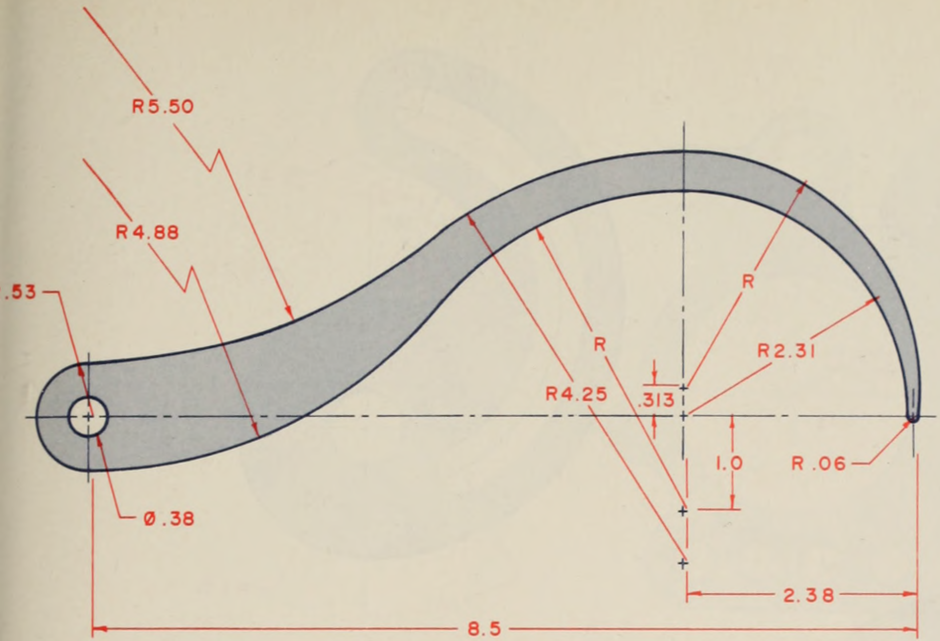
Do not dimension objects.



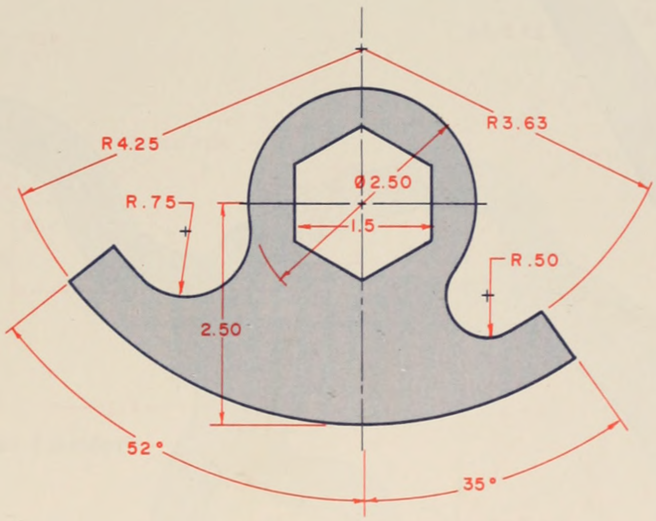
Problem 3-7



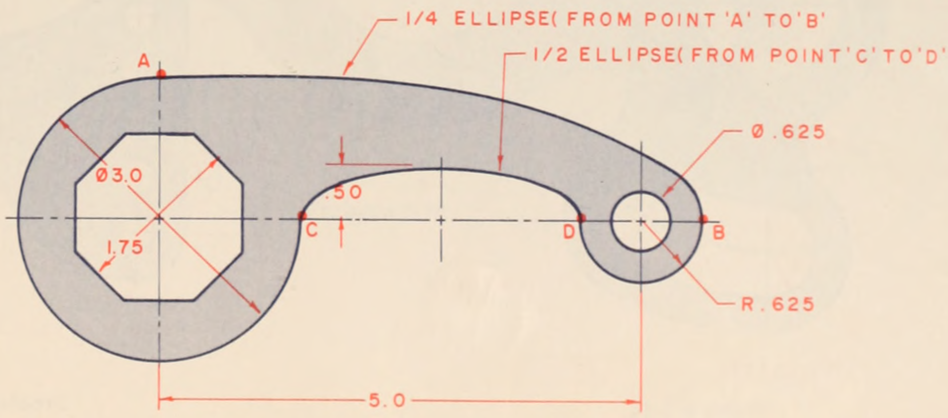
Problem 3-8



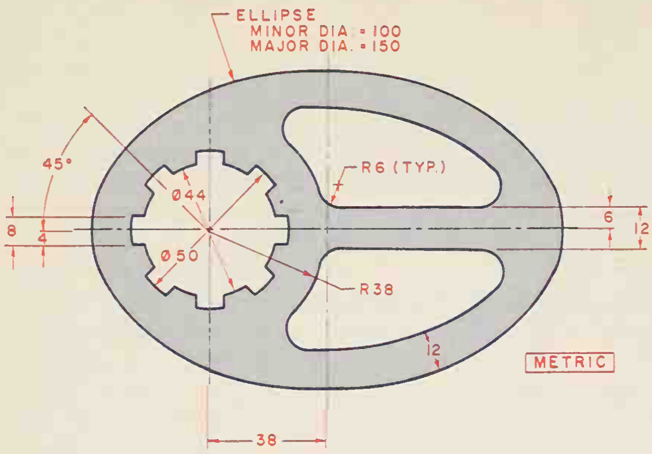
Problem 3-9



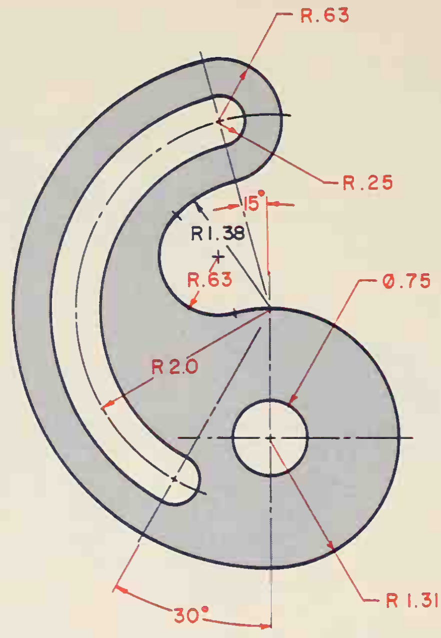
Problem 3-10



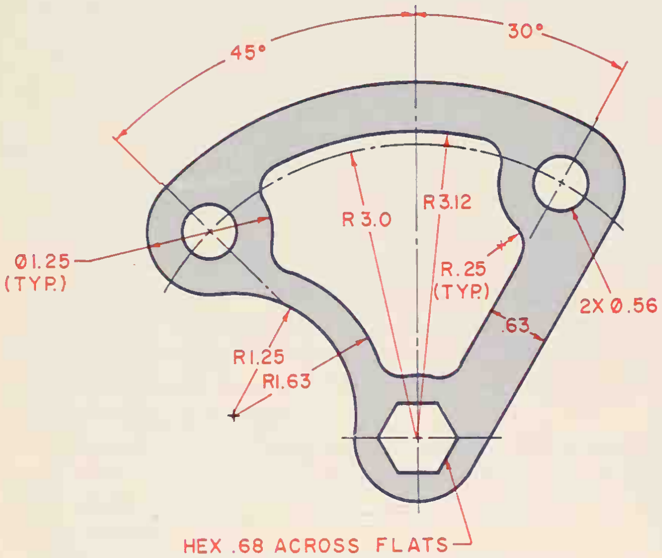
Problem 3-11



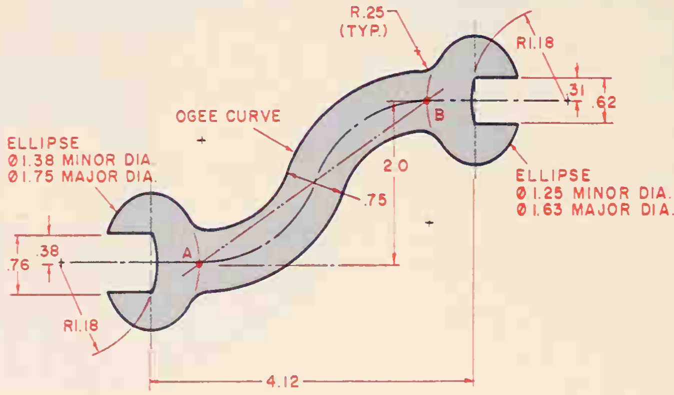
Problem 3-12



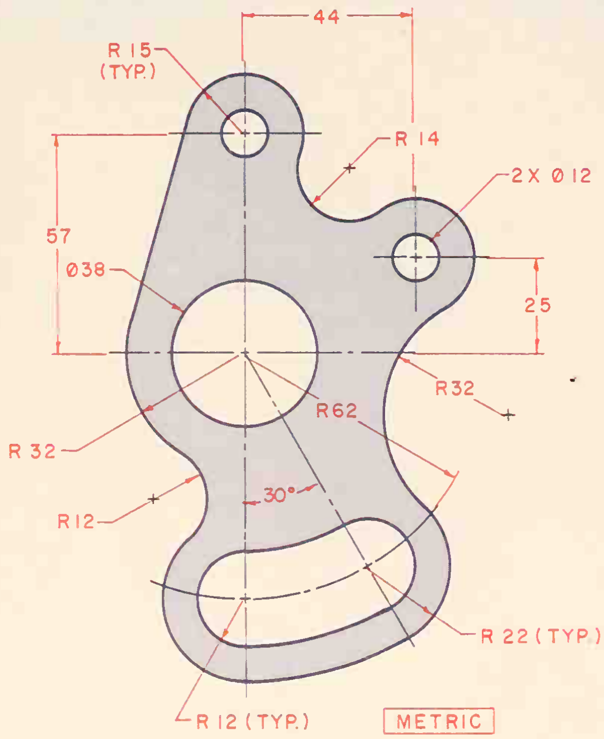
Problem 3-15



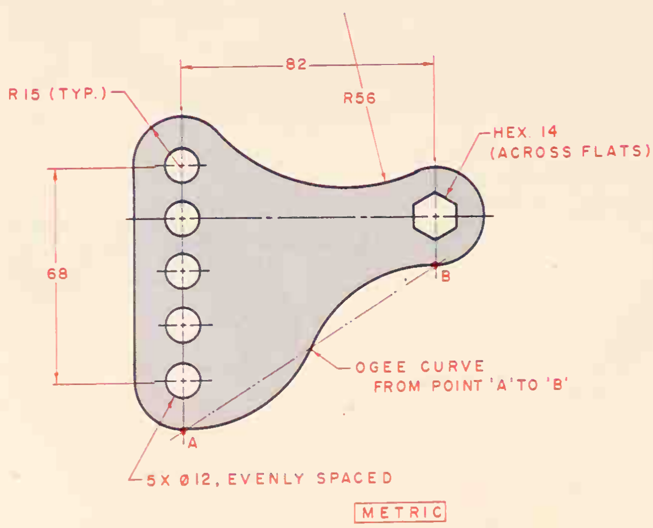
Problem 3-13



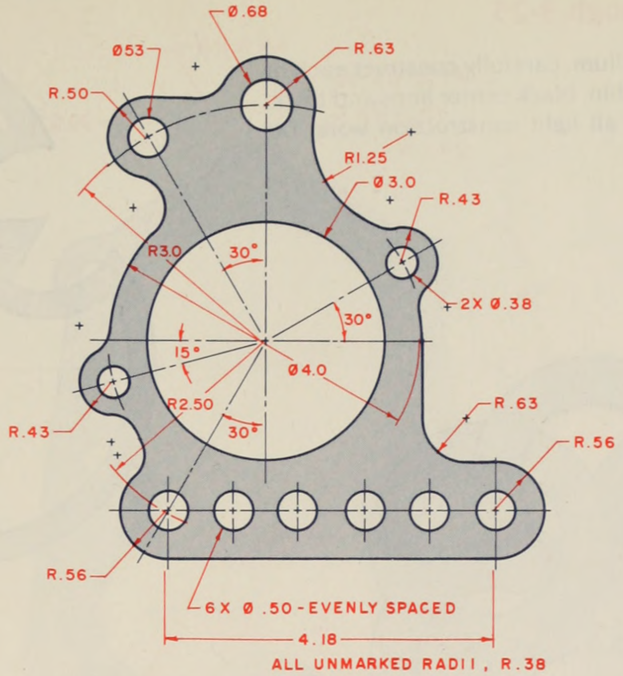
Problem 3-16



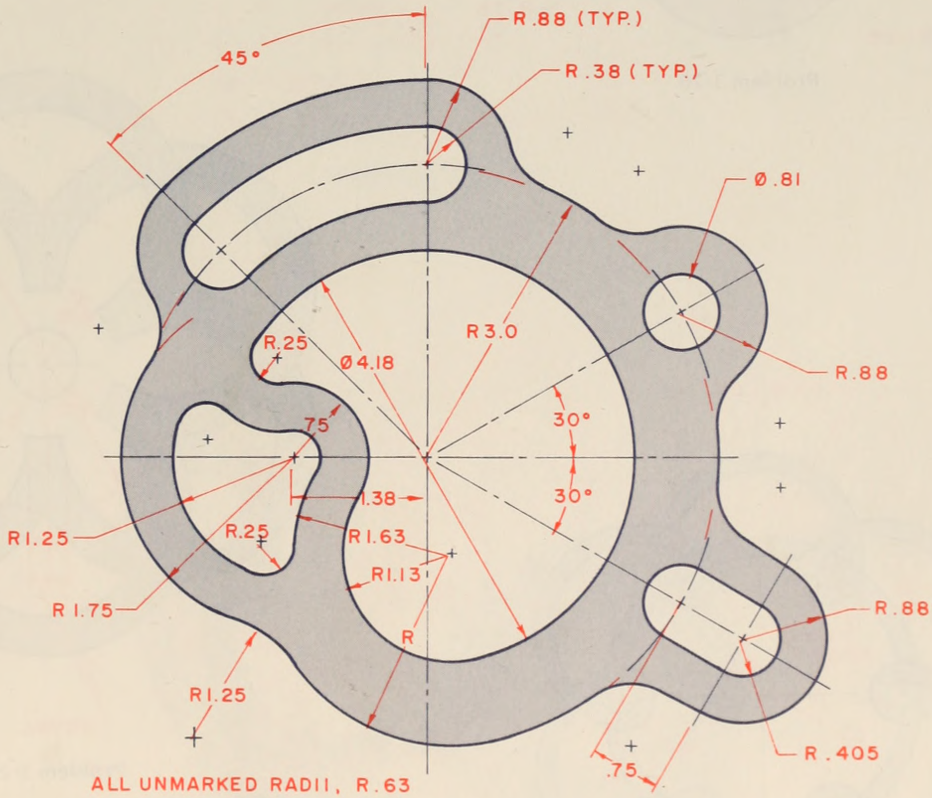
Problem 3-14



Problem 3-17



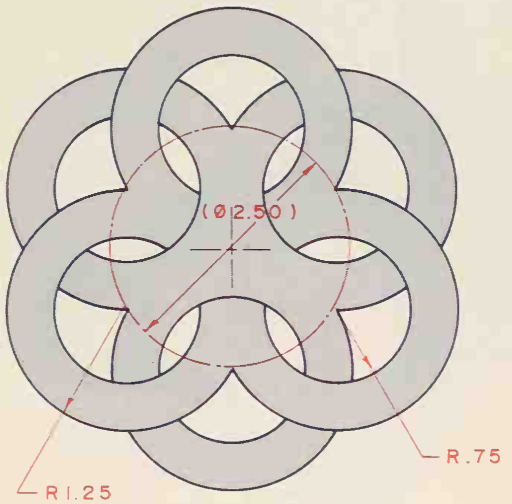
Problem 3-18



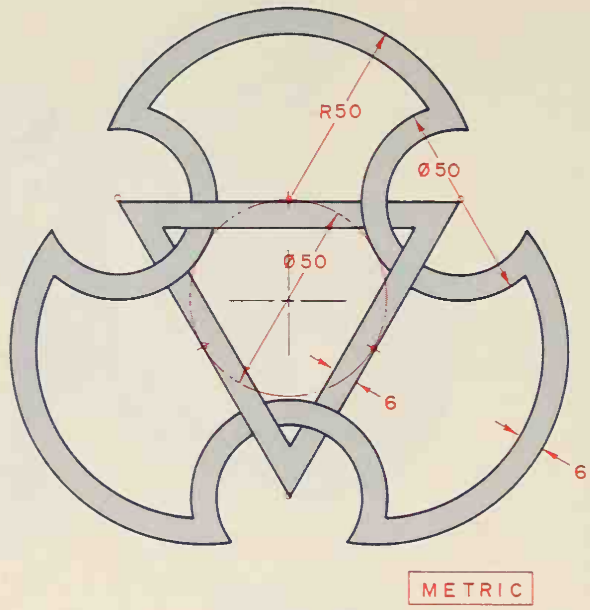
Problem 3-19

Problems 3-20 through 3-25

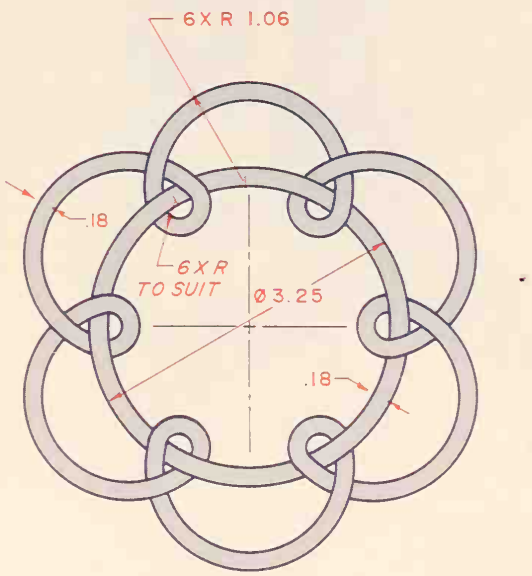
On an A-size sheet of vellum, carefully construct each of the assigned figures. Use thin, black center lines and thick, black object lines. Leave all light construction work. Do not add dimensions.



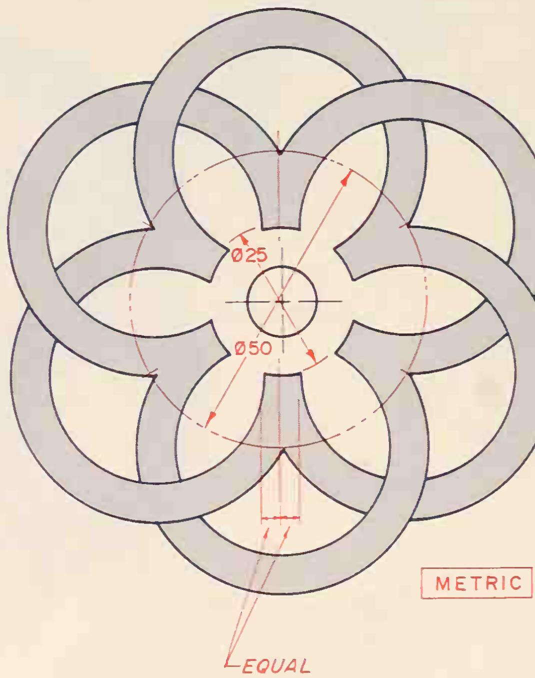
Problem 3-20



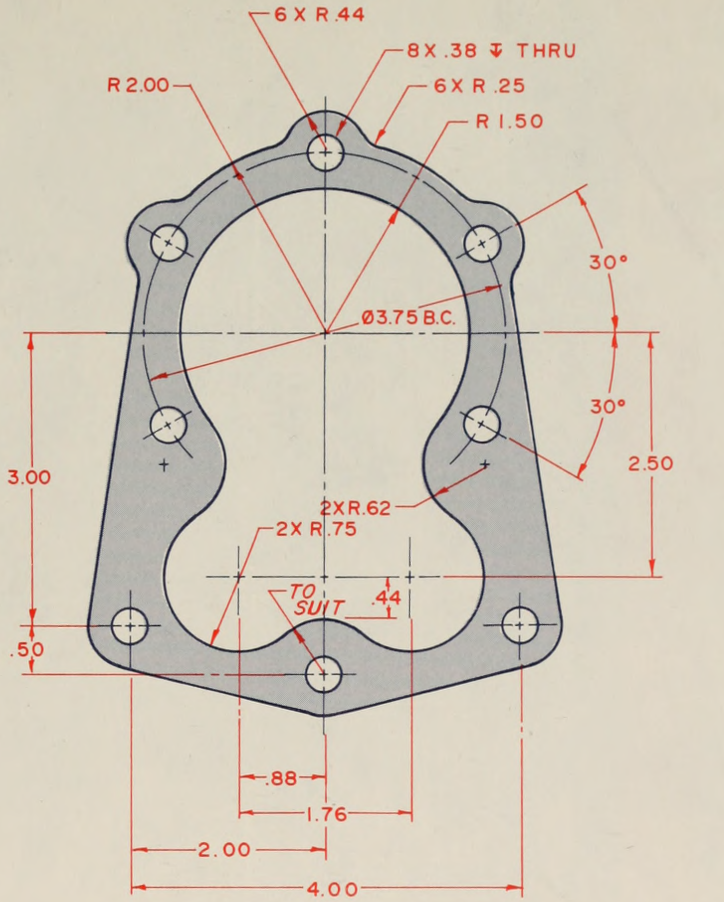
Problem 3-22



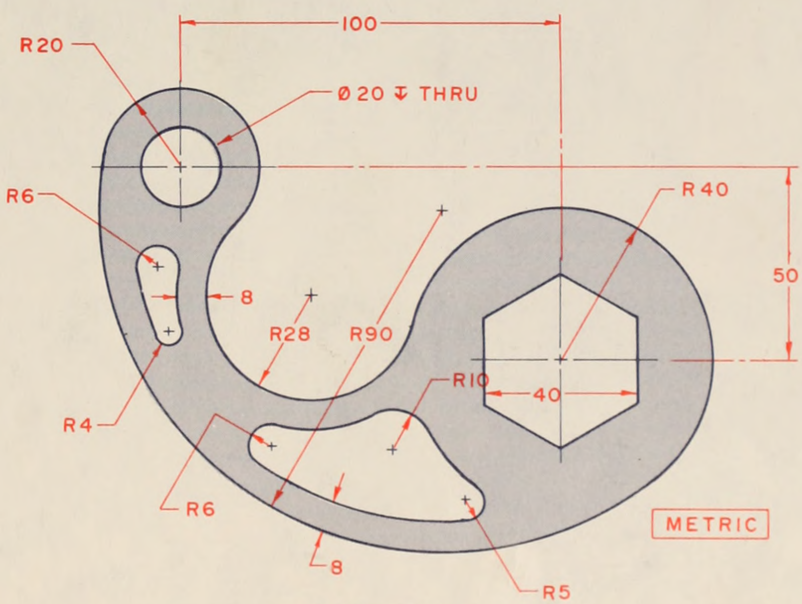
Problem 3-21



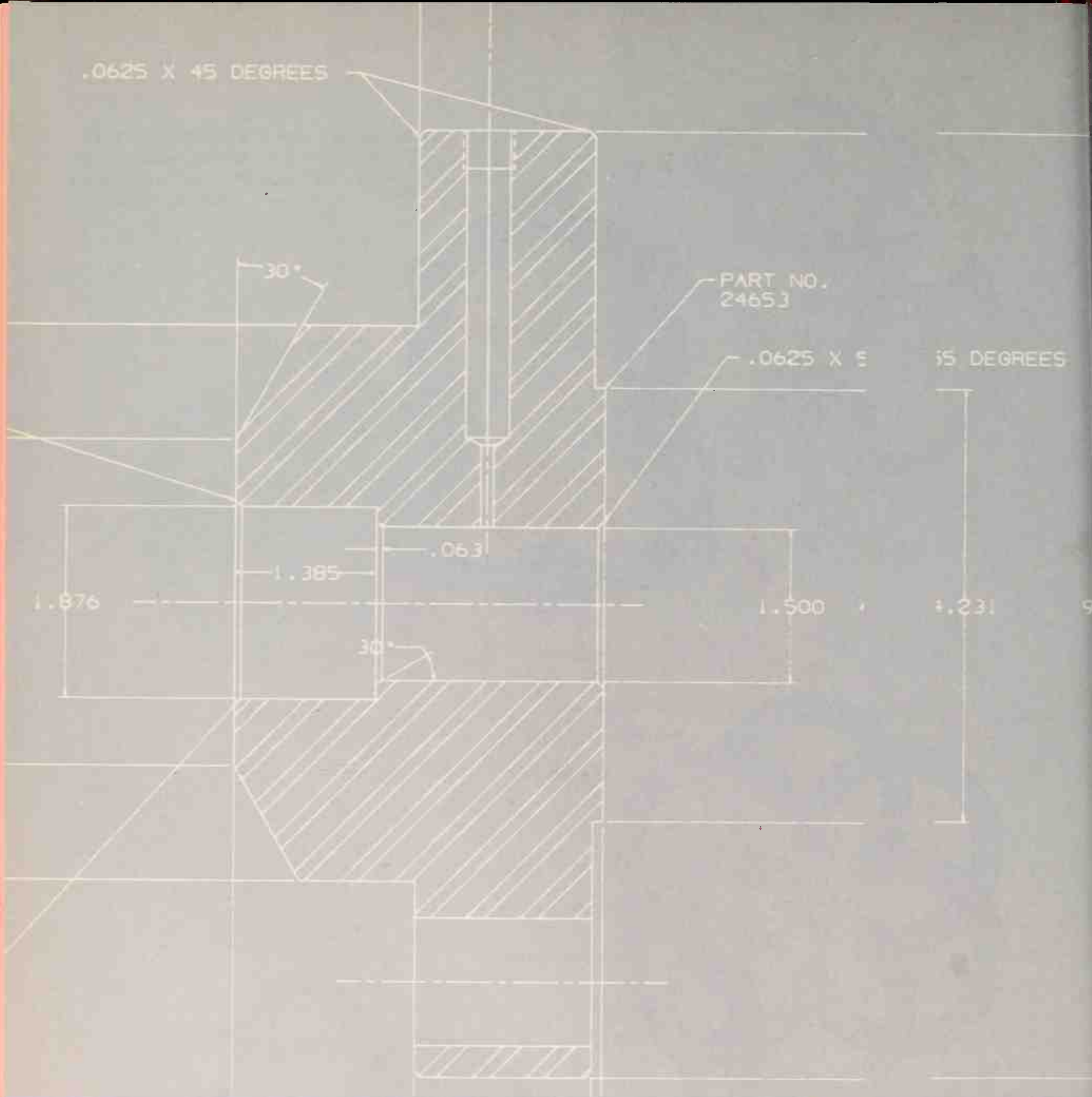
Problem 3-23



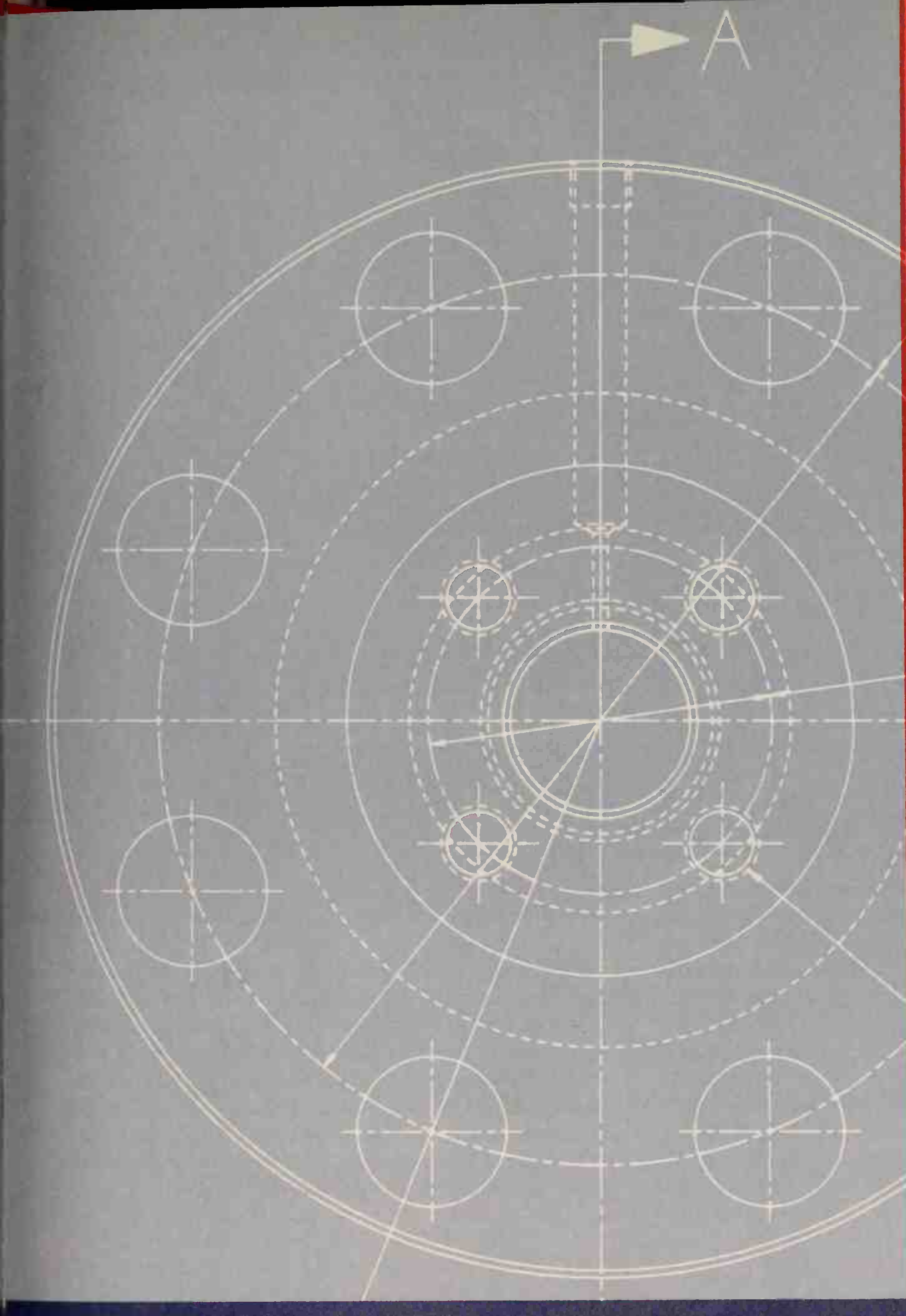
Problem 3-24



Problem 3-25

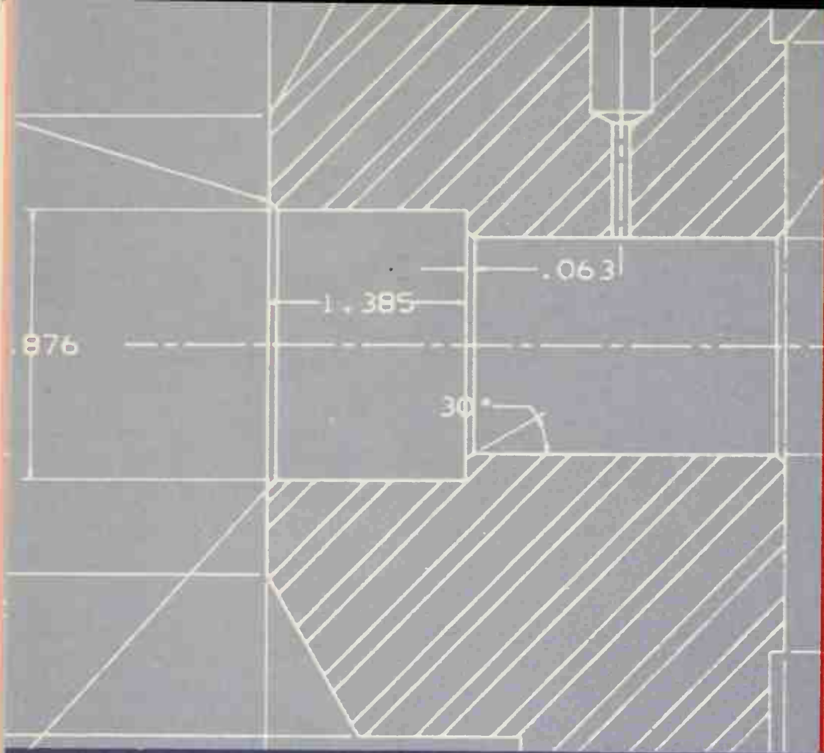


.0625 X 45 DEGREES
30°
PART NO.
24653
.063
1.385
1.876
30°
1.500



SECTION TWO

TECHNICAL DRAWING FUNDAMENTALS



CHAPTER 4

Most drawings produced and used in industry are multiview drawings of one, two, three, or more views. The concepts of multiview projection, that is, taking a three-dimensional object and drawing it on a two-dimensional sheet of paper, must be fully understood and mastered by the student. All drafting practices are fully illustrated in this chapter, and must be learned by the beginning drafter.

MULTIVIEW DRAWINGS

Providing accurate shape descriptions of objects by drawing methods requires that three-dimensional object information be presented in a flat, two-dimensional drawing space. This is usually done by drawing images of the object from multiple directions. Commonly shared methods and interpretations are essential for all who make or use such drawings. Technical drawings seldom use more than lines to outline an object's features. Visual qualities, such as color and texture, are more accurately specified by written requirements.

Viewing an object by eye creates a depth distortion. This phenomenon is recreated in a field of drawing called *perspective projection*, Figure 4-1. This distortion occurs because the visual rays used to create the image in the viewer's eye are not parallel. This distortion, while useful in providing the illusion of distance, results in a loss of image accuracy and fails to provide the information needed for most detailed technical communication.

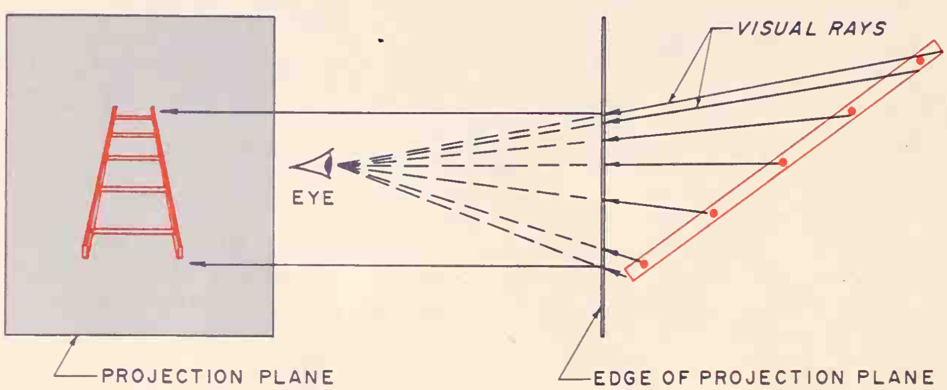


Figure 4-1 Perspective projection

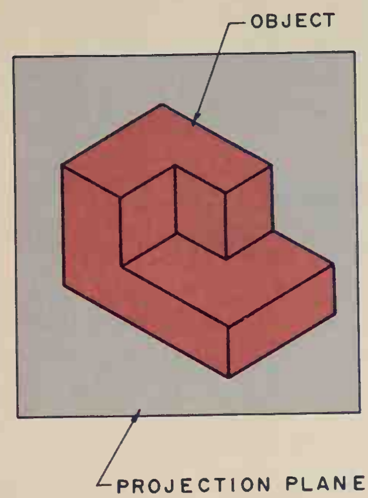


Figure 4-2A Imaginary windowpane in front of object

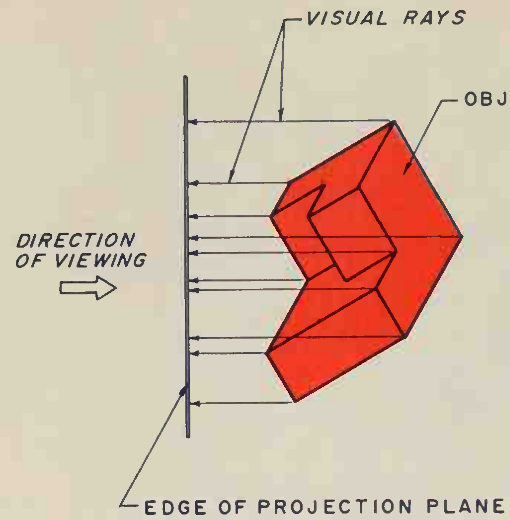


Figure 4-2B Side view of windowpane

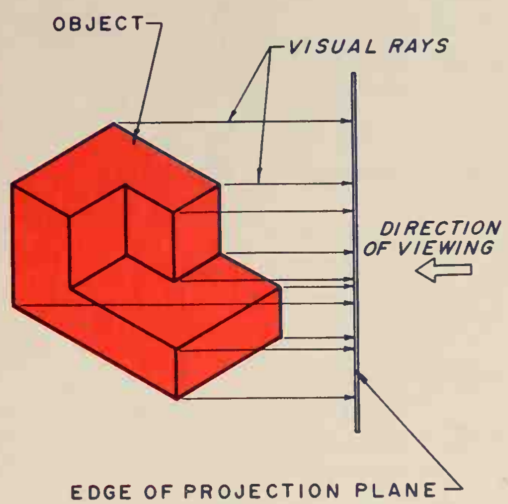


Figure 4-2C Reversed projection

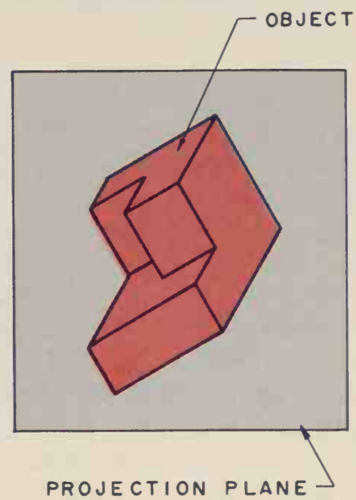


Figure 4-2D Reversed projection

Orthographic Projection

Orthographic projection is the most accurate method of shape description wherein an undistorted image of the object appears in a flat, transparent, but imaginary projection plane. A *projection plane* may be thought of as an imaginary pane of window glass, with an object underneath or behind it, Figure 4-2A. Viewed from the side, the pane of glass appears as a line, Figure 4-2B. Assume that light beams emitting from the surfaces of the object are projected to the projection plane, and that each light beam from each exposed surface is directed toward the viewing plane, Figure 4-2C. The image shown in Figure 4-2A traces the path of each light beam as it intersects the viewing plane. This image is called a *projection*, and illustrates the reflected features of the exposed surfaces of the object. Note, however, that Figure 4-2B is an image created in the same manner from Figure 4-2A. This reversal is shown in Figures 4-2C and 4-2D. Figure 4-2C shows the object's image resulting from the surface projectors striking the viewing plane, as illustrated in Figure 4-2D.

Normal Surfaces

The surface images of the figures just described do not represent the size and shape of their corresponding real surfaces. Rectangular surfaces appear as parallelograms. The lengths of edges are shorter in the image than their actual lengths (a phenomenon known as *foreshortening*). However, if the viewing plane were positioned parallel to some of the object's surfaces, as shown in Figure 4-3A, then the image appearing in that viewing plane would provide the actual size and shape of those surfaces, as shown in

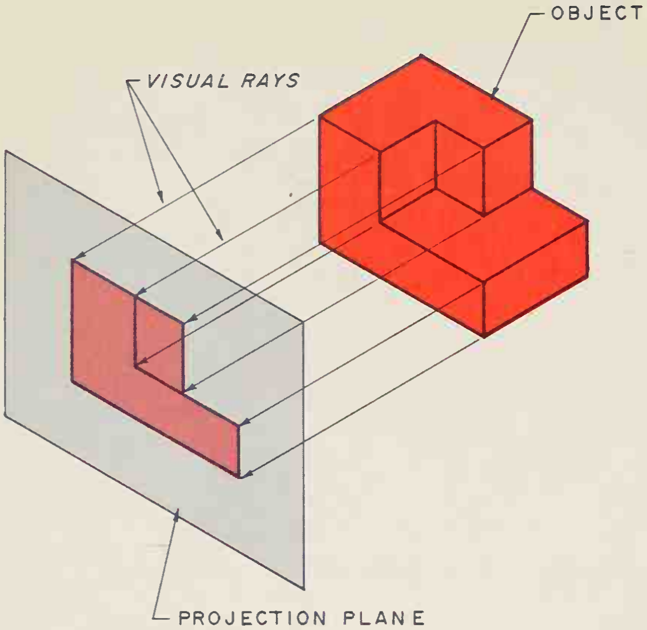


Figure 4-3A Viewing plane parallel to surfaces

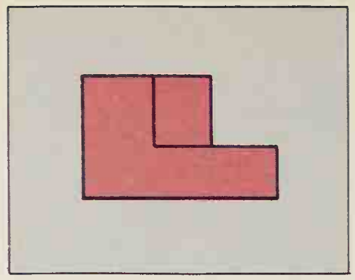


Figure 4-3B Viewing plane provides actual size and shape of surfaces

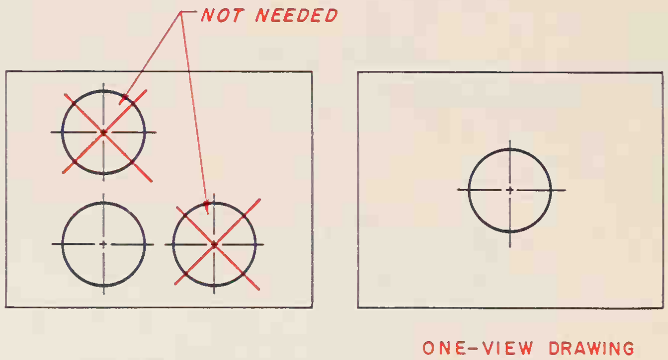


Figure 4-4 Simple one-view drawing

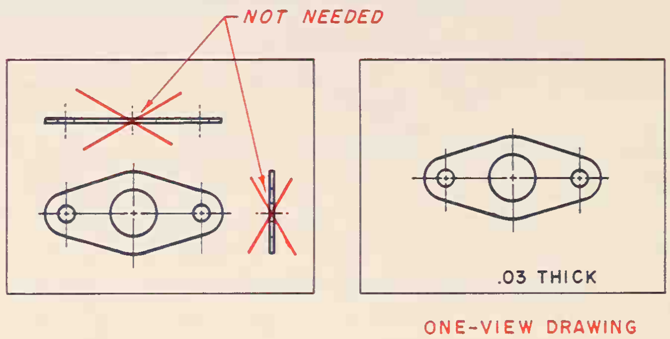


Figure 4-5 Simple one-view drawing

Figure 4-3B. A surface that is parallel to a viewing plane is said to be *normal* to the viewing plane.

A simple object, such as the round cannonball in Figure 4-4, needs only one view to describe its true size and shape. An object such as the flat gasket in Figure 4-5 needs only one view and a callout stating its required thickness. The callout can be noted on the drawing, as illustrated, or listed in the title block under "material." Figure 4-6A shows an object with a viewing plane placed in a normal position relative to some surfaces of the object, resulting in the orthographic views shown in Figure 4-6B. The sizes and shapes of the object's normal surfaces are shown in perfect outline in the orthographic view, but the viewer still cannot determine other features of the object. For example, Figures 4-6C, 4-6D, and 4-6E are different objects that provide exactly the same projected view. Furthermore, not all surfaces of the projected views of Figures 4-6C and 4-6E are shown in their real size and shape, as they are not normal to the viewing plane. There is no way to fully distinguish these without additional information.

Two Orthographic Views

In order to present the images of each viewing plane in a flat drawing area, one of the viewing planes must be repositioned to lie in the same plane of the drawing as the other. The procedure used to do this is to create a fold line where the imaginary perpendicular orthographic viewing planes meet each other along the straight edge of intersection, as shown in

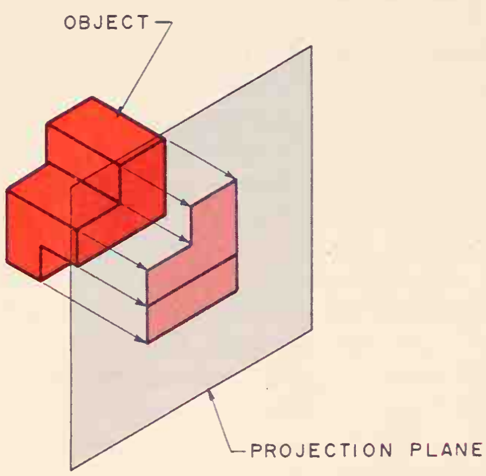


Figure 4-6A Viewing plane in a normal position

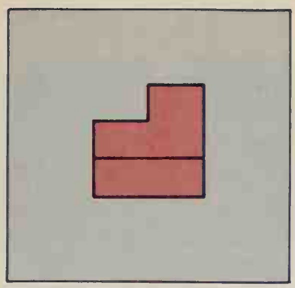


Figure 4-6B Orthographic view of the object

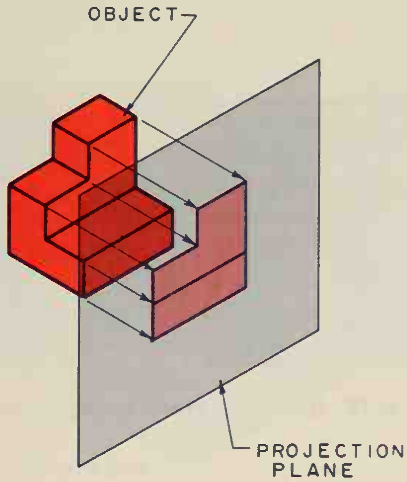


Figure 4-6D Another object with the same orthographic view

Figure 4-7A. The figure shows the object in Figure 4-6A with a second viewing plane positioned. The fold line acts as a hinge line around which the intersecting viewing planes are swung into the same plane, Figure 4-7B. The resulting orthographic views are shown in Figure 4-7C, each of which contains the image of a 90° rotated view or projection of the other. Note that the distance from the viewing plane to the object's surfaces in each image can be determined by locating from the fold line the position of the same surface in the adjoining image. In this procedure, the features and surfaces are always aligned to each other and thus can be located. The same two orthographic views are shown in Figures 4-7D, 4-7E, and 4-7F in haphazard relationship to each other, putting them each in error and making it impossible to determine surface positions or the real shape of the object.

Labeling Two Views

Figure 4-8A shows the positioning of two adjoining orthographic viewing planes to describe the object shown in Figure 4-6C. The orthographic view that presents the most characteristic shape of the object is

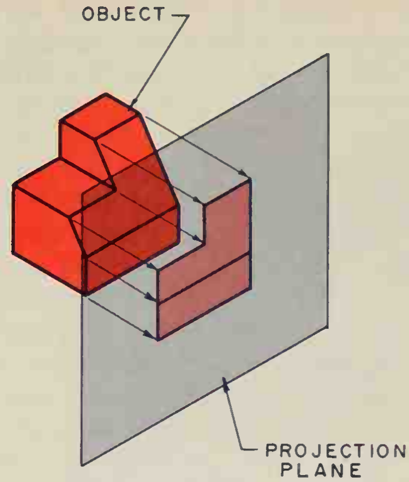


Figure 4-6C Different object with the same orthographic view

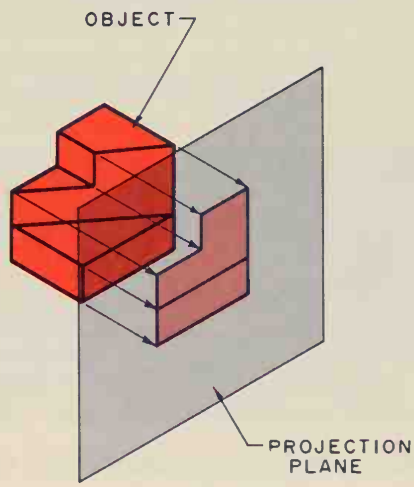


Figure 4-6E Another object with the same orthographic view

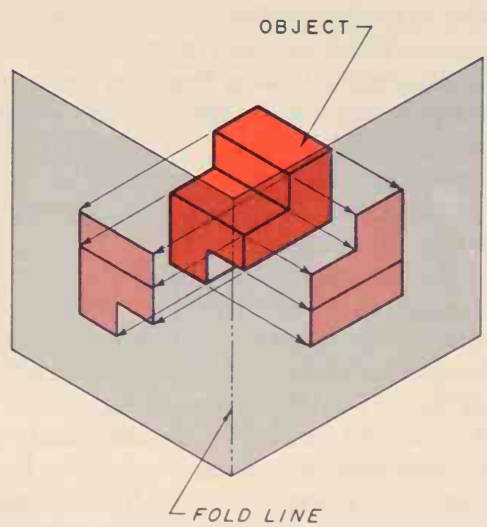


Figure 4-7A Fold line

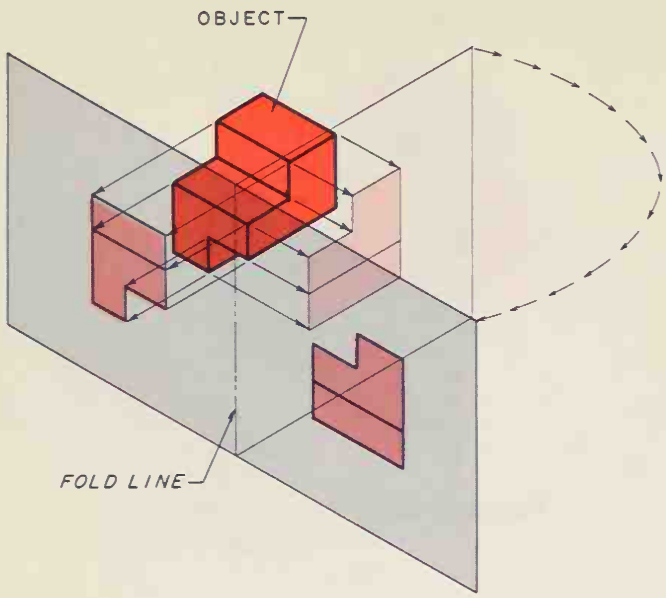


Figure 4-7B Fold line acts as a hinge

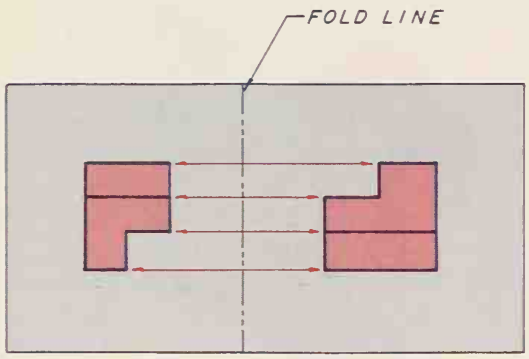


Figure 4-7C Projecting features from one view to the next view

usually selected and identified as the front view. If this is not feasible, the normal surface containing the most visible details is usually the next best choice. Once the front view is selected, the orthographic view that is projected to the right of the front view is identified as the right-side view. The term *front view* is often referred to as the *front elevation* and the *right-side view* is referred to as the *right profile*. To aid in this example, the normal surfaces to each viewing plane in Figure 4-8B are flattened out by shading, but this should not be done in practice.

Note that the edge view of each of the shaded surfaces appears as a line in the other orthographic view from where it is shaded, and that those edge views are always parallel to the fold line. Figure 4-9A shows viewing planes and view images to accurately describe Figure 4-6D. The viewing planes were earlier identified as imaginary; therefore, the fold line is imaginary also. The finished orthographic drawing should not include the borders of a viewing plane, which are usually a matter of choice. This omission is shown

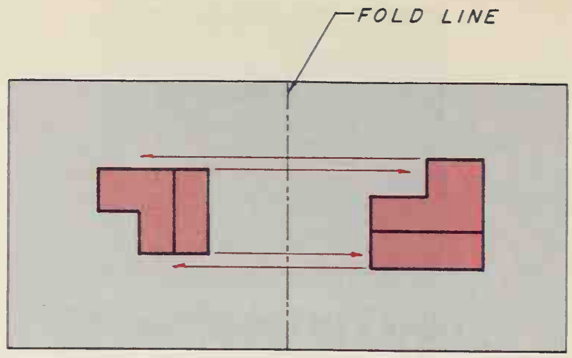


Figure 4-7D Incorrect positioning of views

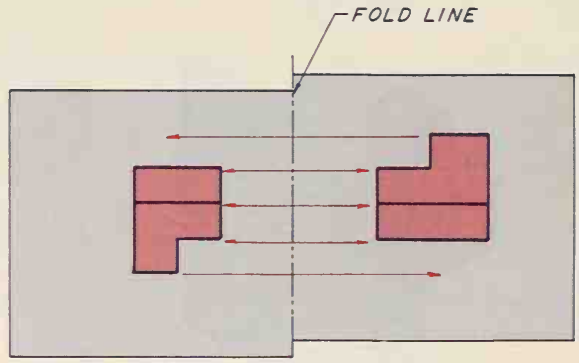


Figure 4-7E Incorrect positioning of views

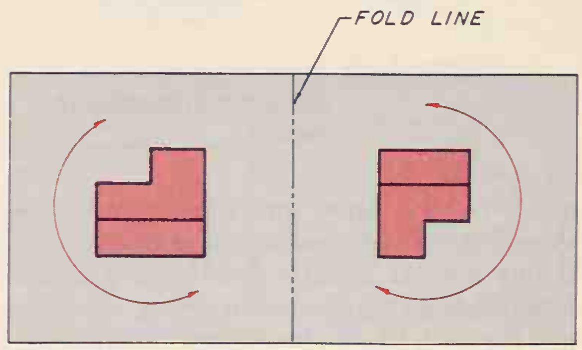


Figure 4-7F Incorrect positioning of views

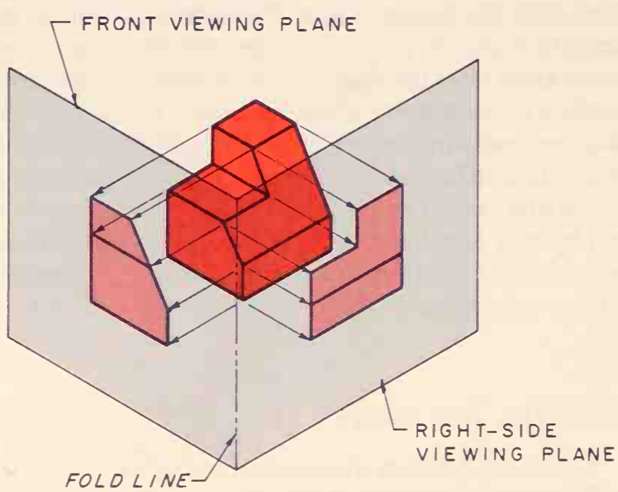


Figure 4-8A Positioning of two adjoining orthographic viewing planes

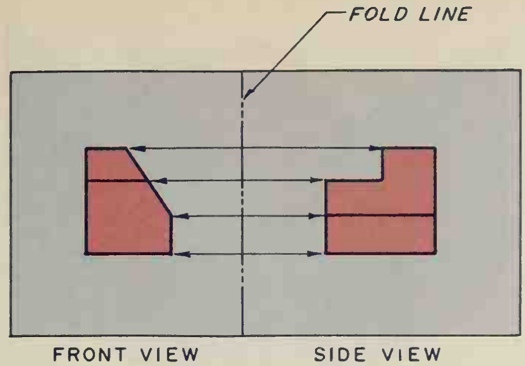


Figure 4-8B Two adjoining orthographic viewing planes flattened out

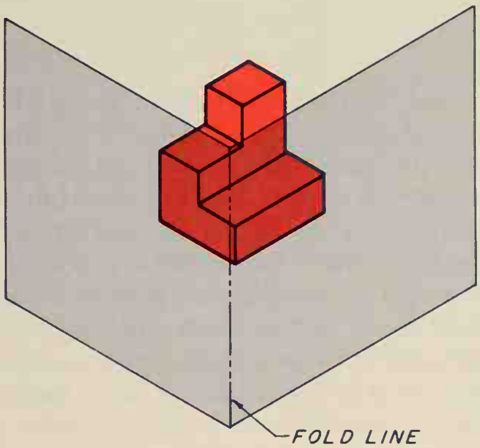


Figure 4-9A Viewing planes and image

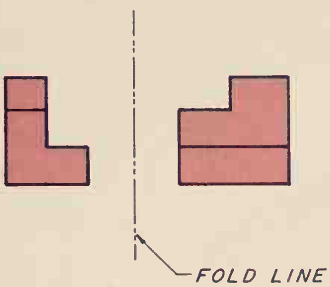


Figure 4-9B Orthographic drawing omitting viewing planes

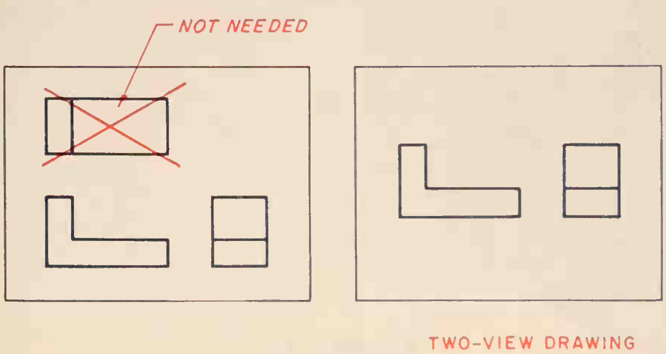


Figure 4-10 Only two views are required

in Figure 4-9B. Often, there is a need to draw the fold line for view constructions, as is discussed later, but it is preferable to remove it from the final drawing. The distance of the image from the fold line identifies the object's location from the viewing plane and is selected by the drafter. This decision is often based on the amount of space available for the drawings, dimensions, and notes.

Many objects can be drawn with only two views. A third view would only duplicate the same information. Figure 4-10 shows an example of a drawing requiring only two views. Do not use more views than needed to draw an object. Too many views will only complicate the drawing, and waste a great deal of drawing time.

Multiple Orthographic Views

Figure 4-11A shows two orthographic views that do not completely describe the object. Multiple interpretations of the object are possible, causing the viewer to be misled by inadequate information. Correctly interpreted, the object appears as shown in Figure 4-11B. Incorrect interpretations are shown in Figures 4-11C, 4-11D, and 4-11E.

A third viewing plane is commonly used to ensure adequate definition of the represented object. The third viewing plane is usually above the object, and perpendicular to the other two. It is called the *top view* or is sometimes identified as the *plan view* in construction-related drawings. This addition to the views is shown in Figure 4-12. The selection of views may be based upon an attempt to present the object's shape using the most efficient use of drawing area,

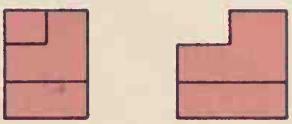


Figure 4-11A Orthographic views of an object

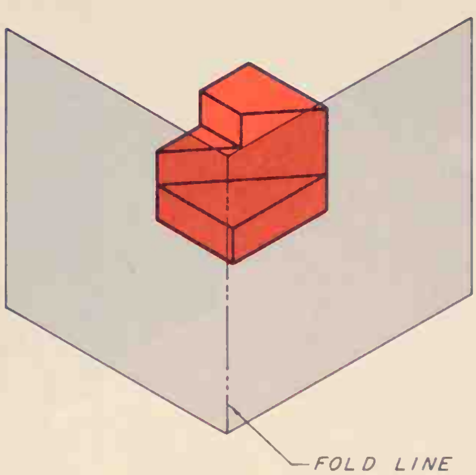


Figure 4-11B Correct interpretation

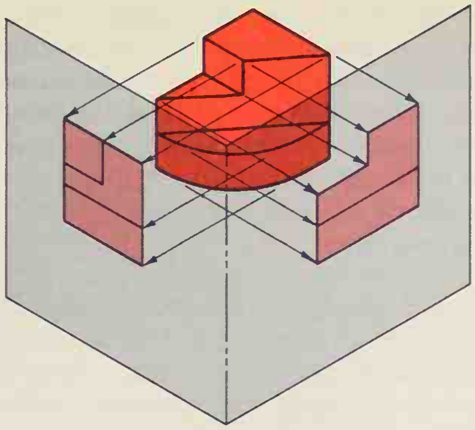


Figure 4-11C Incorrect interpretation

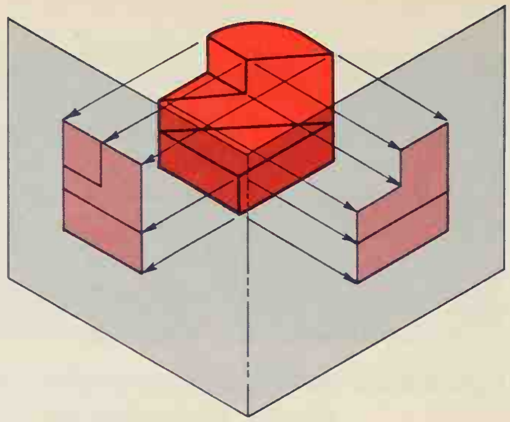


Figure 4-11D Incorrect interpretation

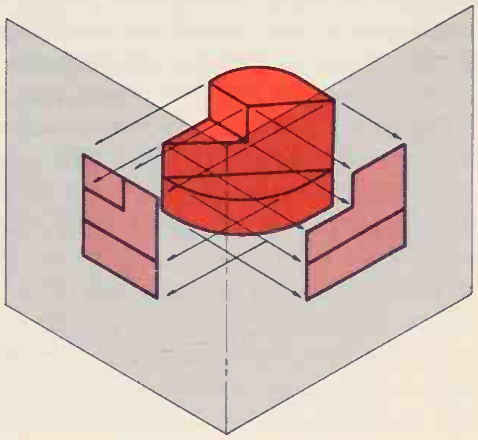


Figure 4-11E Incorrect interpretation

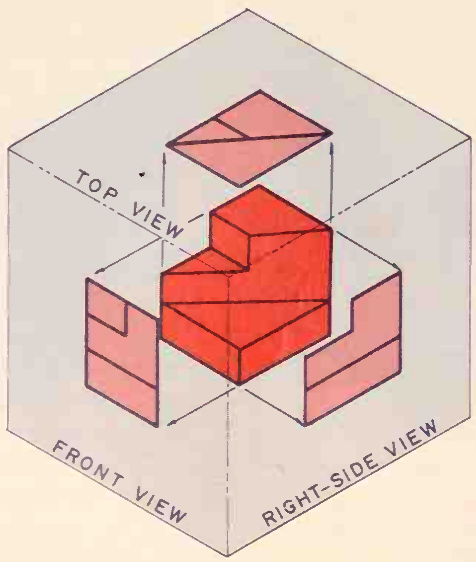


Figure 4-12
Third viewing plane added

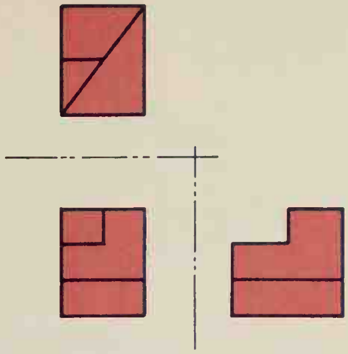


Figure 4-13A Orthographic view of an object

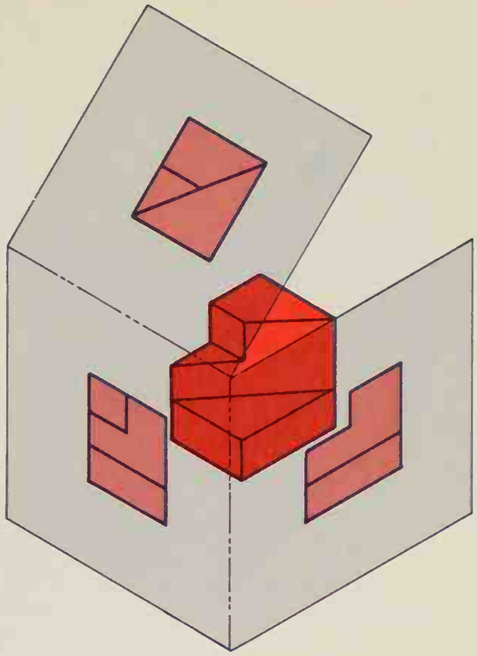


Figure 4-13B Three principal planes

Figure 4-13A, or to maintain the orientation of the object that is most easily understood by the reader, as illustrated in Figure 4-13B. Recall that the front view should be an attempt to show the most characteristic shape of an object. It can be disconcerting to read a view of a building that is drawn sideways.

The three viewing planes shown in Figure 4-12 are called *principal viewing planes*, as they are all perpendicular to one another, beginning with the orientation of the front view. There are three other principal planes. When combined with the front, top, and right side, they form the sides of a transparent box that completely surrounds the object. Figure 4-14A illustrates such a box, and Figure 4-14B shows some of the many possible fold line selections that would result in the multiple orthographic views of the object shown in Figure 4-14C.

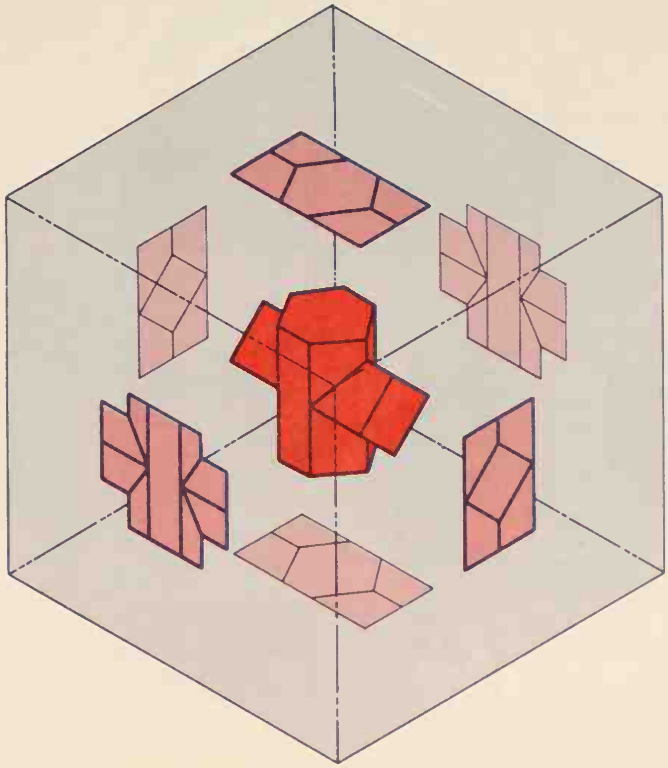


Figure 4-14A Transparent box

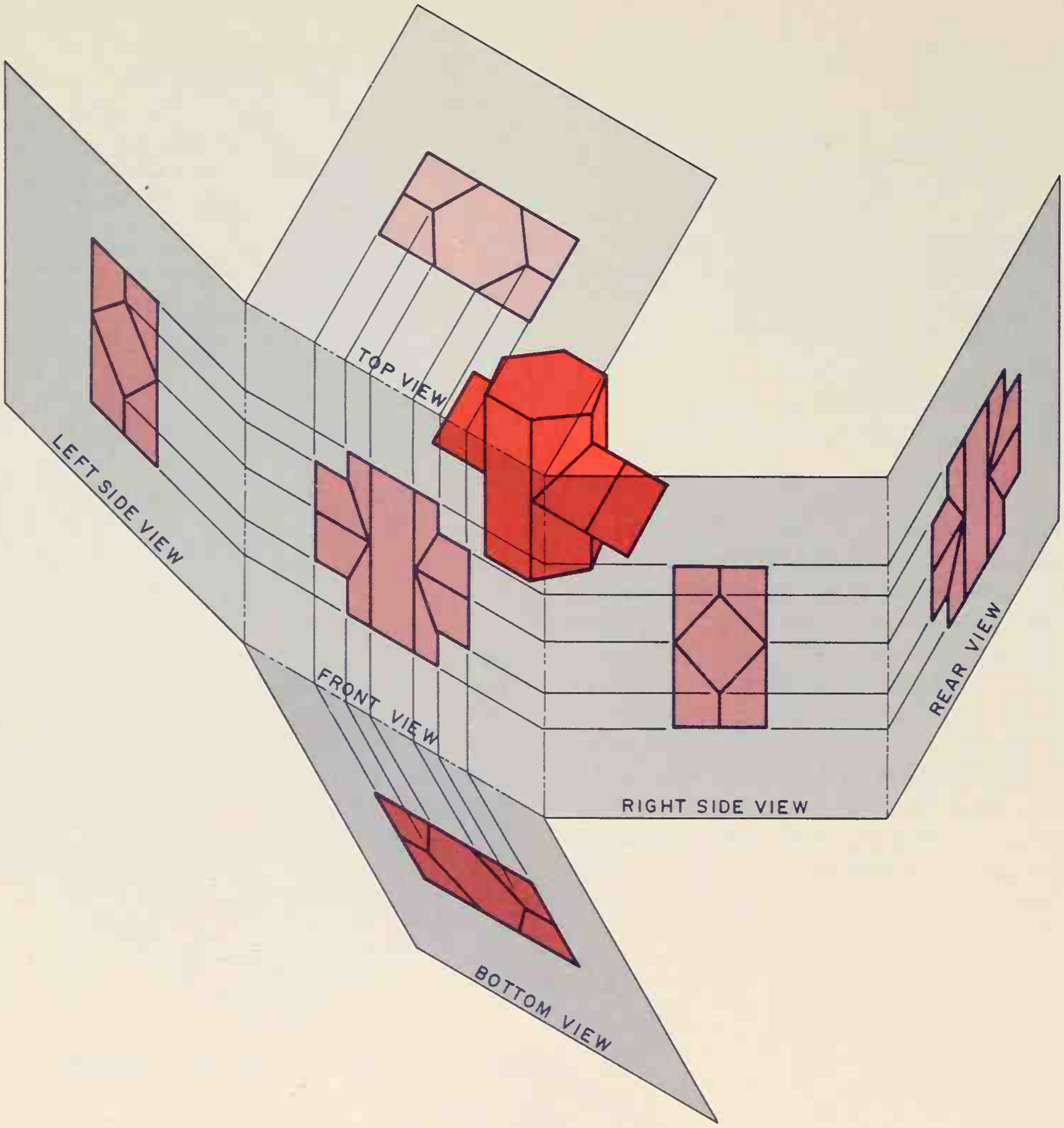


Figure 4-14B Fold line selections

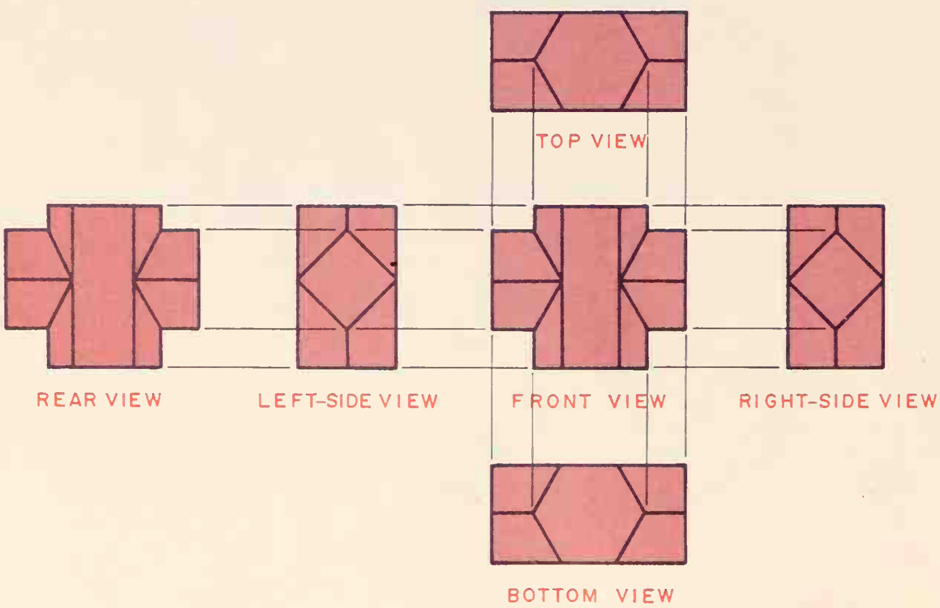


Figure 4-14C Resulting multiple views

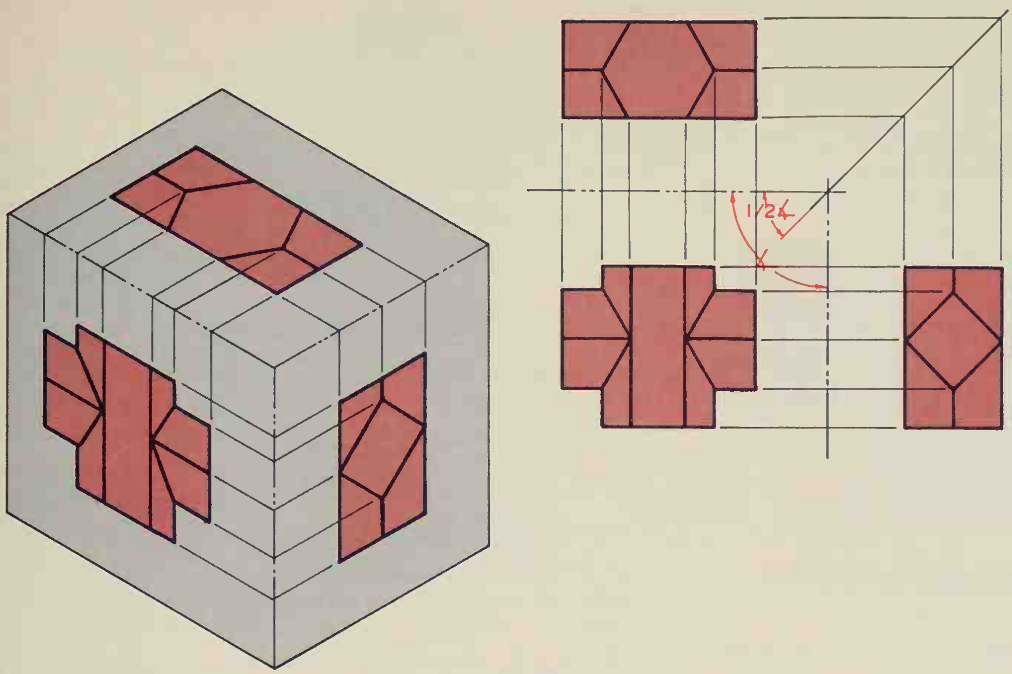


Figure 4-15
Transferring dimensions—
45° projection method

Object Description Requirements

All six views of Figure 4-14C are not necessary; three will provide sufficient information. Either the front view or the rear view may be selected as the front view, as each provides the same information. The common arrangement of top, front, and right-side view then follows. In Figure 4-15, the top view aligns directly above the front view and the right-side view aligns directly to the right of the front view. Both the top view and right-side view images are behind the front view projection plane by the same distance.

Dimension Transfer Methods

Figure 4-15 shows a method of transferring dimensions between the top and right-side views. This method employs a miter line at an angle that is at half of the angle between the intersection of the view fold lines in the drawing space.

In Figure 4-16, using a compass, the distance from the front view fold line to the image in the top view is rotated to the right-view fold line to the image in the right-side view.

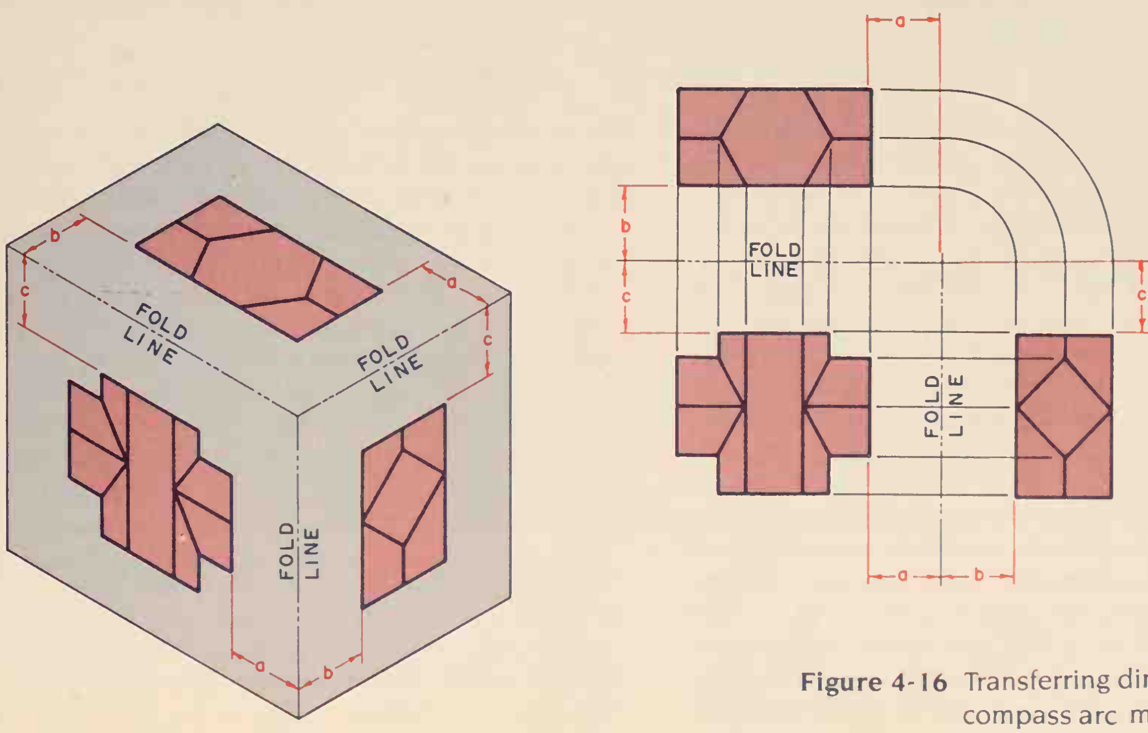


Figure 4-16 Transferring dimensions—compass arc method

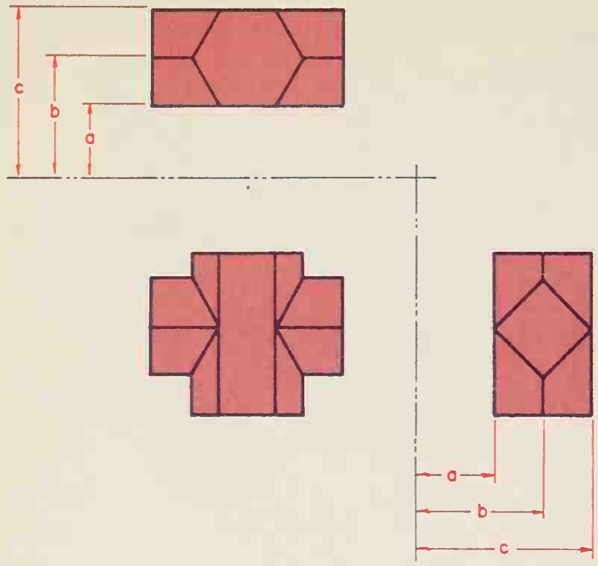


Figure 4-17 Transferring dimensions—transfer method

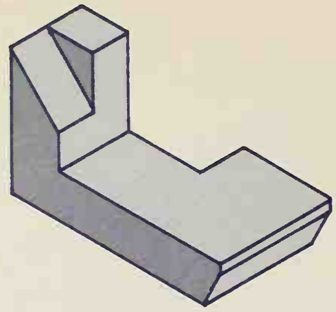


Figure 4-18 Isometric view of an object

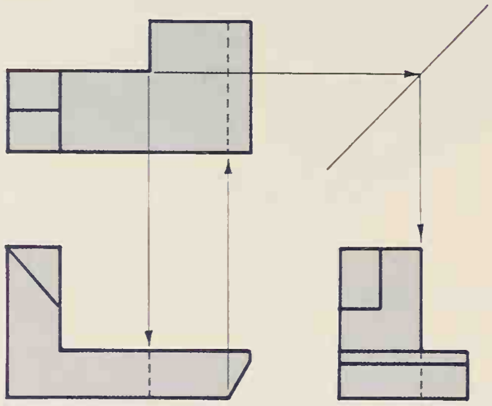


Figure 4-19 Orthographic views of the same object

Figure 4-17 shows the transfer method between top and front views. This method is potentially the most accurate. If the front and top views are drawn first, a fold line is arbitrarily positioned between them, but recall that a fold line must remain perpendicular to the projectors, or projection lines between views. A second fold line is drawn perpendicular to projectors or projection lines to the right of the front view *at any distance from the front view.* The distances from the fold line to the top view feature, dimensions a through c, are simply transferred directly to corresponding dimensions a through c, using a scale or dividers. If the front and right-side view are drawn first, the reverse order of fold line selection and distance transfers would occur.

Hidden Lines

Figure 4-18 is an isometric view of an object. The orthographic top, front, and right-side views of this same object are illustrated in Figure 4-19. *Hidden lines* are used to represent feature outlines whose visual rays must pass through some obstruction before reaching the viewing plane. Hidden lines mark the real but invisible features in each of the viewing planes where they are used.

A hidden line is often covered by a visible (solid) object line in the same view which hides the hidden line. This concept is shown in Figures 4-20A and 4-20B. Surface B aligns with corner A, as shown in Figure 4-20B. This causes part of the hidden line representing surface B in the right-side view of Figure 4-20B to "hide" behind the solid line representing edge B. Considering that each intersection of flat surfaces of an object in orthographic projection is represented by either a solid line or a hidden line, then almost every solid line in Figure 4-20B is covering

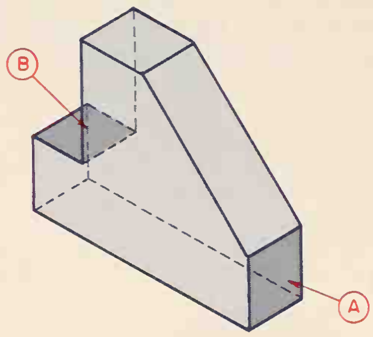


Figure 4-20A Isometric view of an object

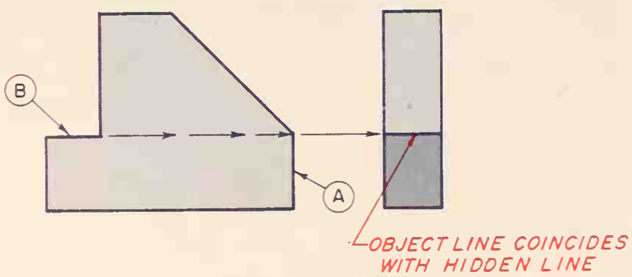


Figure 4-20B Object line takes precedence over hidden line

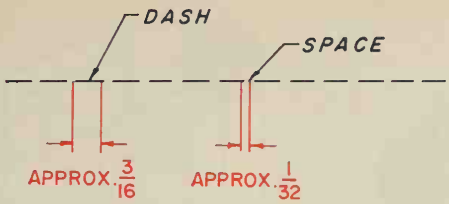


Figure 4-21 Average hidden line construction

one or more hidden lines. The ability to mentally perceive visible and hidden lines from orthographic views can provide the reader with an understanding of the object's actual configuration. This process is called *visualization*.

The lengths of dashes and dash spacing in hidden line construction are allowed to vary according to the size of the features being drawn. The dashes vary from 1/8 inch to 1/4 inch long (3.2 mm to 6.4 mm) and the spacing is correspondingly varied from 1/32 inch to 1/16 inch (0.8 mm to 1.6 mm). Little variation in size should be made from the average hidden line construction shown in Figure 4-21 for most drawing. The technical drawing trainee should concentrate on maintaining some consistency of dash sizes and spacing by estimation. Measuring dash lengths for preciseness is time consuming and does little to improve the learner's recognition time. However, there is some value for beginning drafters to measure their hidden lines at first to gain an awareness of the desired size and spacing. Recall that the line width of a hidden line should be of a medium width, perceptibly narrower than the width of the solid object line. Figure 4-22 illustrates the various drafting practices used in drawing hidden lines.

Center Lines

Center lines are used primarily as origin locations of circular, cylindrical or spherical features, but they can also be used to specify locations of other principal symmetries as well. As with hidden lines, the relative size of long and short dashes can be varied slightly with the size of the image being drawn. Crossed perpendicular center lines indicate a two-coordinate location of where an axis exists, and a single center line indicates the path of an axis. With the exception of noncritical surface radius contours of 1/8 inch or less, the axis of all circular features should be identified in all views.

Surface Categories

Recall that *normal surfaces* are parallel to one of the principal projection planes of the imaginary transparent box surrounding the object. In Figure 4-23, these surfaces are identified as the top, front, and

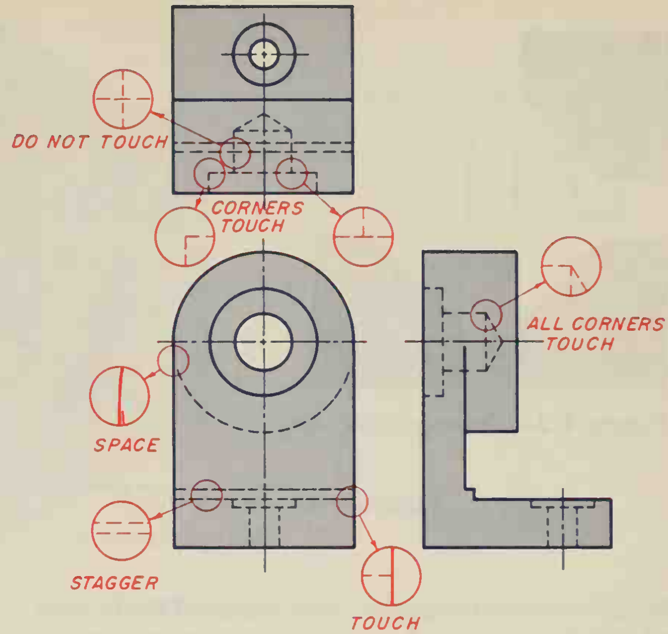


Figure 4-22 Hidden line drafting practices

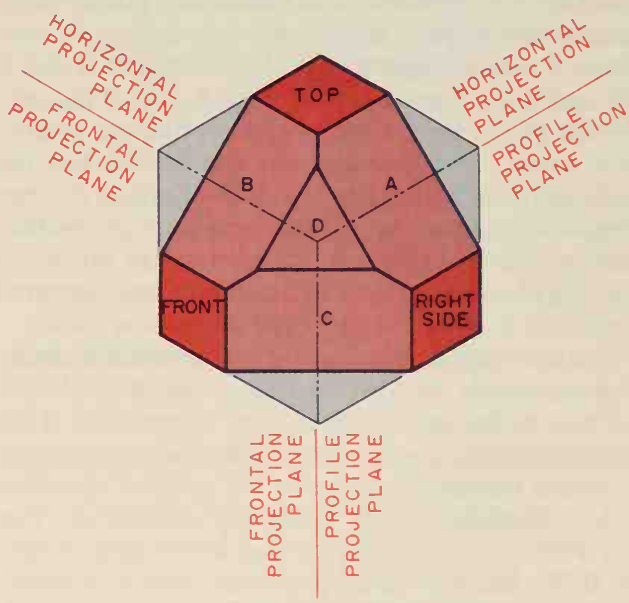


Figure 4-23 Surface categories

right side. The viewing planes containing these images are identified as the horizontal, frontal, and profile projection planes, respectively. A normal surface's size and shape appears in one of the principal views, Figure 4-24, but the surface appears as an edge view or line in the other principal views.

Surfaces A, B, and C are *inclined surfaces*; they are not parallel to any of the principal viewing planes, but each inclined surface is perpendicular to one of them. As with the normal surfaces, a surface that is perpendicular to a principal viewing plane will appear as an edge or line when projected on that plane.

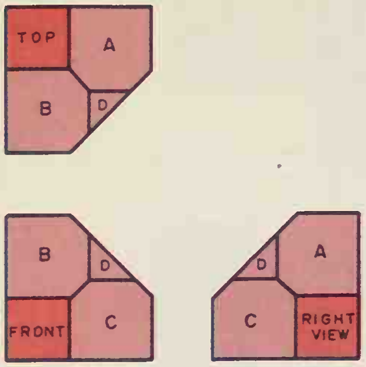


Figure 4-24 Orthographic views

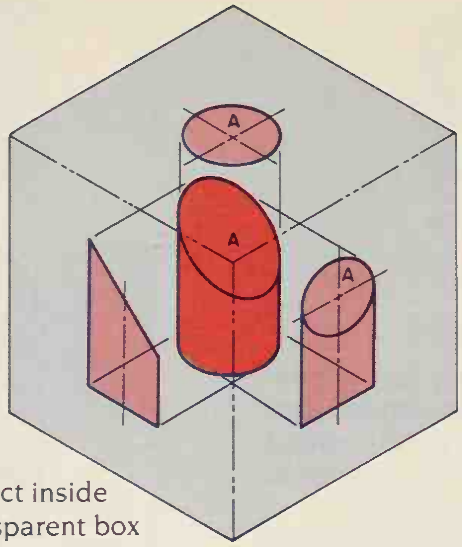


Figure 4-25 Object inside transparent box

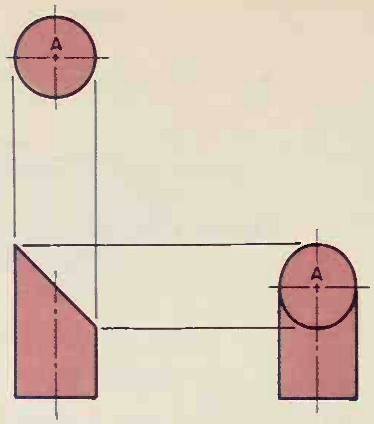


Figure 4-26 Circular image results in this top view

Surface A, for example, is perpendicular to the frontal viewing plane and accordingly appears as a line. It does appear in distorted and smaller size than its real size and shape in both the top and right-side views because of the foreshortening phenomenon. The maximum amount of foreshortening occurs when a surface is perpendicular to the viewing plane, which causes that surface to become so small as to condense it into a single straight line. Surfaces B and C are configured similarly to surface A, with B perpendicular to the right side (or *profile*) principal projection plane, and C perpendicular to the top (or *horizontal*) principal projection plane. Surface D is not perpendicular to any of the principal projection planes and is, therefore, categorized as an *oblique* viewing plane. It appears in a partially foreshortened condition in all of the principal projection planes.

The transparent box of principal projection planes that surrounds cylindrical surfaces uses the cylindrical axis as the line of orientation, Figure 4-25. If the cylindrical axis is made perpendicular to one of the principal viewing planes, then the cylindrical surface is foreshortened into a single-line circular arc. Figure 4-25 shows a cylinder whose axis is perpendicular to the top horizontal principal projection plane, and the circular image that results in the top view is shown in Figure 4-26. The lateral surface of the cylinders cannot be classified as normal, inclined or oblique, as the surface has a quality of continuous change in orientation. Surface A in Figure 4-26 is inclined to the horizontal viewing plane, creating elliptic contour with the lateral side. If surface A is 45° from the horizontal viewing plane, a circular image of the surface will appear in the right-side view.

Planning the Drawing

Before beginning a three-view drawing of any object, make a sketch of the object. Figure 4-27B shows preliminary sketches of the object in Figure 4-27A. The sketches were used to aid in selecting the best front view and its best position. Sketches reduce the possibility of errors in the finished drawing, and are helpful in selecting the required views and their positions.

Follow these basic steps before beginning a three-view drawing:

Step 1. Visualize the object. Be sure you have a good mental picture of exactly what the object actually is.

Step 2. Decide which view to use as the front view by sketching it in various positions. See Figure 4-27B. Keep in mind:

- the front view is the most important view.
- the front view should show the most basic shape in profile.
- the front view should be drawn so that it appears in a stable position. To accomplish this, always place the heavy part at the bottom surface of the view.
- the front view should be placed in such a position that the other views have as few hidden edges as possible. This may take a little practice, but is very important.
- the front view should show the most detail.

Step 3. Decide how many views are needed to completely illustrate the object without question.

Step 4. Decide in which position to place the front view. Figures 4-28, 4-29, and 4-30 illustrate *poor* positioning. Study each figure carefully to understand why each is poor practice. Figure 4-31 illustrates the *best* position for this object. Do not measure distances or use a straightedge when making a sketch. A sketch should be nothing more than its name implies.

Step 5. Make sure the views are neat and centered within the work area.

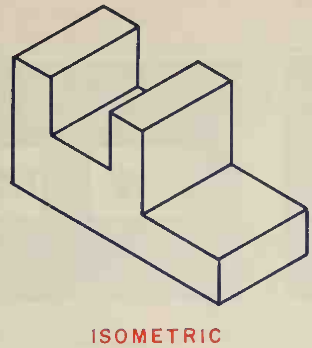


Figure 4-27A Isometric view of an object

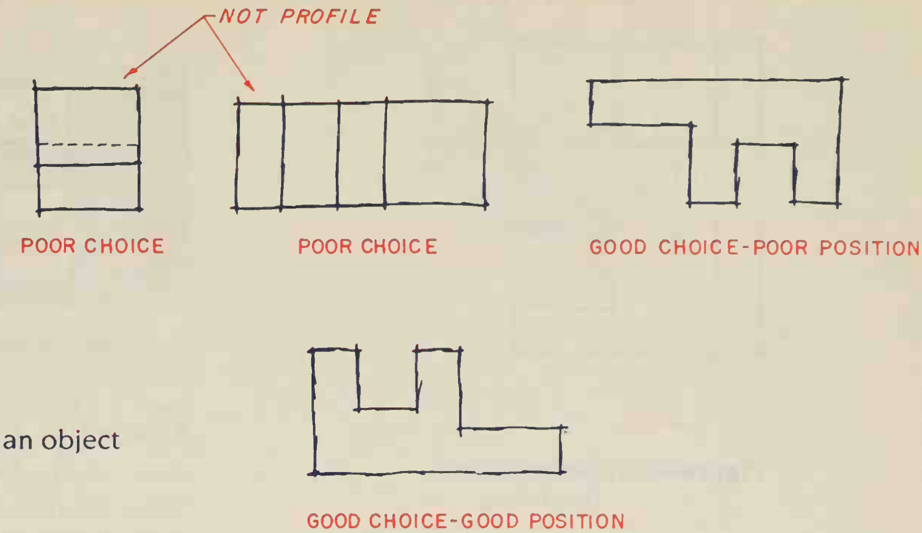


Figure 4-27B Sketches of object to determine front view

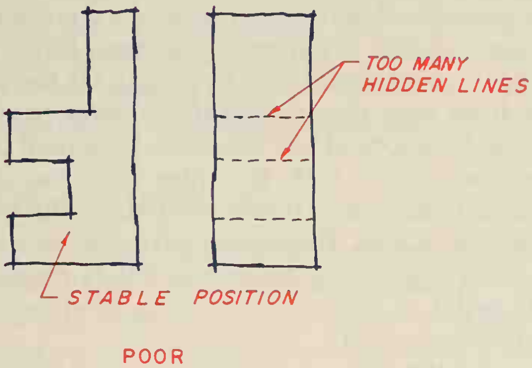


Figure 4-28 Poor front view—too many hidden lines

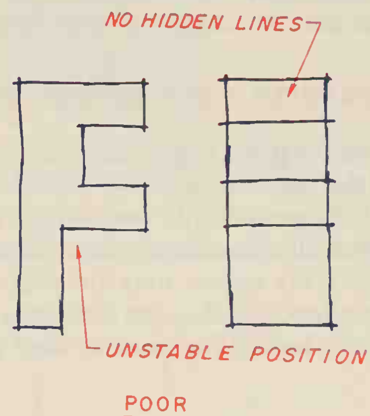


Figure 4-30 Poor front view—unstable

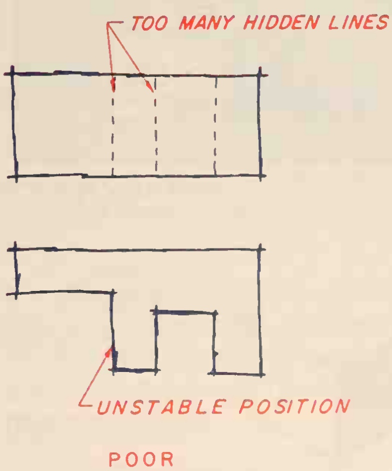


Figure 4-29 Poor front view—unstable, too many hidden lines

Positioning the Views within the Work Area

The example shown on the left of the Figure 4-32 is poorly centered. It has wasted space on both sides of the top view and front view, and both views are too close to the top and bottom of the paper. Objects should never be drawn within ½ inch (12 mm) of the border lines. The example shown on the right of Figure 4-32 is better than the first example, because it appears balanced and well centered. A rule to remember is to try to keep the white space evenly distributed around the view, if possible.

Sketching Procedure

Sketching should be done freehand, quickly, and only to an approximate scale. Do not take the time to make fancy sketches, and do not use any straightedges or compasses. Select the front view, and, using

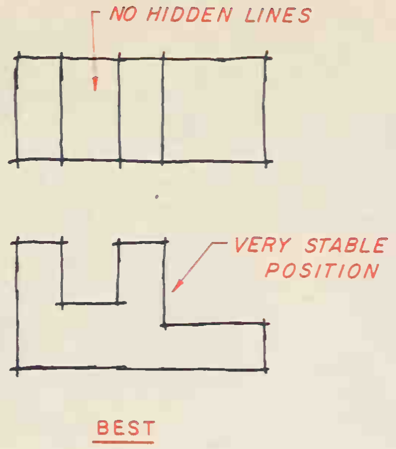


Figure 4-31 Best position-front view

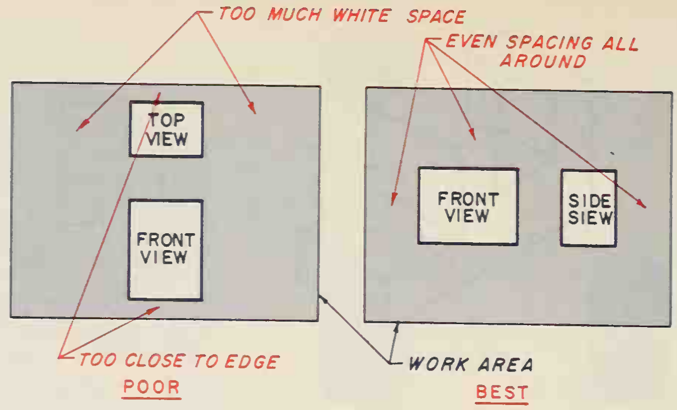


Figure 4-32 Positioning the views within the work area

the criteria previously outlined for the most important view, sketch it in position. Project upwardly to make the top view, and horizontally to make the right-side view. Lightly draw the basic shape of each view first, and then add the details to each view.

Centering the Drawing

The drawing must be neatly centered within the work area of the paper or within the border, if one is provided. A full one-inch (25 mm) space should be placed between all views drawn, regardless of which scale is used. This space may be adjusted with increased experience, and as the demands of dimensioning are introduced. Figures 4-33 and 4-34 show the procedures used to center a drawing within a specified work area. Given is an isometric view of the object with all dimensions added. In this example, the total *horizontal* distance of the views (front view and side view) is determined by adding 4.0, the width of the front view, plus the 1.0 space between views, plus the 2.0 depth of the side view, for a total of 7.0 inches. See Figure 4-33. To center these two views horizontally, subtract 7.0 from 11.0, the width of the example work area. The answer 4.0 represents available extra space. This answer, or 4.0, is divided in two in order to have equal spacing on either side; refer to dimension D.

To center the drawing vertically, the same basic procedure is followed. The total *vertical* distance of the

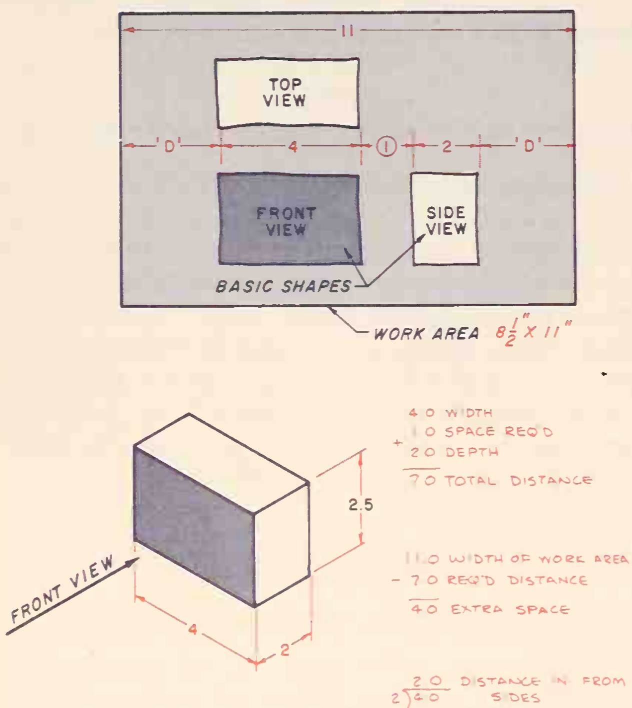


Figure 4-33 Centering views horizontally

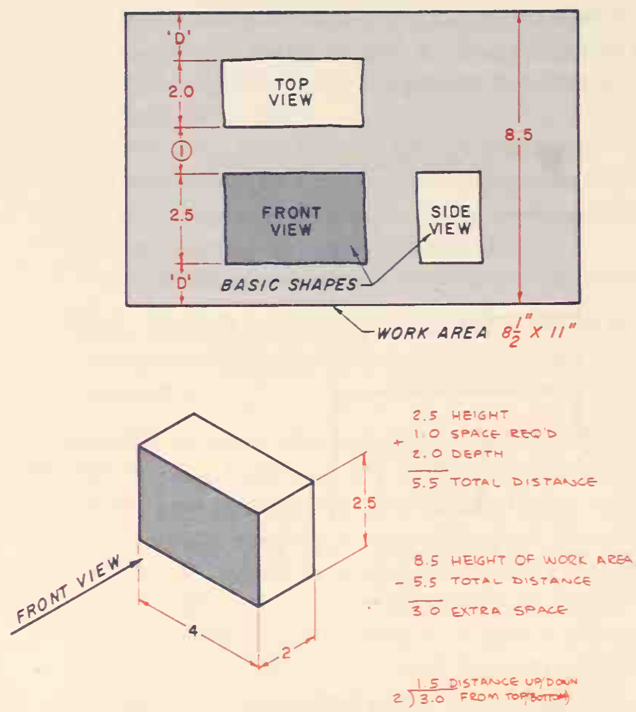


Figure 4-34 Centering views vertically

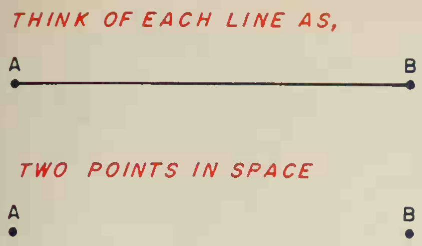


Figure 4-35 A line is made up of two points in space

two views is determined by adding the 2.5 height of the front view, plus the 1.0 space between views, plus the 2.0 depth of the side view, for a total of 5.5. See Figure 4-34. To center these two views vertically, subtract 5.5 from 8.5, the width of the example work area. This answer, 3.0, represents the available extra space. This space is divided by two to distribute it equally. One half of 3 or 1.5 inches is placed at the bottom of the work area, and the other half or 1.5 inches is placed above the top view. This centers the required view vertically. The same process is followed each time a drawing is to be centered, regardless of the drawing size or available work area.

Numbering Drawings

Many times, a multiview drawing is so complicated that the drafter is not quite sure of how some part of a view will look. Numbering points of various features of the more difficult drawings makes them easier to visualize, and helps to ensure that the final drawing is correct. Think of a drawing as a group of points in space joined together by lines. For instance, think of each line as two points in space, Figure 4-35. If the ends of a line can be found, all that has to be done to complete a line is to connect the ends. Once the ends have been found and numbered in one view, the same can be done in other views by simple projection. Figure 4-36 is an isometric view of a simple object. Each end of each line has been assigned a number.

Use the following steps to add numbers to a difficult drawing:

Step 1. Lightly draw the basic shape of the required views. Draw the light projection line also.

Step 2. Assign a number to each corner of the view where the profile is found. In this example, the front view has been used as a starting point. See Figure 4-37 and refer to the isometric view in Figure 4-36.

Step 3. Project these points up to the top view. Number the points in the top view, as shown in Figure 4-38.

Step 4. Project these points across from the front view to the right-side view, Figure 4-39. Project

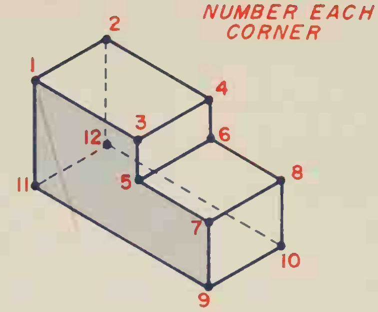


Figure 4-36 Given: an isometric view of an object

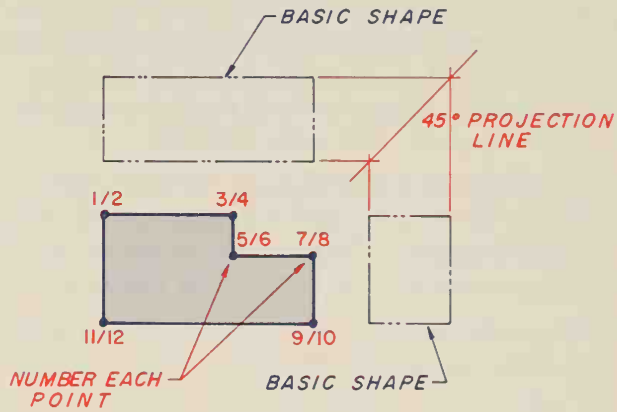


Figure 4-37 Number one view

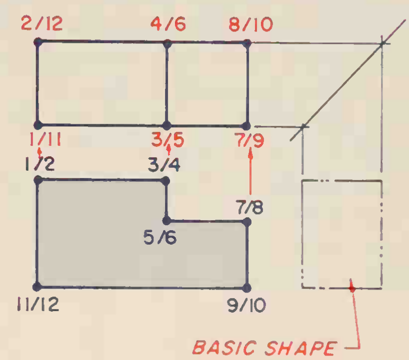


Figure 4-38 Project numbers into the top view

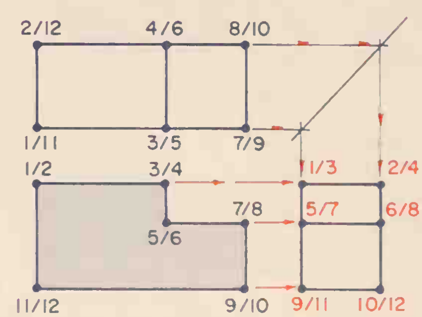


Figure 4-39 Project numbers into the right-side view

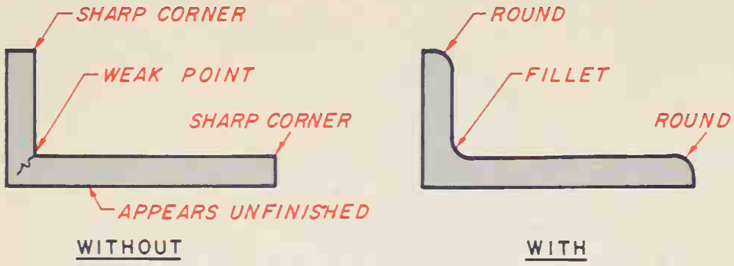


Figure 4-40 Rounds and fillets

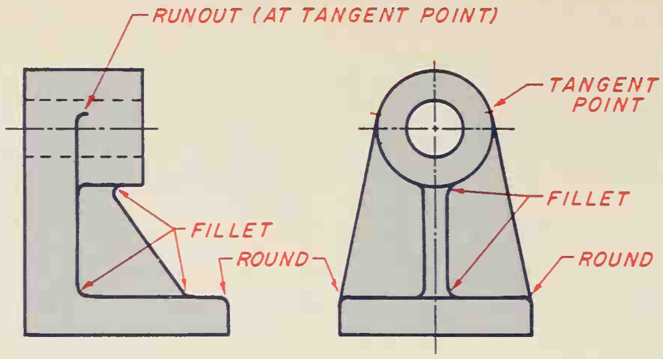


Figure 4-41 Runouts

the same points from the top view, over to the 45° line. Where the lines meet the 45° line, project down to the right-side view. The points where these lines cross are the exact locations of each point. Number all points, as shown in Figure 4-39. Other methods may be employed. Review Figures 4-15, 4-16, and 4-17.

Step 5. Connect points together, for example, point 1 to point 2, point 3 to point 4, and so on until the figure is completed in each view. Refer to the isometric view if necessary, Figure 4-36.

Note: If a point can be found in any two views, regardless of which two views, it can be projected into the third view.

Rounds and Fillets

It is very difficult to manufacture objects with absolutely square corners, especially with processes that require the object's material to flow into position. *Rounds* replace sharp external edges on cast objects, and are rounded outside corners.

Fillets are the opposite of rounds; they are inside rounded corners. Cast objects tend to crack due to the strain placed on the metal during the cooling process. Fillets distribute the strain and prevent cracking. Rounds and fillets also enhance the appearance of an object. Examples of rounds and fillets are shown in Figure 4-40.

Fillets and rounds

- remove sharp corners from the object.
- add strength to the object.
- enhance the appearance of the object, giving it a "finished" look.

Runouts

Runouts are curved surfaces formed where a flat and curved surface meet, Figure 4-41. To find the exact intersection where a runout will occur

- locate the tangent points of the curved surface, Figure 4-42.
- project these tangent points to the next view.
- add the runouts, as shown in Figure 4-43.

Take care to study in which direction the runouts must be drawn.

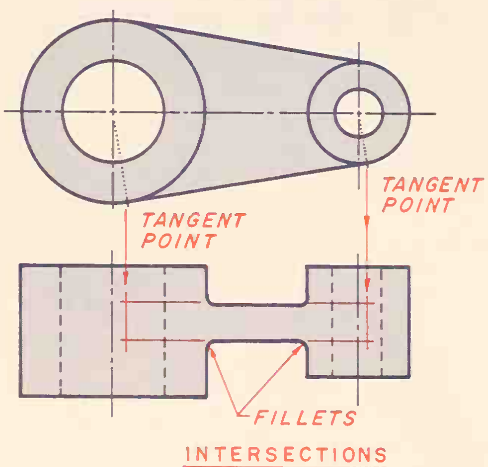


Figure 4-42 Locate the tangent points

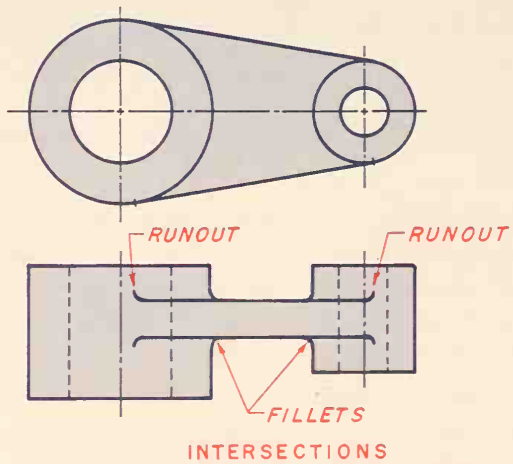


Figure 4-43 Complete runouts at tangent points

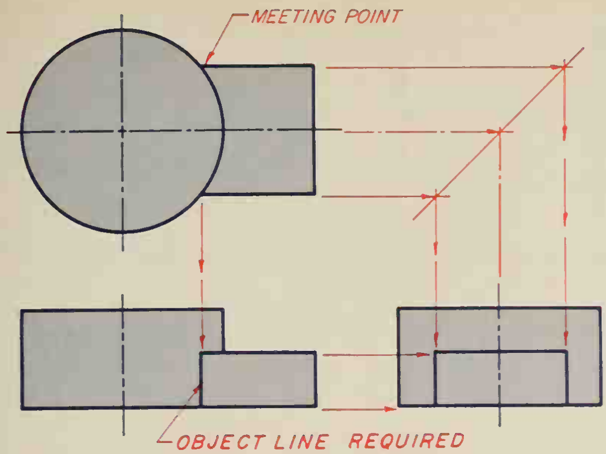


Figure 4-44 Intersecting surfaces

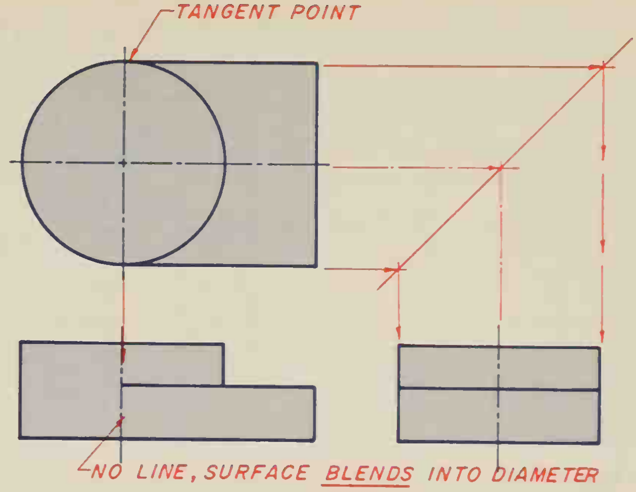


Figure 4-45 Intersecting surfaces

Treatment of Intersecting Surfaces

Figures 4-44 through 4-47 show how to illustrate various intersecting surfaces. In these examples, rounds, fillets, and runouts have been omitted to simplify the drawings. In actual practice, rounds, fillets, and/or runouts probably would have been added. In Figure 4-44, the flat surface meets the cylinder sharply (see top view), making a visible edge necessary in the front view. The meeting point in the top view is the exact location of the object line in the front view and right-side view.

In Figure 4-45, the flat surface blends into the cylinder, stopping at the point of tangency. Notice in the top view, the tangent point is located at the center line, and, in the front view, blends in at that exact point.

In Figure 4-46, the surface blends into the cylinder, stopping at the point of tangency, similar to Figure 4-45 except on an angle. Again, the tangent point is projected into the front view and right-side view.

In Figure 4-47, the radius blends into the base, stopping at the point of tangency. Notice that a line is drawn in the top view extending to the tangent point of the arc in the front view.

Curve Plotting

Some multiview drawings have a curved surface that must be projected into other views. The following steps are used to plot a curved surface.

Step 1. Lightly complete the basic shape of each view, Figure 4-48. Locate the center of the arc, point X.

Step 2. From this point, divide the arc into equal spaces (any spacing will do), Figure 4-49. In this example, 30° spaces have been used. The more spaces, the more accurate the plotted curve will be. Increments of 10° would be more accurate than 30° but would take more drawing time.

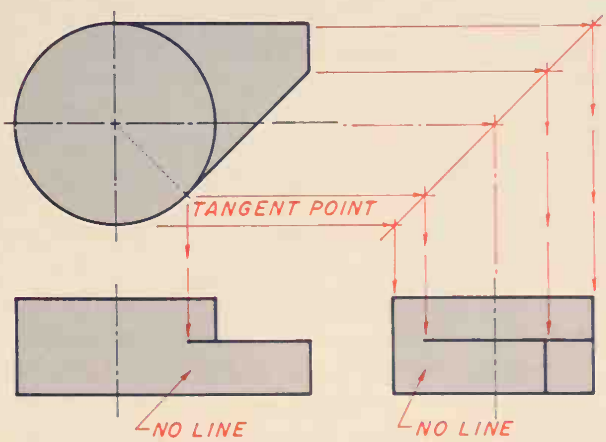


Figure 4-46 Intersecting surfaces

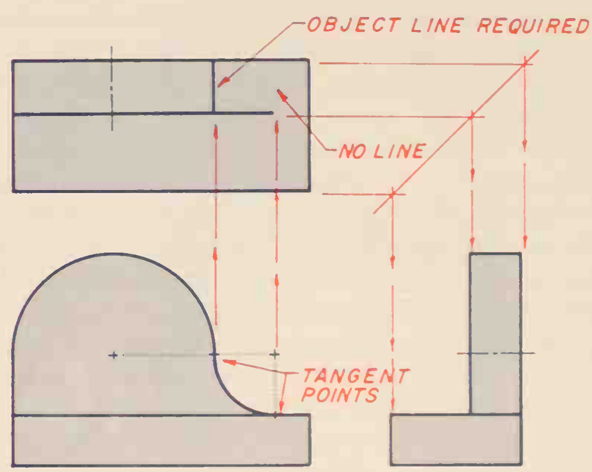


Figure 4-47 Intersecting surfaces

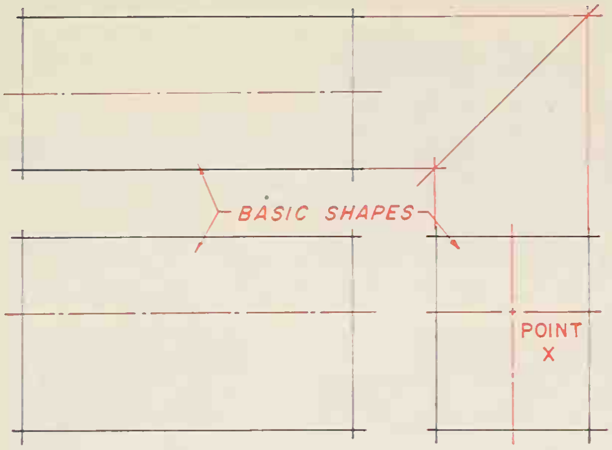


Figure 4-48 Curve plotting—Step 1

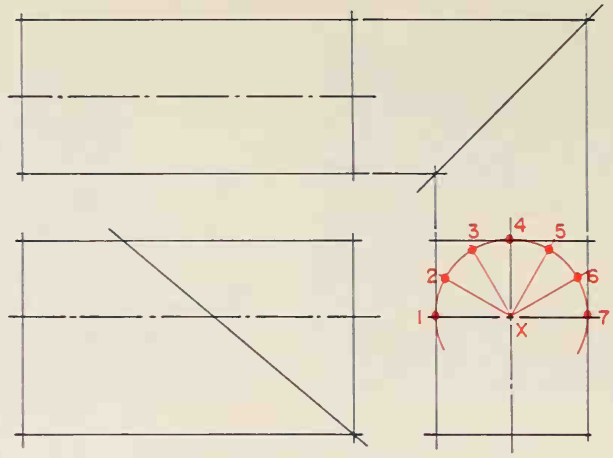


Figure 4-49 Curve plotting—Step 2

Step 3. Number or letter the points in order clockwise. Figure 4-50. In this example, start and end at the beginning and ending of the arc.

Step 4. Project these points up from the right-side view to the 45° axis line, and to the left to the top view. Figure 4-51.

Step 5. Project over to the slanted surface in the front view and locate each point on the slanted surface.

Step 6. Project these points up from the front view to the top view.

Step 7. Where the lines projected from the given points in the right-side view intersect with those from the front view is the exact location of points 1 through 7 in the top view (see Figure 4-51). Number all points at their intersection.

Step 8. Using an irregular curve, complete the drawing, as shown in Figure 4-52.

Cylindrical Intersections

A drafter can often indicate the intersection of cylinders, without actually showing the line of intersection between them. If there is a considerable difference in the diameters of each of the intersecting cylinders, then a straight line is capable of indicating the cylindrical intersection, as shown in Figures 4-53A and 4-53B. If there is little difference between the intersecting cylindrical diameters, then a simple arc is constructed or approximated through three principal points, as shown in Figures 4-54A and 4-54B.

On occasion, it is necessary to define the actual edge of intersection between two cylinders, especially in sheet metal construction. Figure 4-55 shows line elements on each of two intersecting cylindrical surfaces that are parallel to each of their respective cylindrical axes, and to a common (frontal) viewing plane.

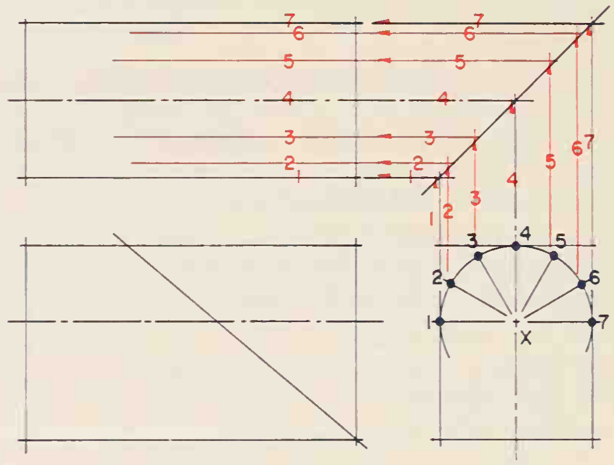


Figure 4-50 Curve plotting—Step 3

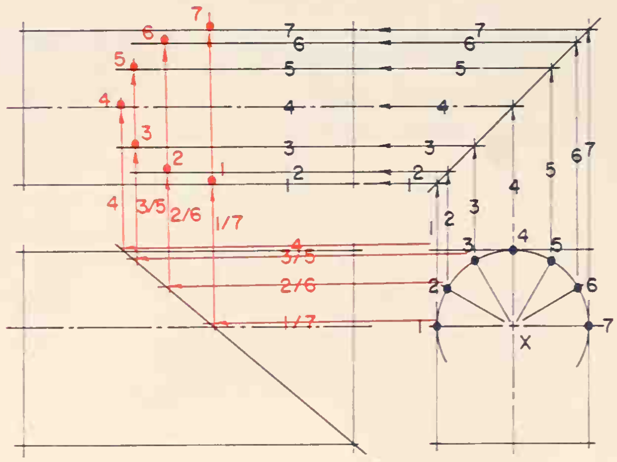


Figure 4-51 Curve plotting—Step 4

Note that each of the intersecting line elements, 1 through 4, are the same distance from the frontal viewing plane. Using this relationship to construct a line of intersection, line element locations are reflected on the perimeter of the smaller intersecting

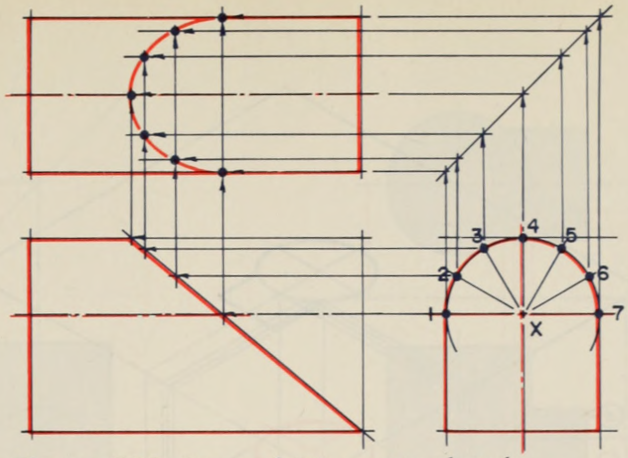


Figure 4-52 Curve plotting—completed

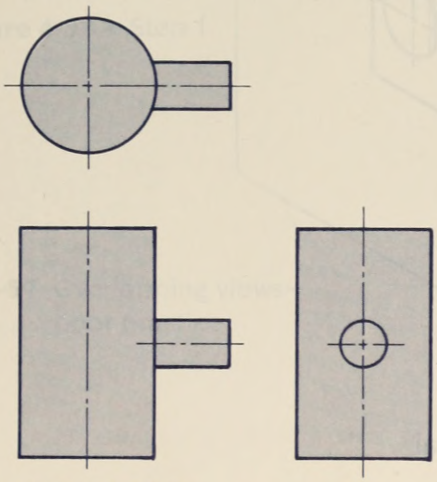


Figure 4-53A
Cylindrical intersections
(straight line)

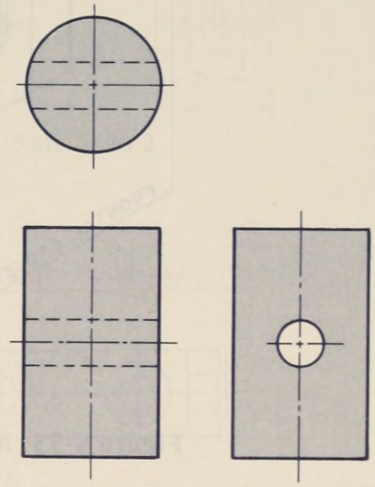


Figure 4-53B
Cylindrical intersections
(straight line)

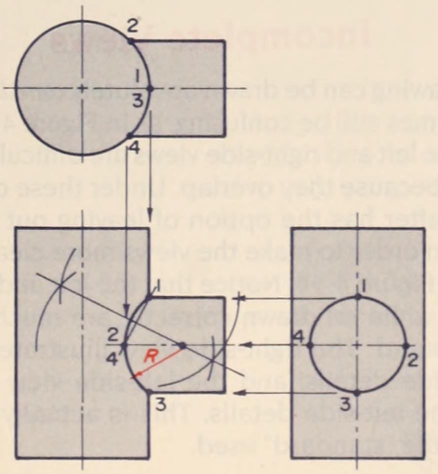


Figure 4-54A
Cylindrical intersections (arc)

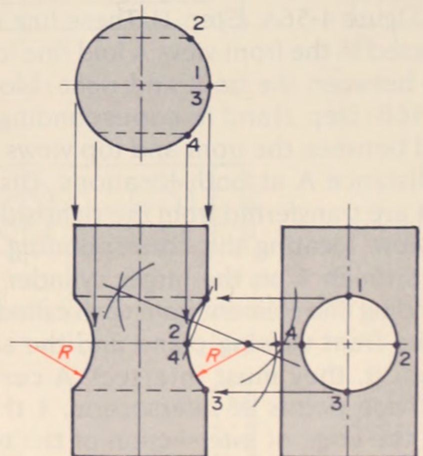


Figure 4-54B
Cylindrical intersections (arc)

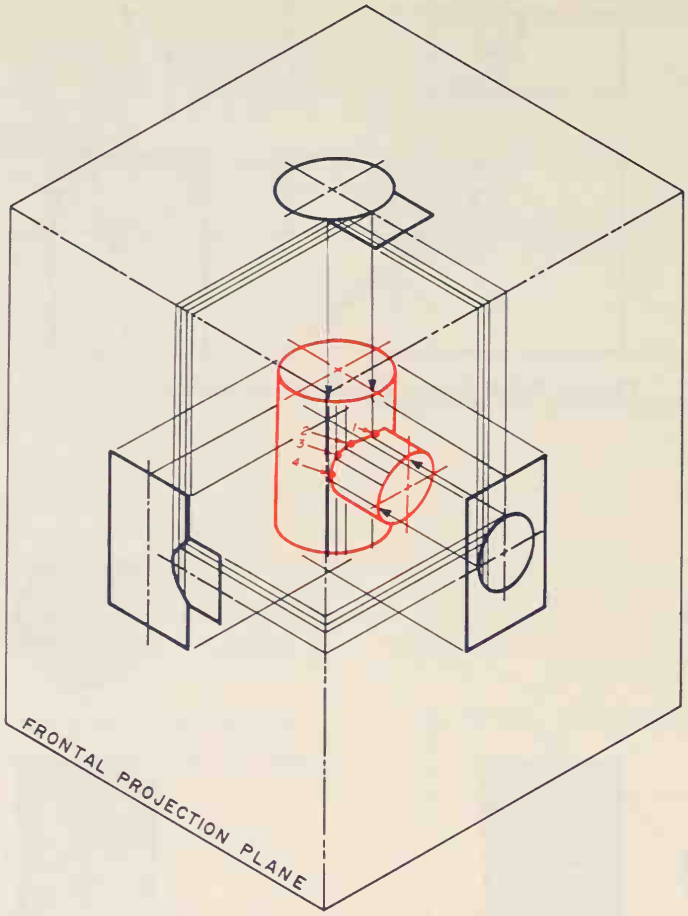


Figure 4-55 Two intersecting cylindrical surfaces

cylinder, Figure 4-56A, (Step 1). These line elements are projected in the front view. A fold line location is reflected between the front and right-side views in Figure 4-56B (Step 2) and its corresponding position is located between the front and top views by maintaining distance A at both locations. Distances 1 through 4 are transferred from the right-side view to the top view, locating the corresponding line elements 1 through 4 on the larger cylinder. As each corresponding line element from each cylinder is parallel to the front viewing plane and the same distance from it, they must intersect. A curve fitted through these points of intersection, 1 through 4, indicates the edge of intersection of the two cylinders. Additional points of intersection of corresponding line elements would be required to complete the edge of intersection in Figure 4-56B.

Incomplete Views

A drawing can be drawn absolutely *correctly*, but may sometimes still be confusing, as in Figure 4-57. Notice how the left and right-side views are difficult to understand because they overlap. Under these conditions, the drafter has the option of leaving out some features in order to make the views more clearly understood, Figure 4-58. Notice that the left and right-side views, while *not* drawn correctly, are much easier to understand. The right-side view illustrates only the right-side details, and the left-side view illustrates only the left-side details. This is actually incorrect, but is the "standard" used.

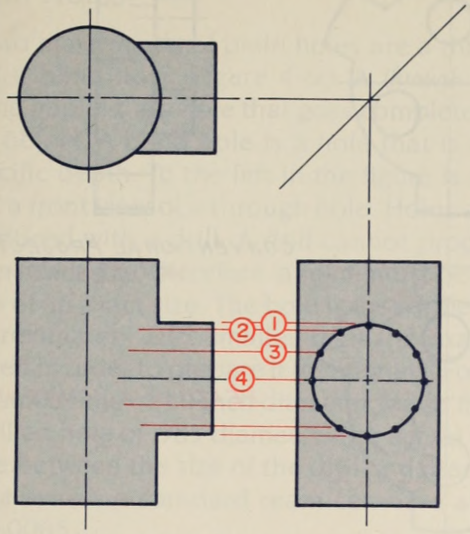


Figure 4-56A Step 1

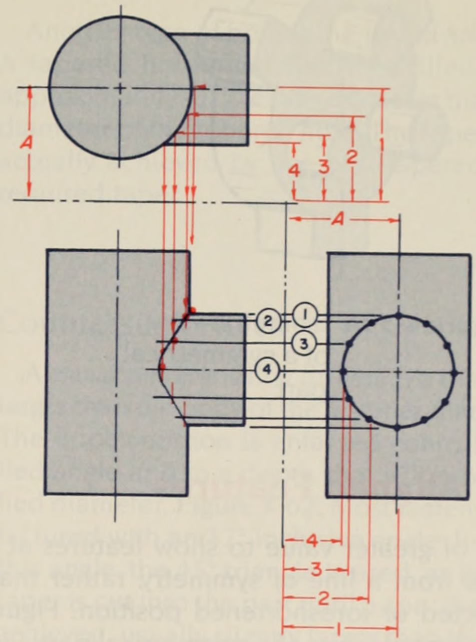


Figure 4-56B Step 2

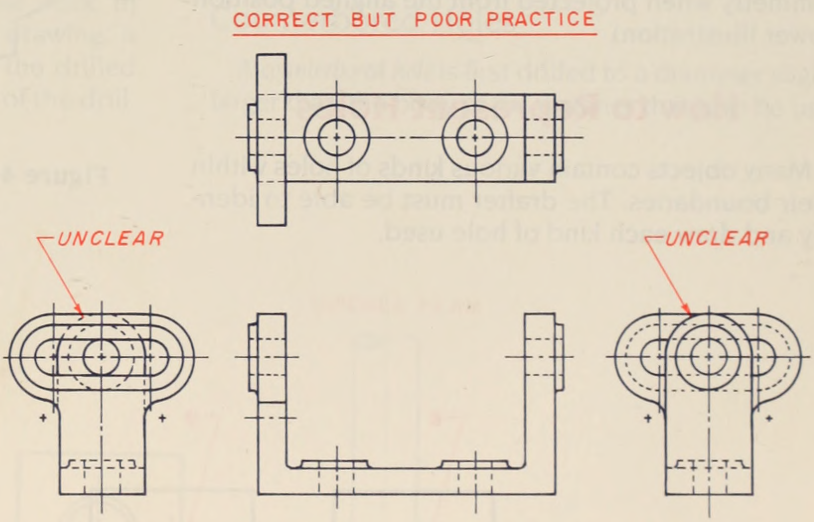


Figure 4-57 Overlapping views—poor practice

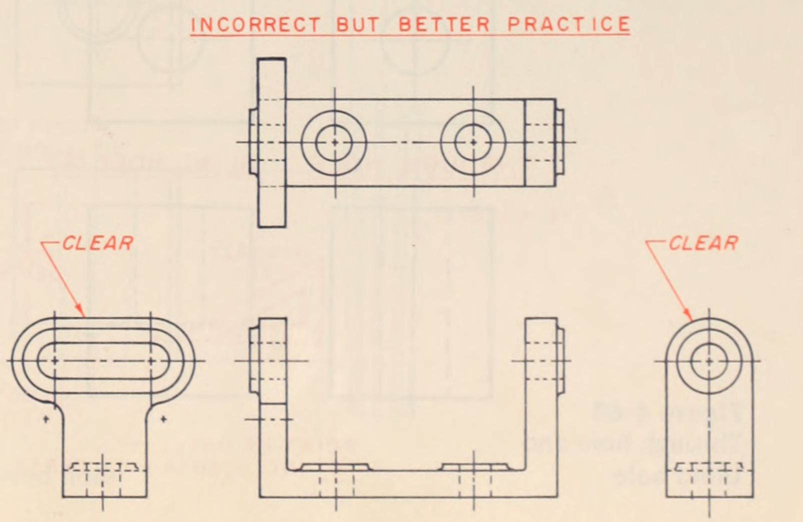


Figure 4-58 Omitting some details—better practice

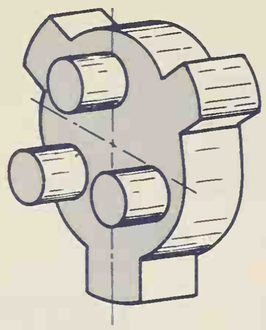


Figure 4-59A Isometric view of a symmetrical part

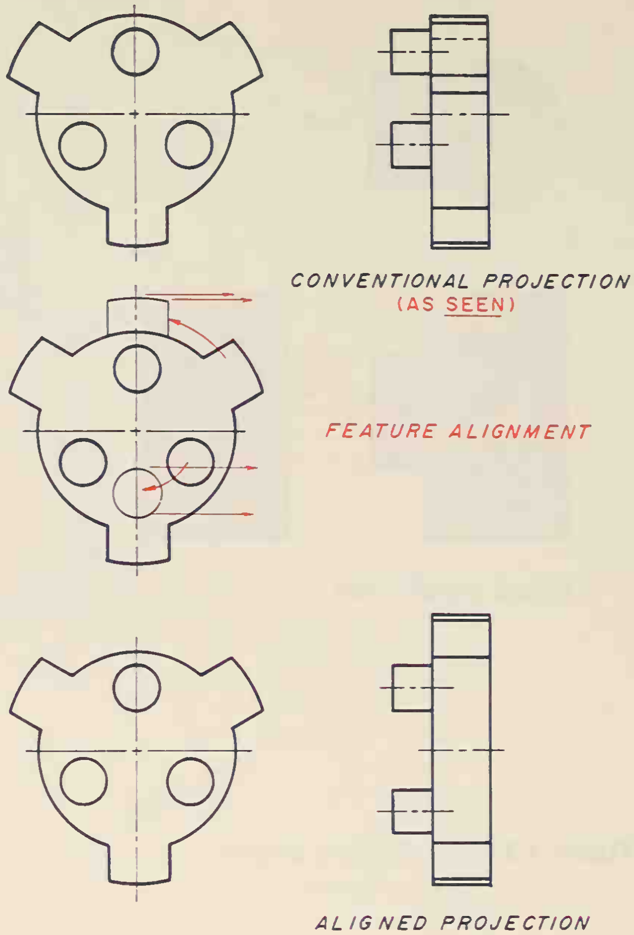


Figure 4-59B Aligned projection

Aligned Features

It is often of greater value to show features at a real distance from a line of symmetry, rather than in the projected or foreshortened position. Figure 4-59A is an isometric view of a symmetrical part. Figure 4-59B indicates how this symmetrical part appears confusing in conventional projection (top illustration) but gives a better indication of the part's symmetry when projected from the aligned position (lower illustration).

How to Represent Holes

Many objects contain various kinds of holes within their boundaries. The drafter must be able to identify and draw each kind of hole used.

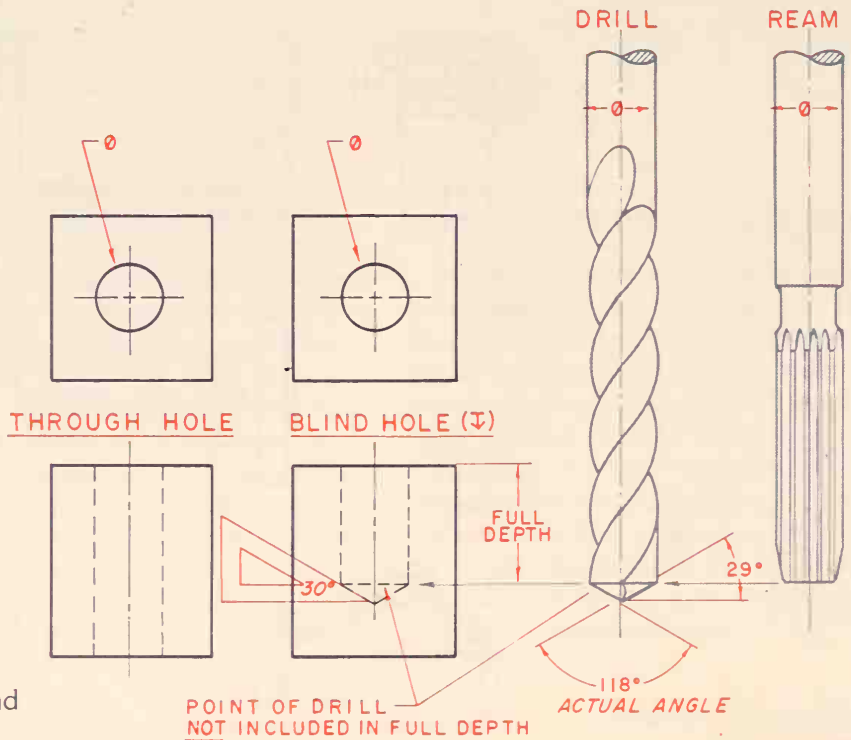


Figure 4-60 Through hole and blind hole

Plain Holes

Two major kinds of plain holes are a through hole and a blind hole, Figure 4-60. A *through hole*, as its name implies, is a hole that goes completely through the object. A blind hole is a hole that is made to a specific depth. To the left in the figure is a top view and a front view of a through hole. Holes are usually produced with a drill. A drill cannot produce holes of an exact size; therefore, a ream must be used for a hole of an exact size. The hole is first drilled to a size approximately .015 smaller than the exact size required in order to prepare it for reaming. For example, a reamed hole of 1.0-inch diameter would first require a drilled hole of .985 diameter. The actual size difference between the size of the drill and ream is called the *allowance*. A standard ream can have a tolerance of +.0005.

Blind Holes

A *blind hole* is a hole that is drilled to a specific depth. Referring back to Figure 4-60, note that the tip of the drill is conical and has a taper. This taper is approximately 118° for general purpose work. In representing the tip of the drill on the drawing, a 30°-60° triangle is used. The *full depth* of the drilled hole includes only the cylindrical portion of the drill.

Tapered Holes

Another type of hole is the *tapered hole*, Figure 4-61. A tapered hole must first be drilled using a drill approximately .015 less in diameter than the smaller diameter of the tapered hole. The tapered portion is actually achieved by use of a tapered ream of the required taper.

Countersunk Holes

A *countersunk hole* is first drilled to a diameter slightly larger than the body of the fastener that is to be used. The upper portion is enlarged conically to a specified angle and to a depth that will produce a specified diameter, Figure 4-62. Most fasteners are manufactured with an 82° inclusive angle. In representing this angle, the 45° triangle is used, as illustrated. The taper is cut into the part until a specified diameter is achieved, usually slightly larger than that of the head of the fastener.

Counterbored Holes

A *counterbored hole* is first drilled to a diameter slightly larger than the body of the fastener that is to be used.

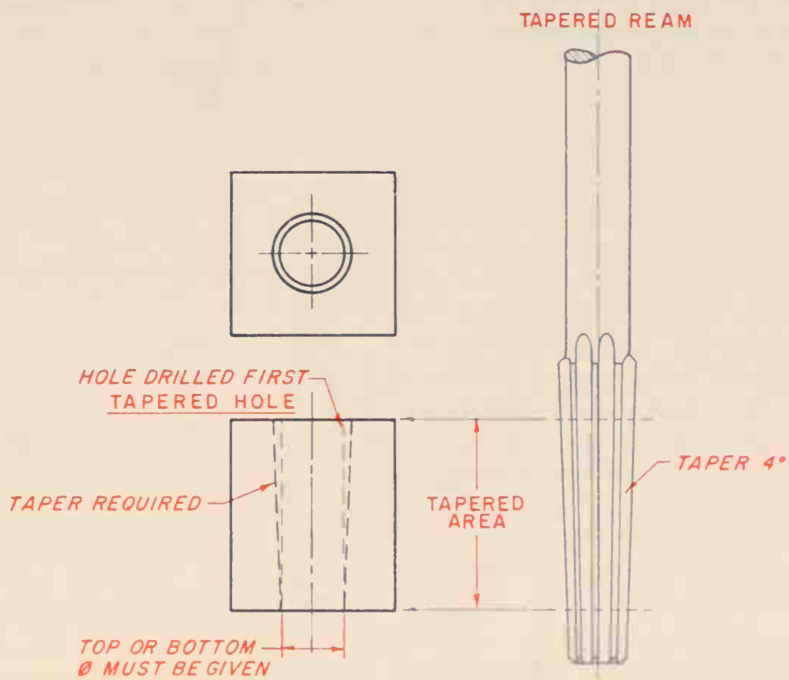
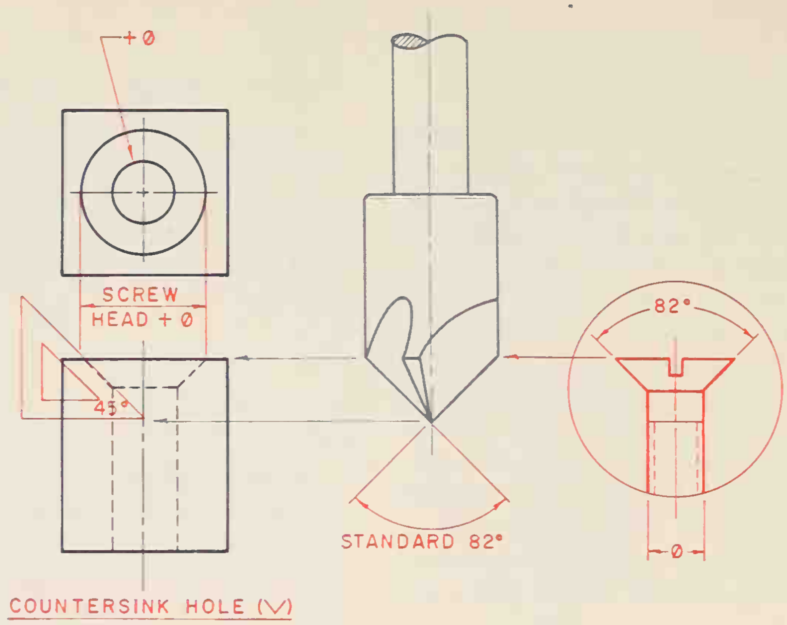


Figure 4-61 Tapered hole

Figure 4-62
Countersunk hole



The upper portion is enlarged cylindrically to a specified diameter and depth, Figure 4-63. A counterbore is usually slightly larger than the head of the fastener, and slightly deeper than the height of the fastener's head. A pilot of the counterbore is used to help guide the cutter portion and to keep in centered.

Spotface

A spotface is used in conjunction with some holes. A *spotfaced hole* is used to form a flat surface for a head of a fastener, Figure 4-64. A spotface is very similar to a counterbore, except that the depth is not specified as this is left up to the craftsperson at the time of manufacture. To illustrate the depth of the spotface, show it at a depth of .06. Think of the spotface as a washer used to provide a flat surface for the head of a fastener.

Conventional Breaks

Long objects, such as a pipe, as illustrated in Part A of Figure 4-65, would appear very small if drawn 1/4 size scale in order to fit it on a sheet of paper. By using a *conventional break*, the same pipe can be drawn *full size* with a central portion "broken" or removed, as illustrated in Part B of Figure 4-65. This gives a much clearer understanding of the object. Note that the broken-out or removed section must be the same section throughout its entire length.

Kinds of Conventional Breaks

There are three major kinds of "breaks" used to remove center portions of an object: the "S" break, the "Z" break, and the freehand break. The "S" *break* is used for round objects. To draw the "S" break, refer

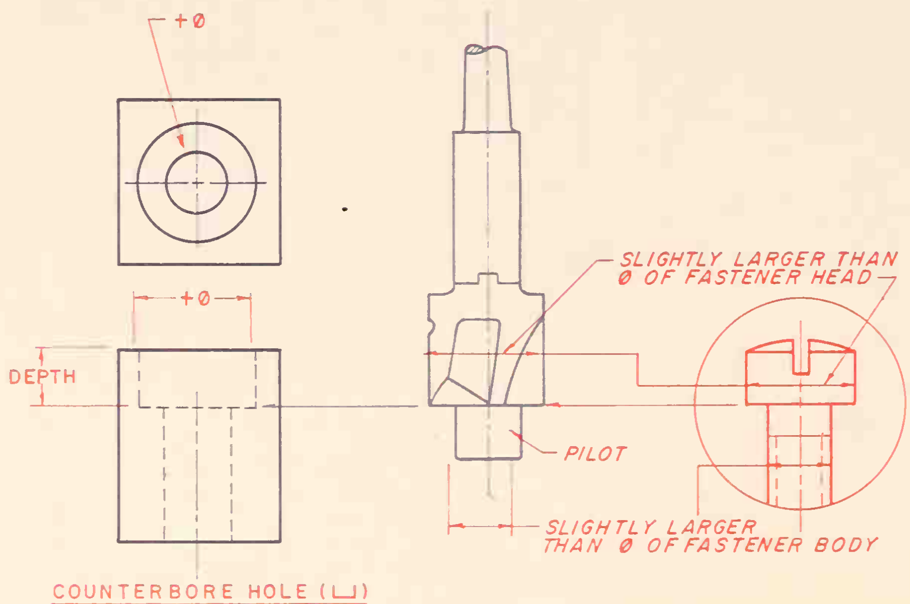


Figure 4-63
Counterbored hole

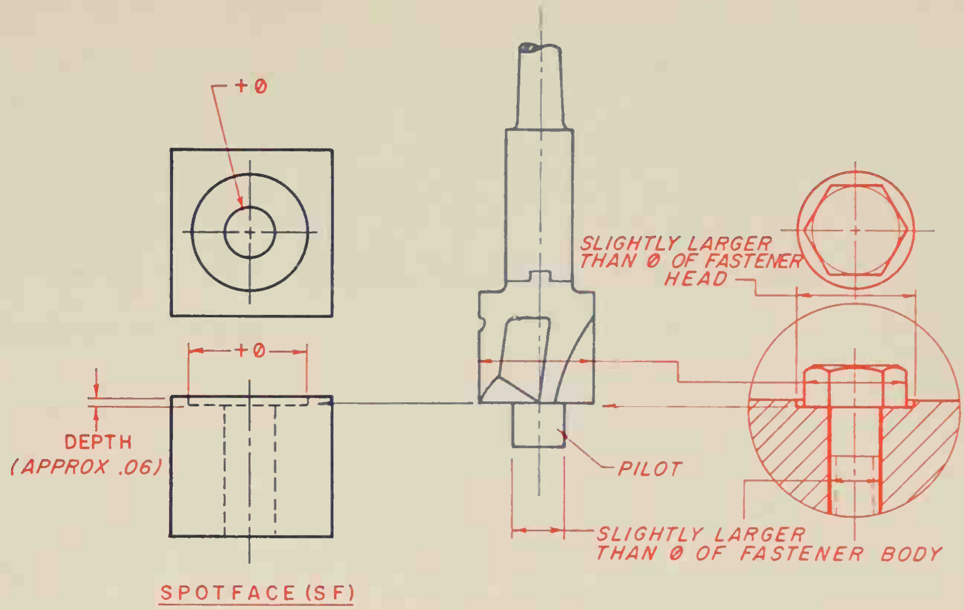


Figure 4-64 Spotfaced hole

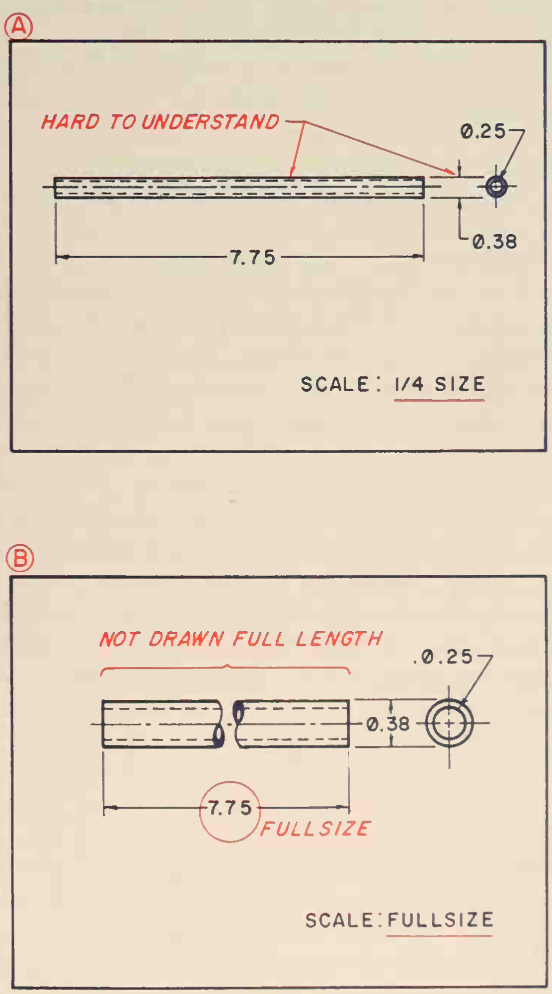


Figure 4-65 Conventional breaks

to Figure 4-66, Steps 1 through 5. A template can also be used to draw the "S" break. The "Z" *break* is usually used for thin, long or wide parts, Figure 4-67, Part A. The "Z" itself is drawn freehand, as illustrated. The *freehand break* is used to illustrate long, rectangular parts, Figure 4-67, Part B.

Visualization

Visualization is the process of recreating a three-dimensional image of an object in a person's mind, using the evidence and clues provided by orthographic drawings or other presentations. This process has been the focus of much investigation, often used for studying a person's ability to perceive (such as in intelligence tests). The goal of reading an orthographic drawing is to visualize accurately information about the relative positions of an object's surfaces and geometric features.

There is some evidence that an active "what if" imagination is a key ingredient in the visualization process. For example, in attempting to find the cause of a discovered broken window, a "what if" attitude seeks further clues, and a nearby baseball would provide a different probability of the event than would a scattering of bird feathers. Correspondingly, a solid-line circle in a view causes a "what if" visualizer to seek further evidence. If an adjoining view has a solid-line rectangle, bisected by a center line (axis) that

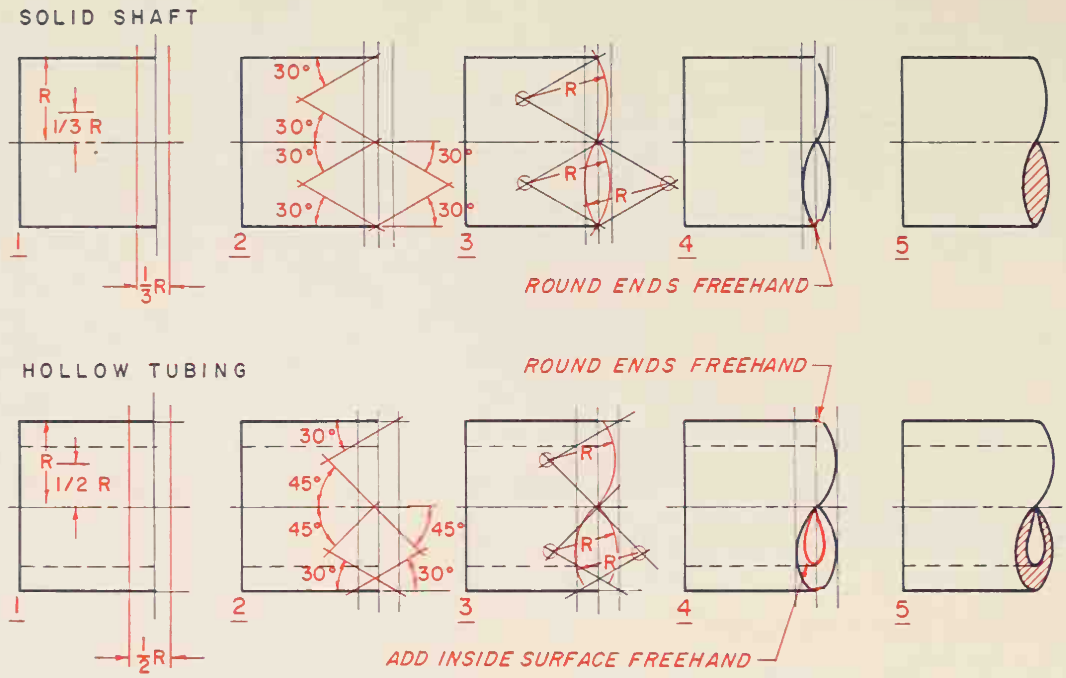


Figure 4-66 "S" break

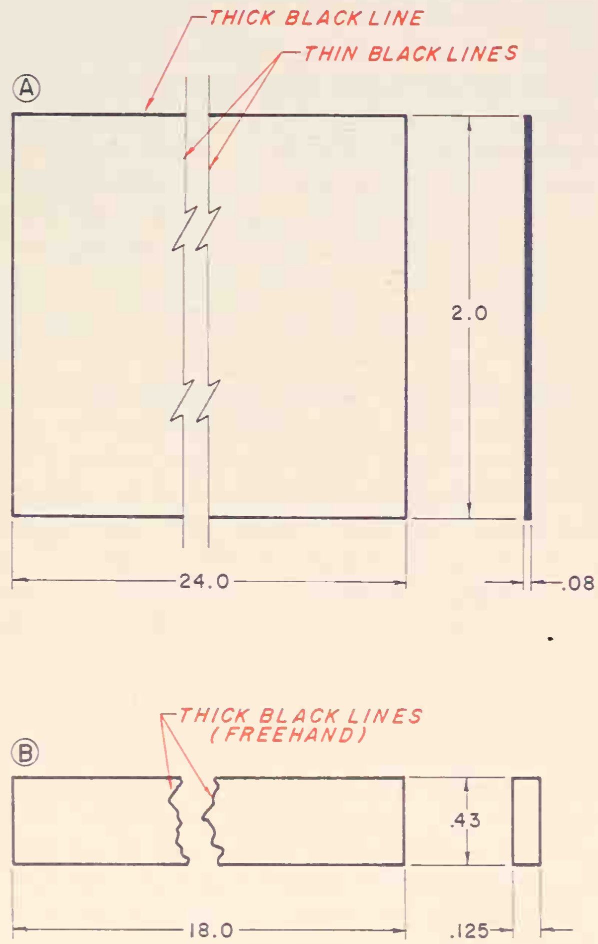


Figure 4-67 "Z" break and freehand break

aligns with the circle's center, a solid cylinder is indicated (see Figure 4-68). If the aligned rectangle has hidden lines, a hole is indicated (see Figure 4-69). A single orthographic view seldom is capable of providing three-dimensional evidence, and the reader must consider two or more views simultaneously in seeking an understanding of feature outlines.

Engineering drawings all follow the same procedures, and none is any more or less difficult to read than another. However, the quantity of geometric information varies considerably among drawings, and the time required to interpret the information varies accordingly. Visualization practice using simple drawings is required by most individuals to gain experience in mental three-dimensional image construction. Even experienced drafters often use modeling clay to form a three-dimensional object from orthographic views. In such cases, it is best to cut away the outline of each orthographic view, rather than piece together components to form the outline. Once a *brilliant* (or *gestalt*) image of the object has been perceived three-dimensionally, the possibility of error in its drawing or construction will be minimized, as it will be "real" to the visualizer.

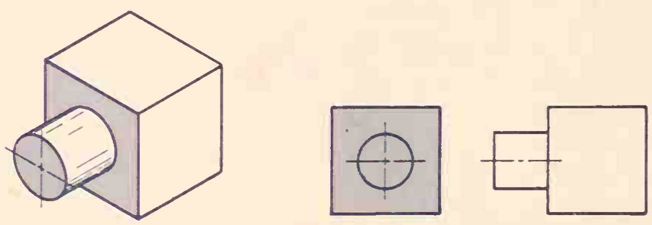


Figure 4-68 Visualization of an object

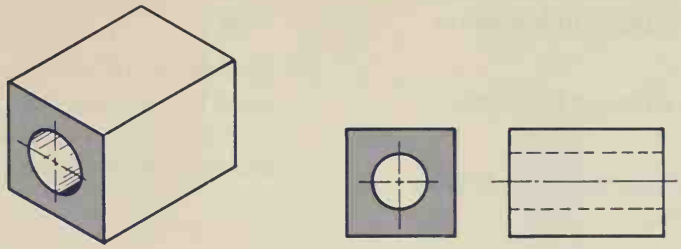


Figure 4-69 Visualization of an object

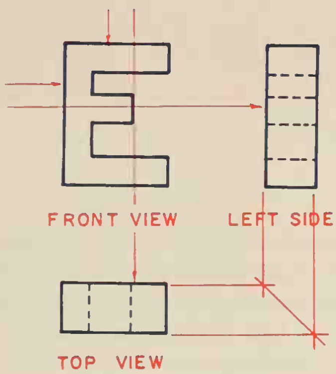


Figure 4-70
First-angle projection

First-Angle Projection

While the United States and Canada use the third-angle projection multiview system, most of the rest of the world uses first-angle projection. In *third-angle projection*, the top view is projected directly above the front view. The right side is projected directly to the right of the front view, as has been explained throughout this chapter.

First-angle projection also starts with the front view as the most important view and starting point, but *rotates* the views from the front view, Figure 4-70. Starting from the front view, rotating the object to the right, you will be viewing the left side; therefore, the left side appears and is drawn to the right of the front view. Again, starting from the front view, rotating the object down toward the viewer, you will be viewing the top view; therefore, the top view appears and is drawn below the front view. Each viewing plane displays an image from the object's far side, rather than the near-side image of third-angle projection.

Due to the increase in international exchange of parts and drawings, the projection method used should be indicated on the drawing. If it is not indicated, simply note the drawing's country of origin. Figure 4-71A illustrates the symbol used to denote third-angle projection. Figure 4-71B illustrates the

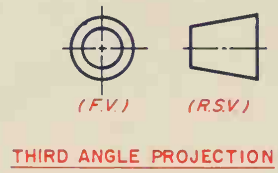


Figure 4-71A
Third-angle projection symbol

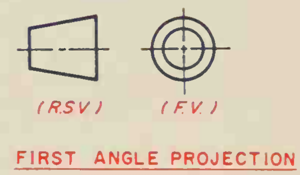


Figure 4-71B
First-angle projection symbol

symbol used to denote first-angle projection. Both symbols illustrate the front view (F.V.) and the right-side view (R.S.V.). The symbols are usually placed within the title block of the drawing.

Review

1. Why is a sketch so important?
2. Explain the following terms (use illustrations if necessary): runout, rounds, and fillets.
3. Explain the difference between a perspective view and a multiview of an object.
4. What is considered the work area?
5. Where is the third-angle projection multiview system used? Where is the first-angle projection multiview system used?
6. What is the standard depth calloff for a spotface?
7. For what is the lightly constructed 45° angle projection line used?
8. In representing the tip of a drill in a blind hole, what triangle is used?
9. List three important considerations that must be used in positioning the front view.
10. How many views are used to describe an object?

11. To illustrate a countersunk hole, what triangle is used to draw the countersunk portion of the hole?

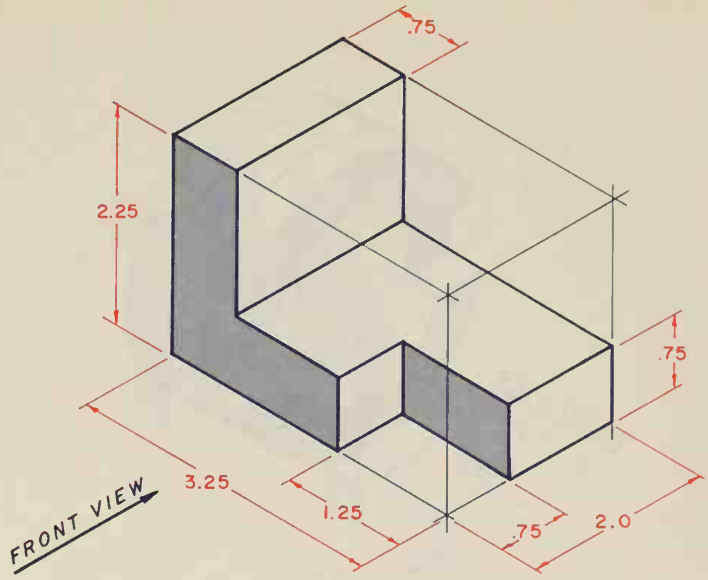
12. When and why should a drawing be lightly numbered?

13. List three major kinds of conventional breaks and note why each is used.

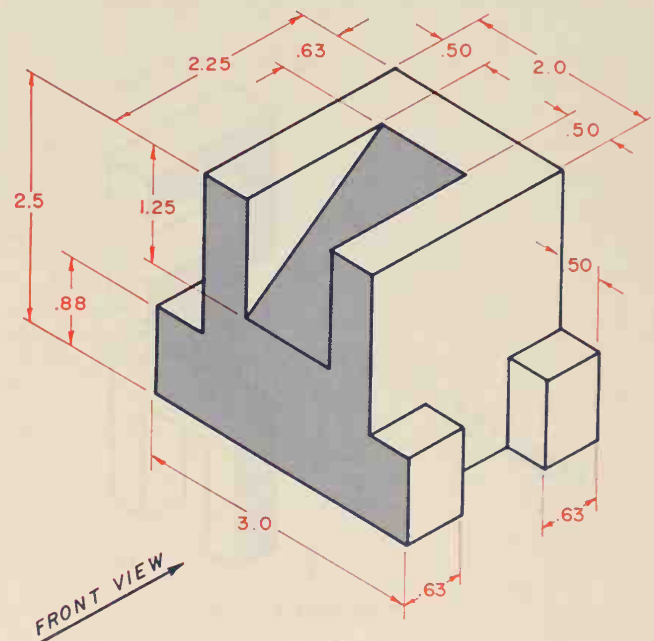
14. When is it permissible to use an incomplete view?

15. Explain in full the mathematical procedure used to center a typical three-view drawing with a 1" (25 mm) space between views within the work area. Make a sketch if necessary.

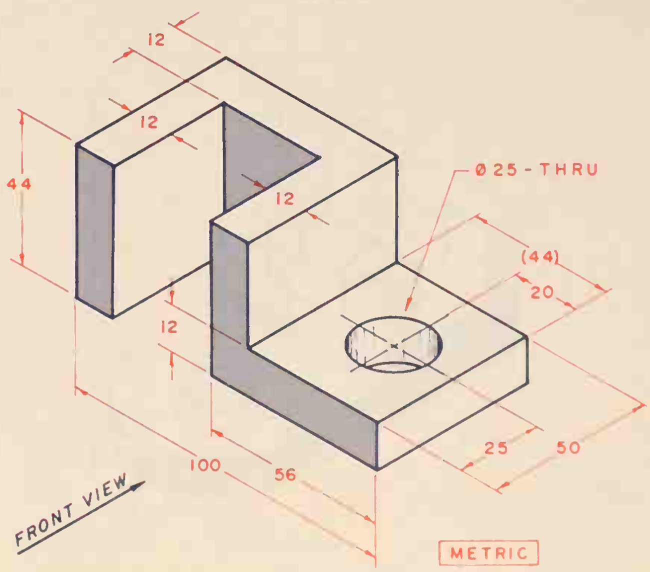
Chapter Four Problems



Problem 4-1



Problem 4-2



Problem 4-3

The following problems are intended to give the beginning drafter practice in visualizing the multiview system, practice in choosing and sketching the required view, practice is using drafting instruments and using correct line thickness. As these are beginning problems, no dimensions will be used at this time.

The steps to follow in laying out all drawings throughout this book are:

Step 1. Study the problem carefully.

Step 2. Choose the view with the most detail as the front view.

Step 3. Position the front view so that there will be the least number of hidden lines in the other views.

Step 4. Make a sketch of all required views.

Step 5. Center the required views within the work area with a 1-inch (25 mm) space between each view.

Step 6. Use light projection lines. Do not erase them.

Step 7. Lightly complete all views.

Step 8. Check to see that all views are centered within the work area.

Step 9. Check to see that there is a 1-inch (25 mm) space between all views.

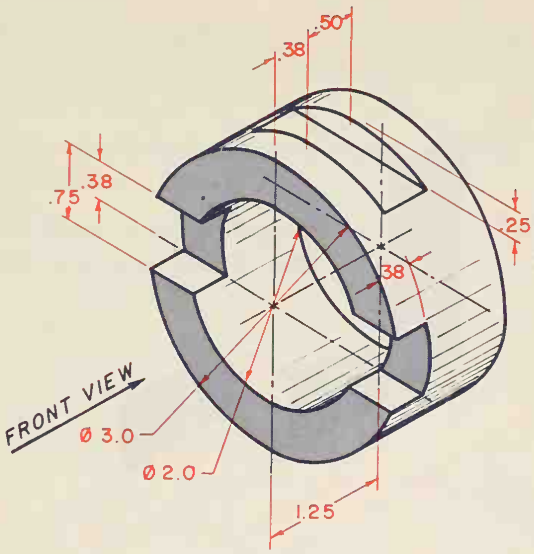
Step 10. Carefully check all dimensions in all views.

Step 11. Darken in all views using correct line thickness.

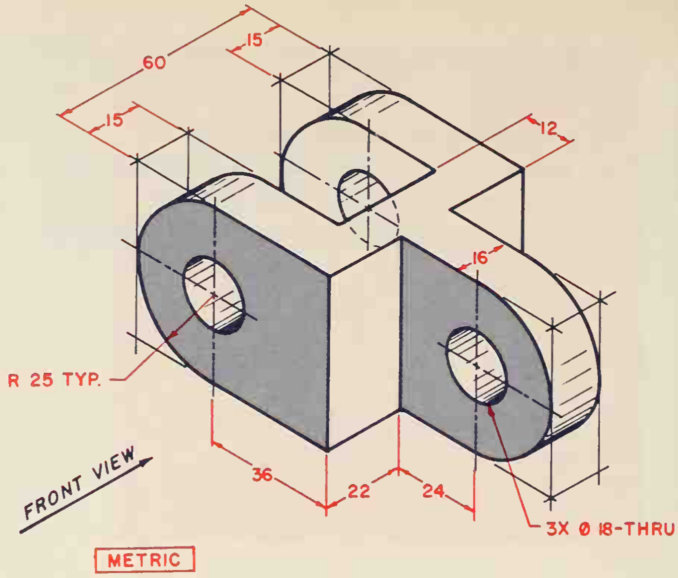
Step 12. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problems 4-1 through 4-11

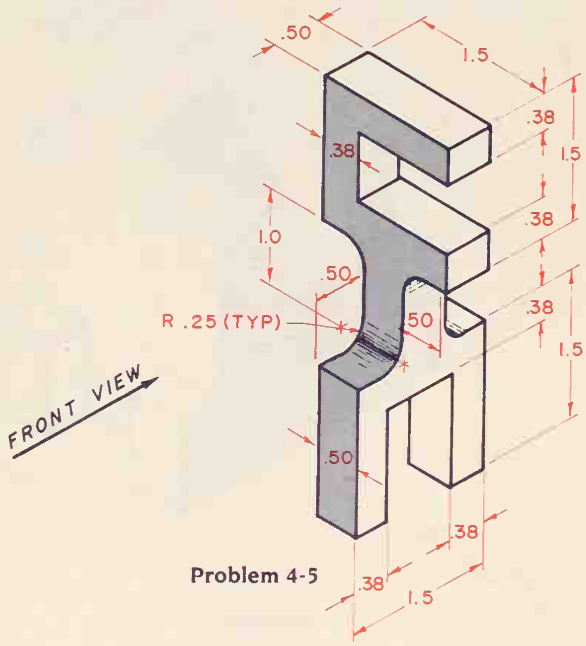
Construct a 3-view drawing of each object, using the listed steps.



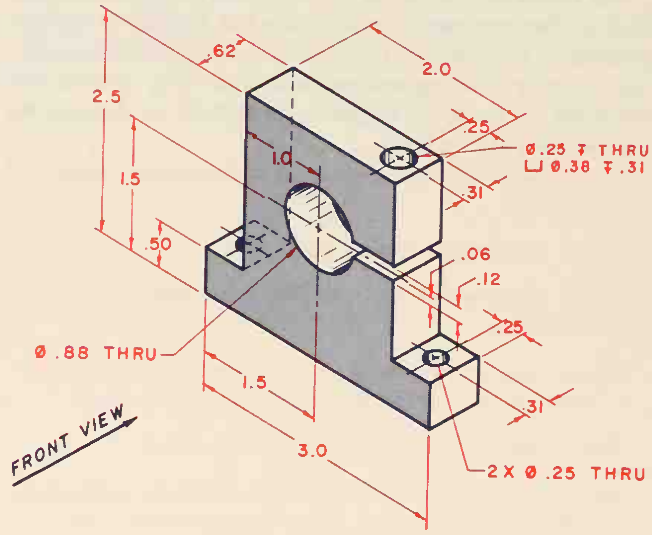
Problem 4-4



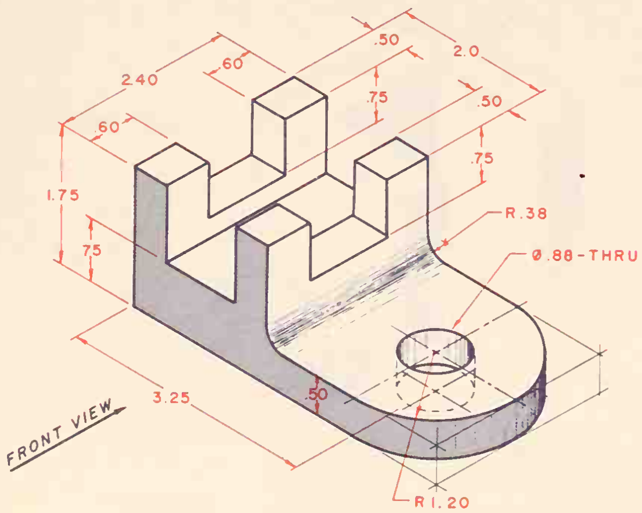
Problem 4-7



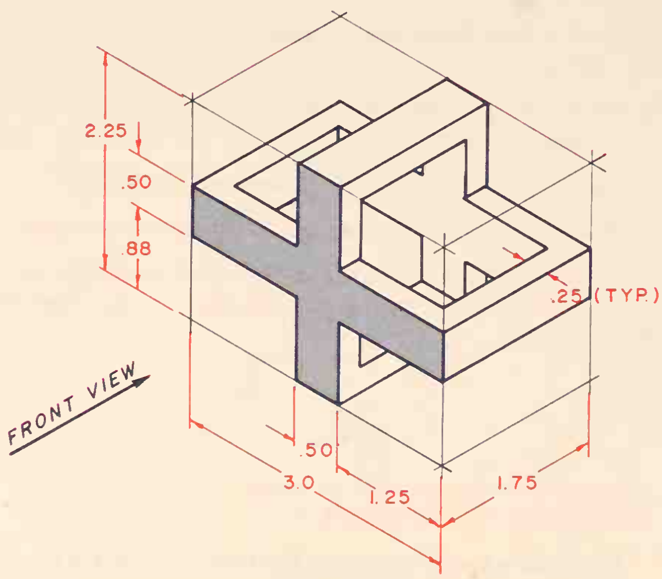
Problem 4-5



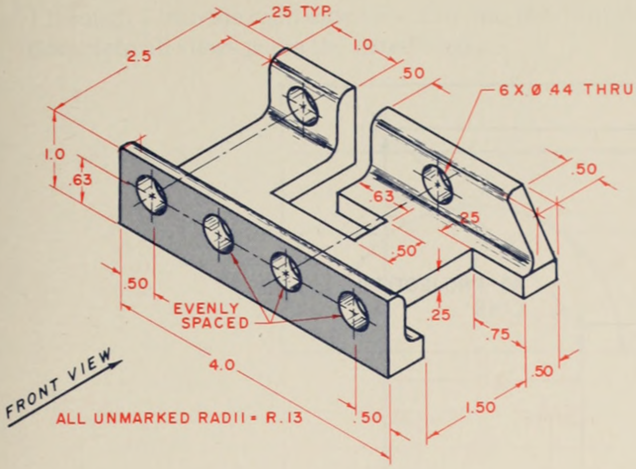
Problem 4-8



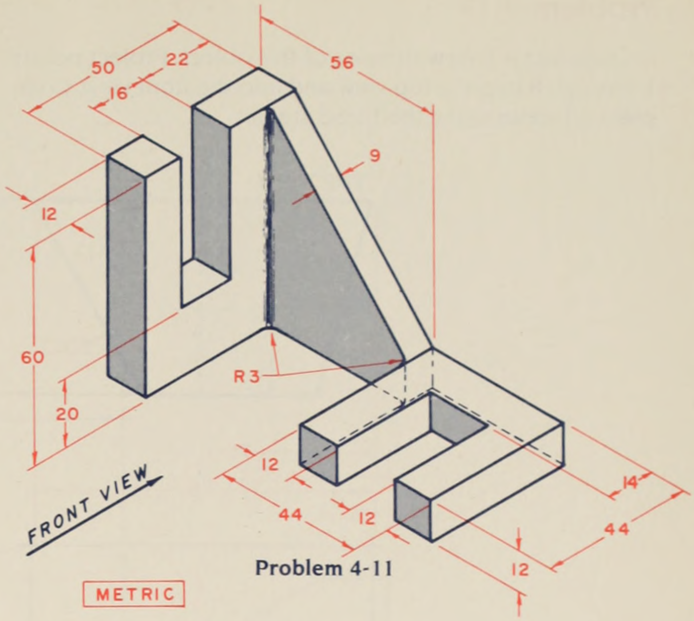
Problem 4-6



Problem 4-9



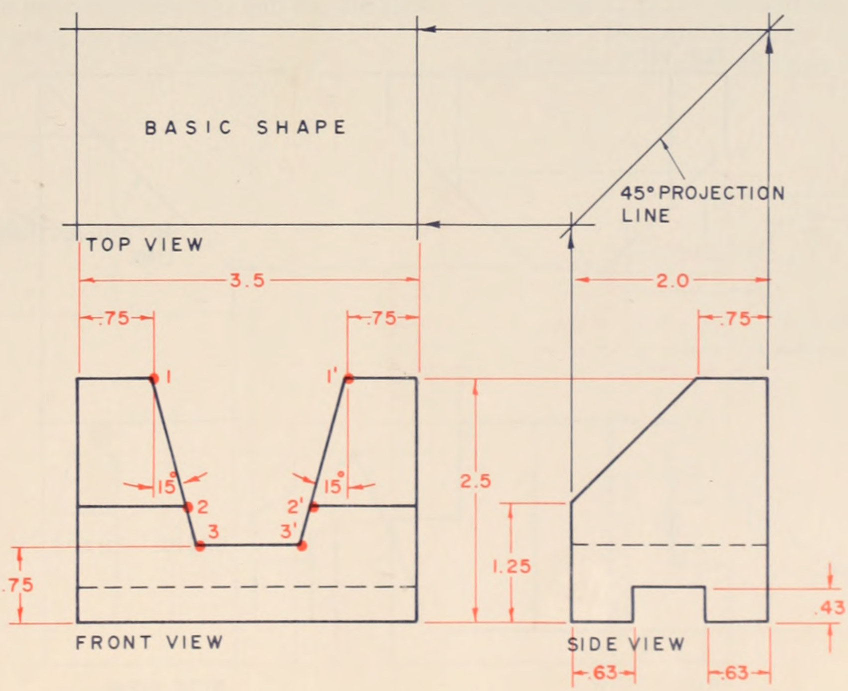
Problem 4-10



Problem 4-11

Problem 4-12

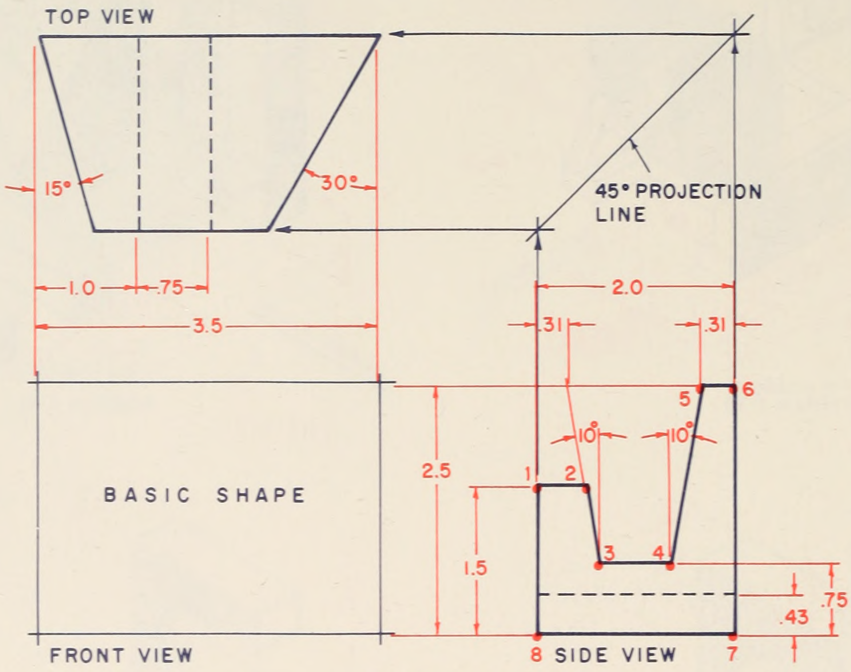
Construct a 3-view drawing of this object. Project points 1, 2 and 3 into the right-side view and into the top view. Complete all views using the listed steps.



Problem 4-12

Problem 4-13

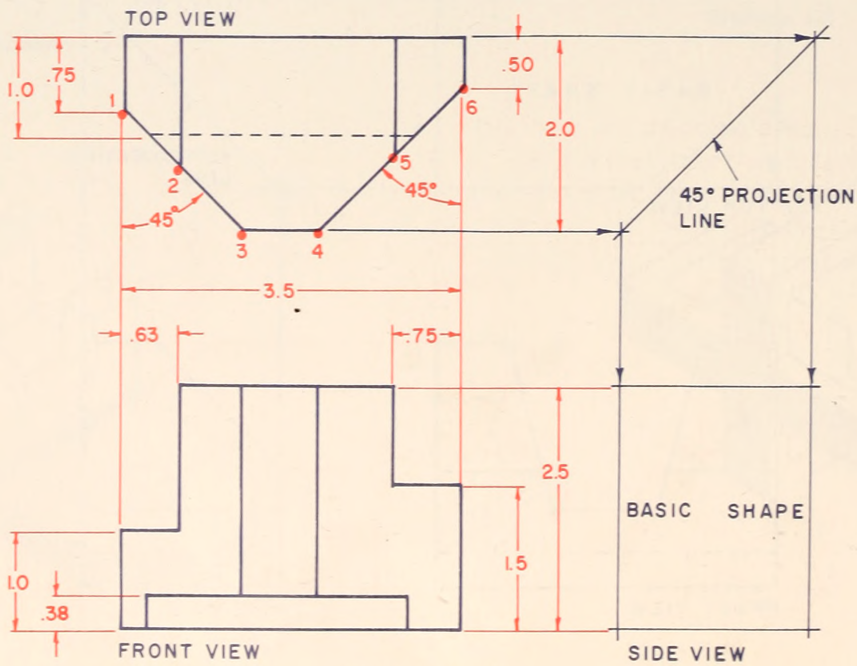
Construct a 3-view drawing of this object. Project points 1 through 8 into the top view and into the front view. Complete all views using the listed steps.



Problem 4-13

Problem 4-14

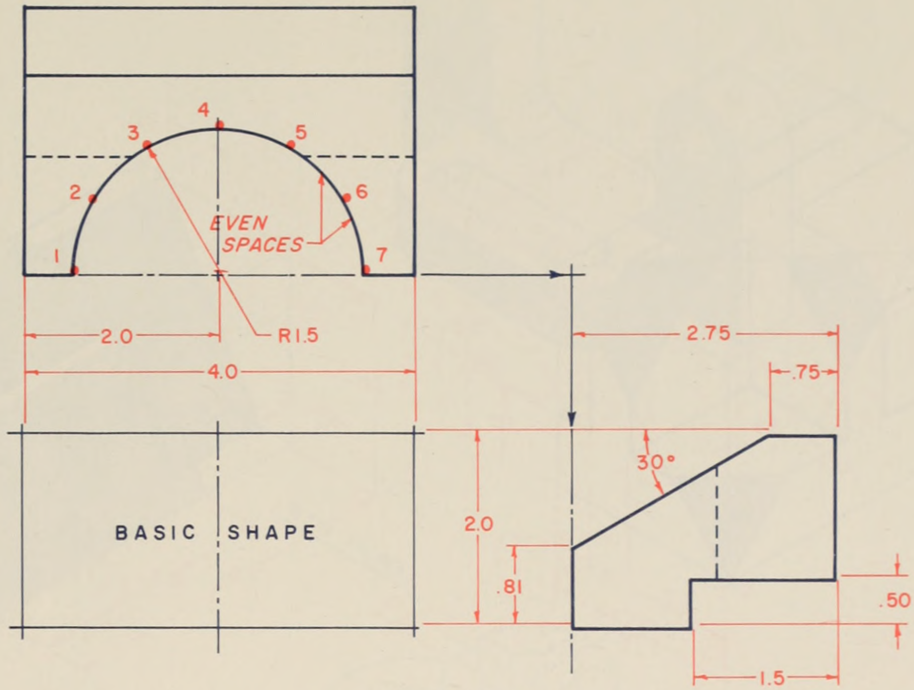
Construct a 3-view drawing of this object. Project points 1 through 6 into the front view and into the right-side view. Complete all views using the listed steps.



Problem 4-14

Problem 4-15

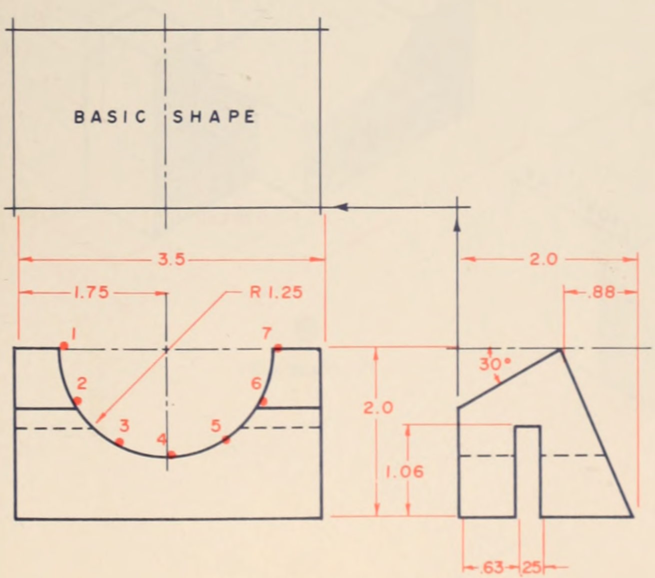
Construct a 3-view drawing of this object. Project points 1 through 7 into the right-side view and into the front view. Complete all views using the listed steps.



Problem 4-15

Problem 4-16

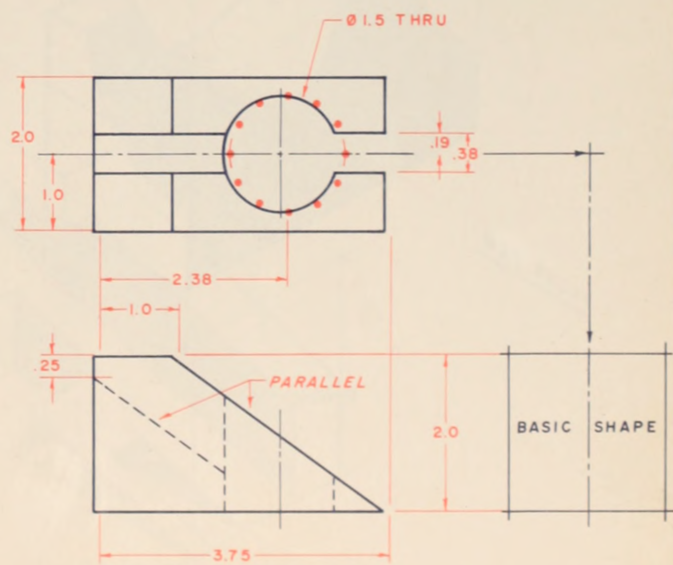
Construct a 3-view drawing of this object. Project points 1 through 7 into the right-side view and into the top view. Complete all views using the listed steps.



Problem 4-16

Problem 4-17

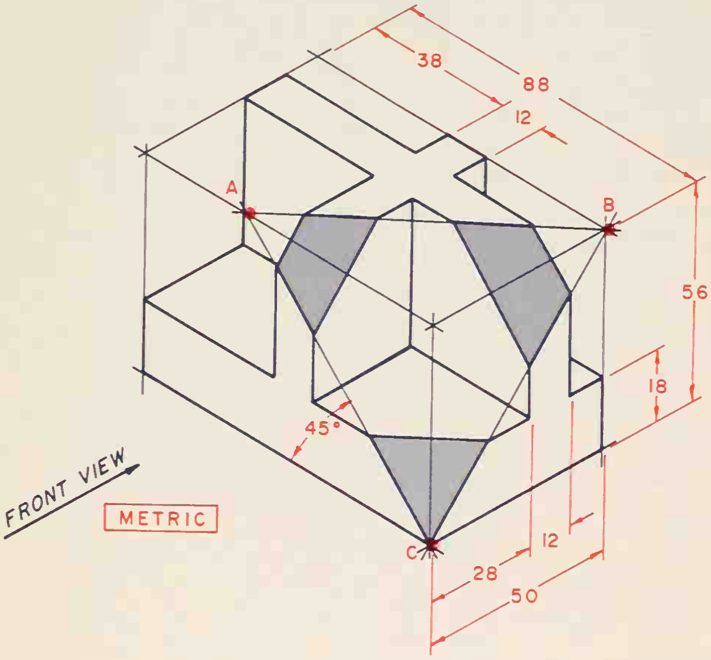
Construct a 3-view drawing of this object. Locate and number 12 points around the 1.5 diameter hole. Project points 1 through 12 into the front view and into the right-side view. Complete all views using the listed steps.



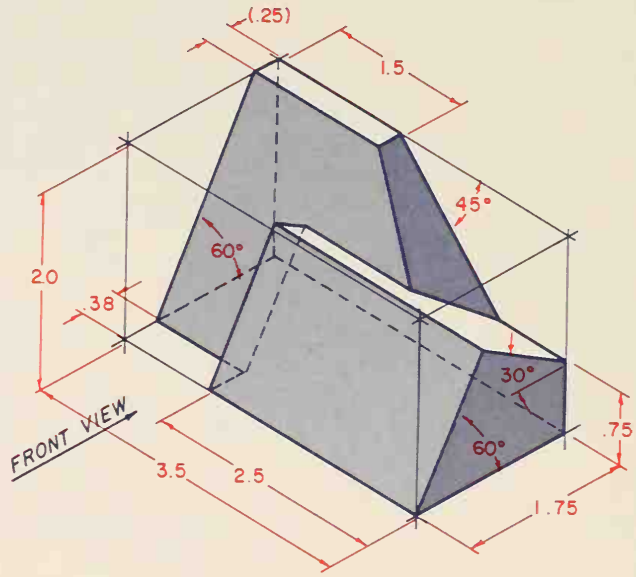
Problem 4-17

Problems 4-18 through 4-25

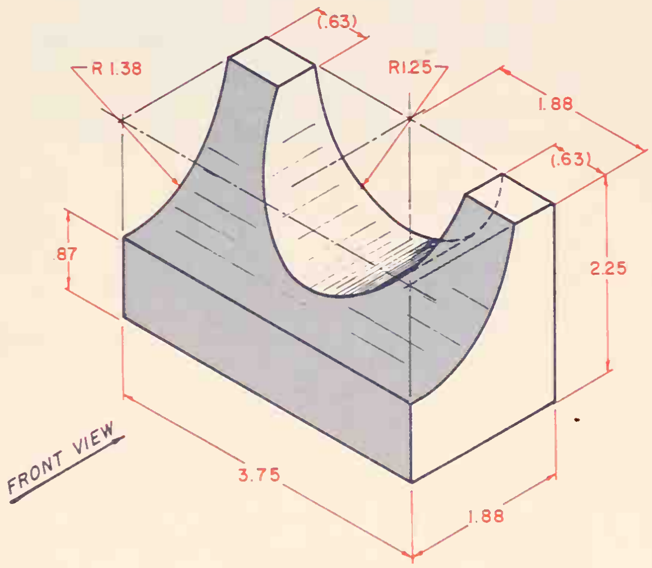
Construct a 3-view drawing of each object, using the listed steps.



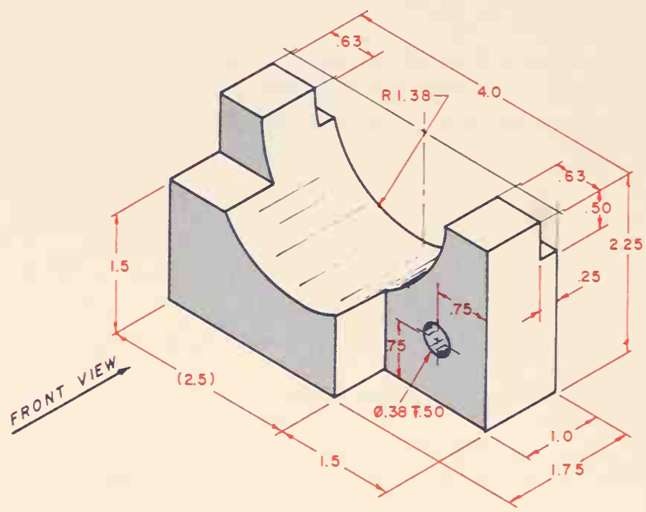
Problem 4-18



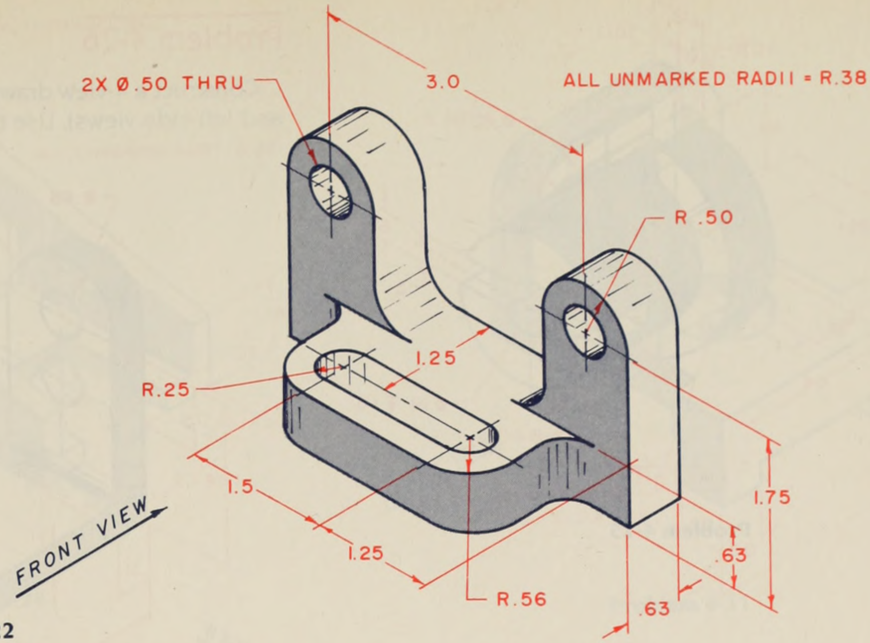
Problem 4-20



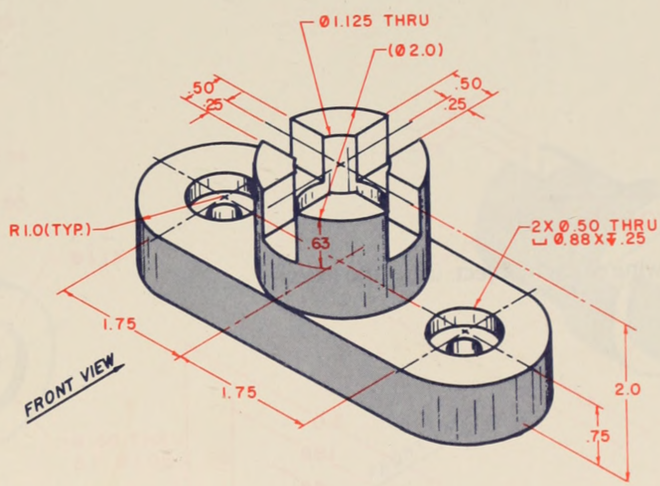
Problem 4-19



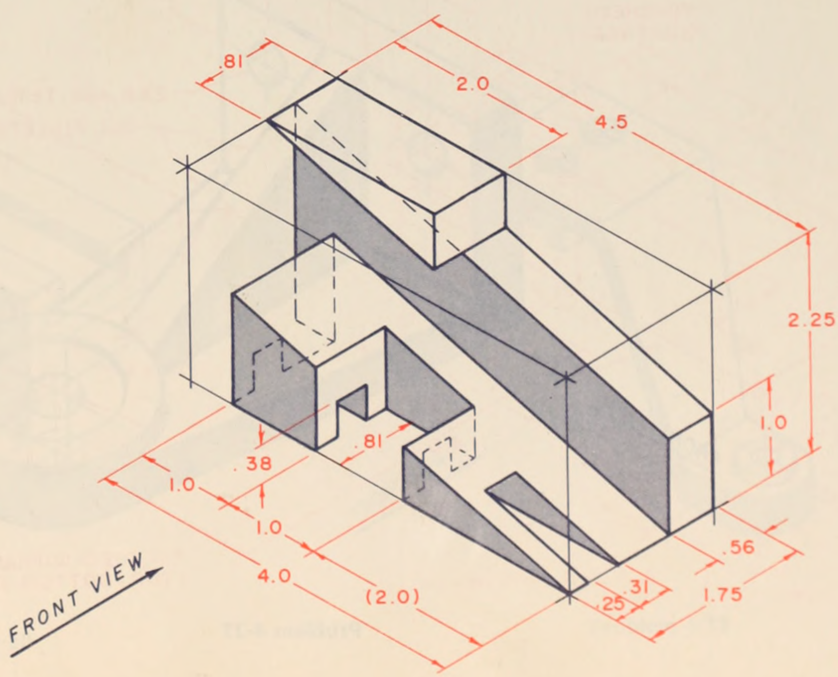
Problem 4-21



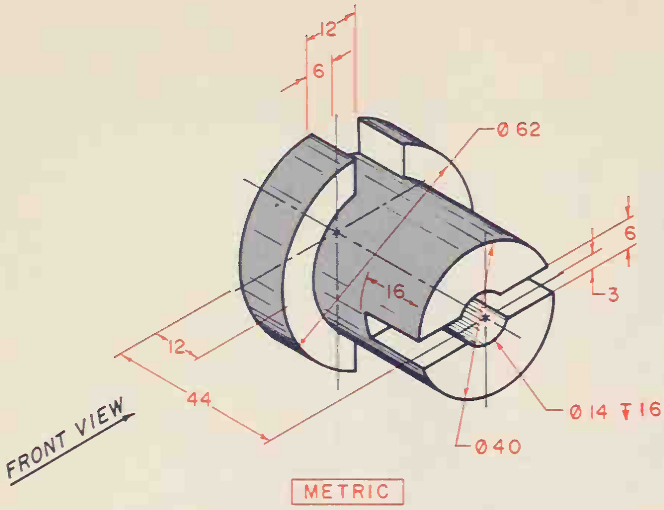
Problem 4-22



Problem 4-23



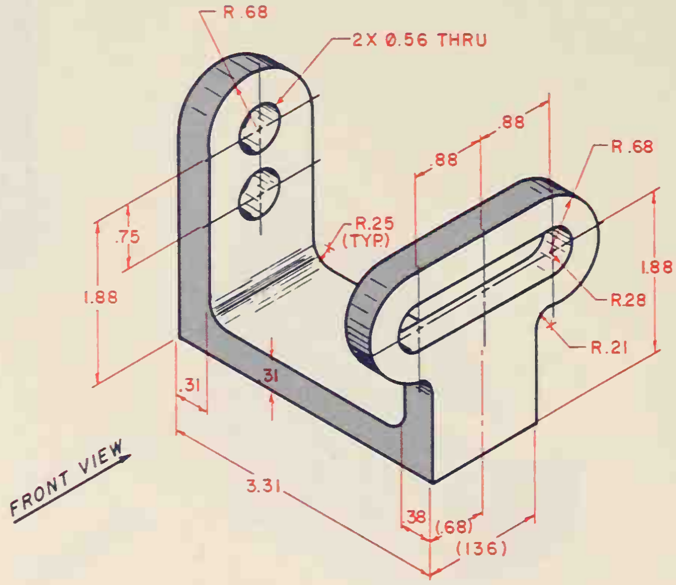
Problem 4-24



Problem 4-25

Problem 4-26

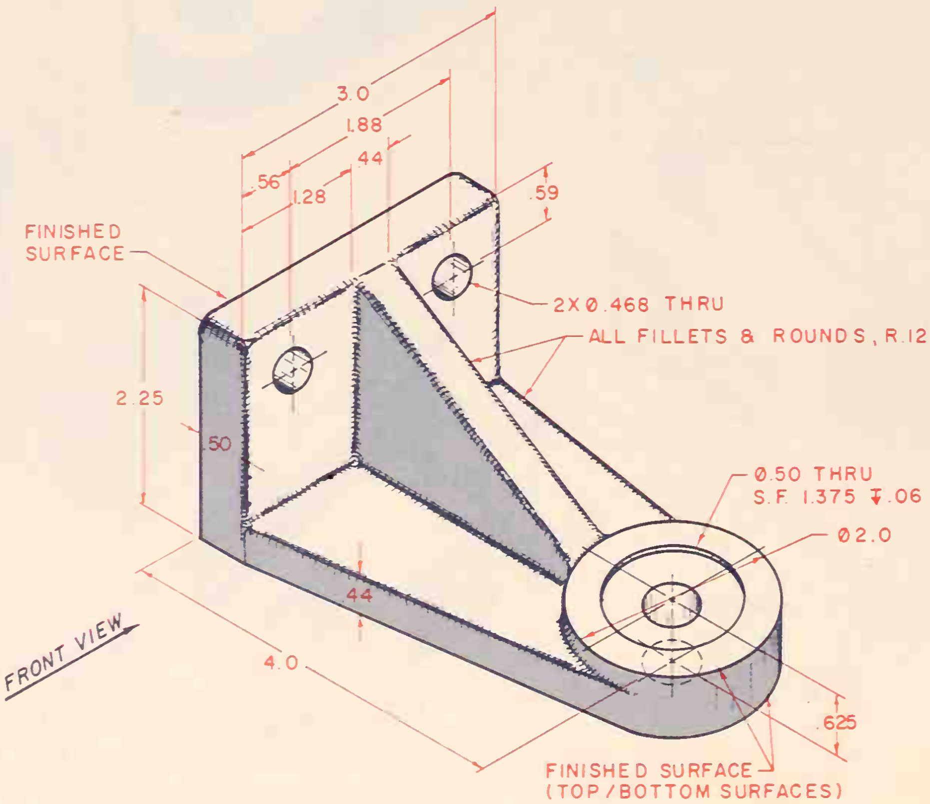
Construct a 4-view drawing of this object (front, top, right, and left-side views). Use the listed steps.



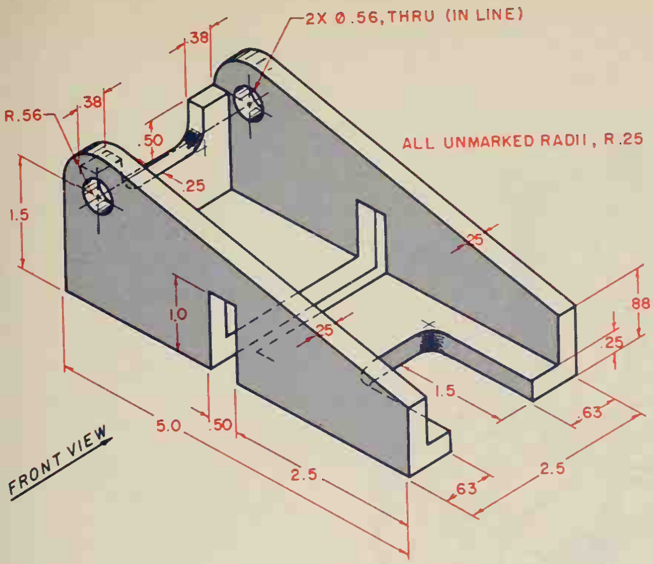
Problem 4-26

Problems 4-27 through 4-36

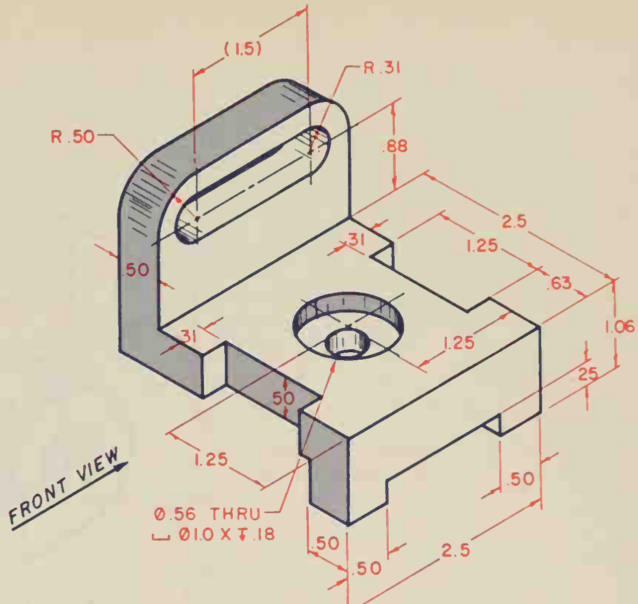
Construct a 3-view drawing of each object, using the listed steps.



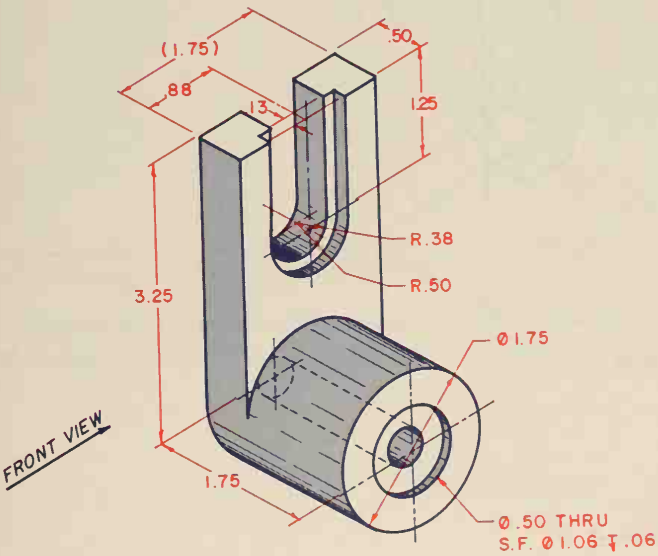
Problem 4-27



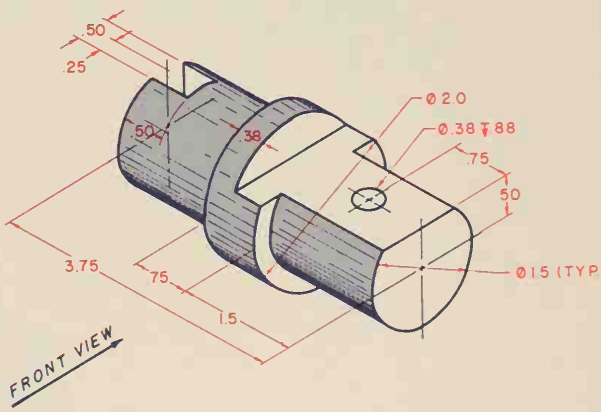
Problem 4-28



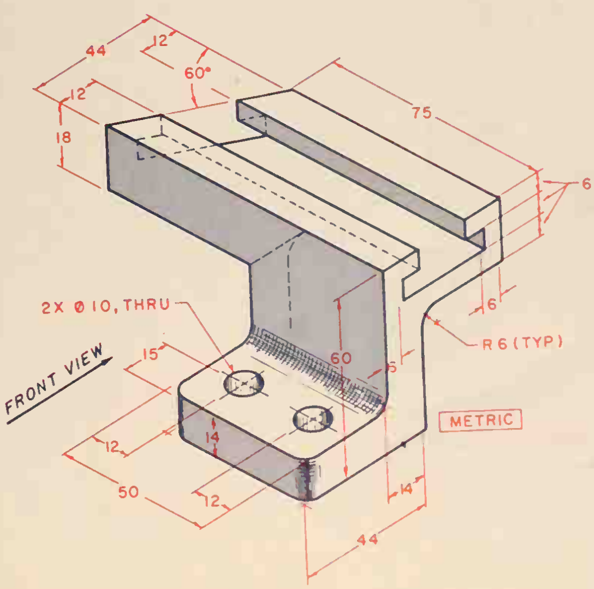
Problem 4-31



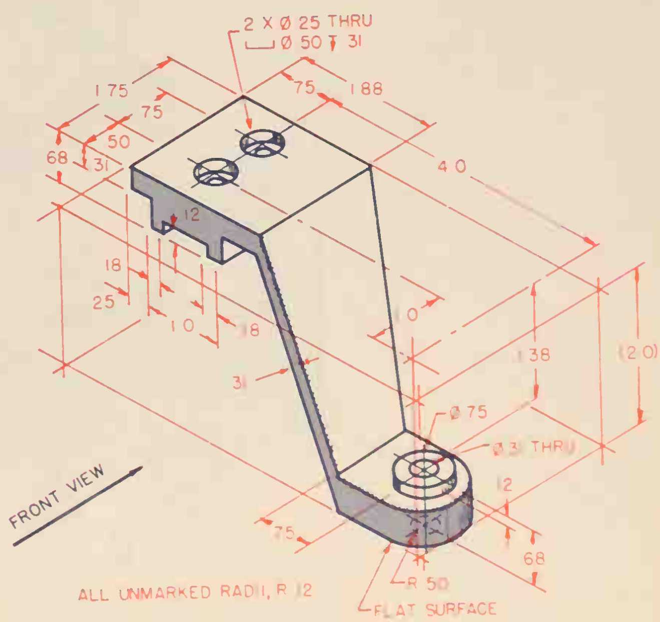
Problem 4-29



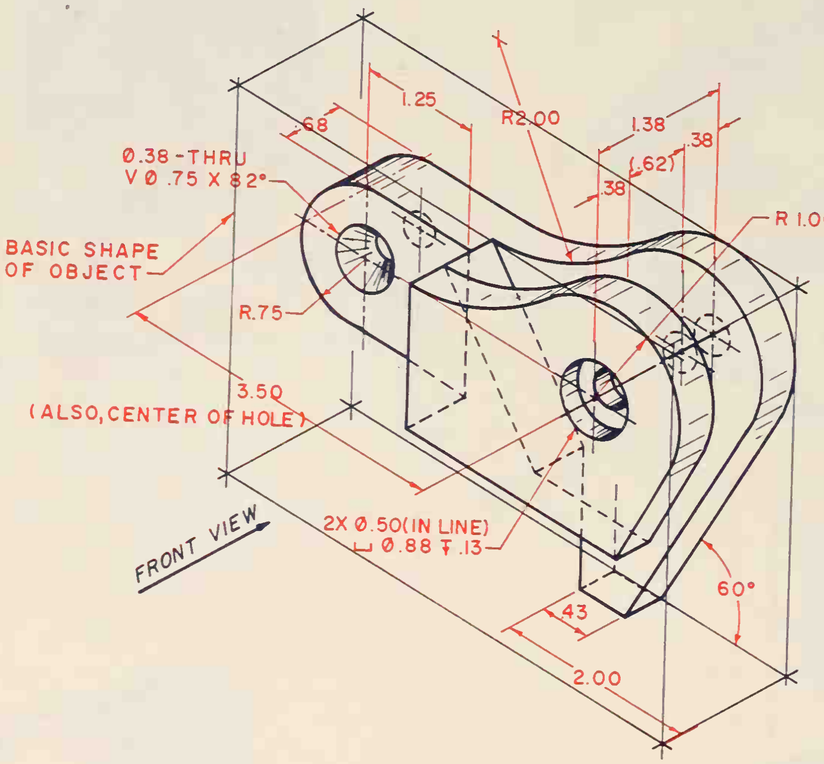
Problem 4-32



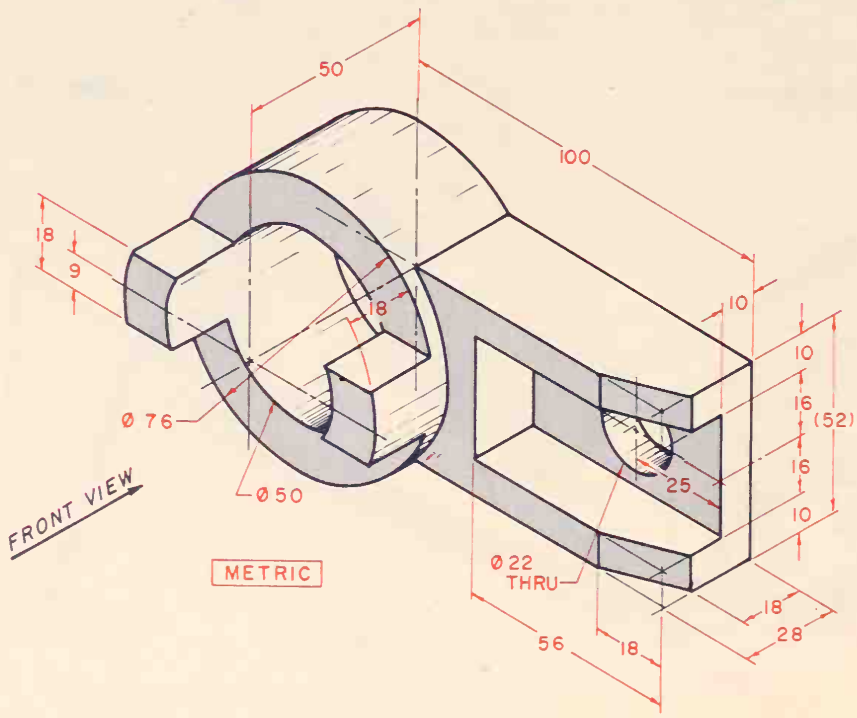
Problem 4-30



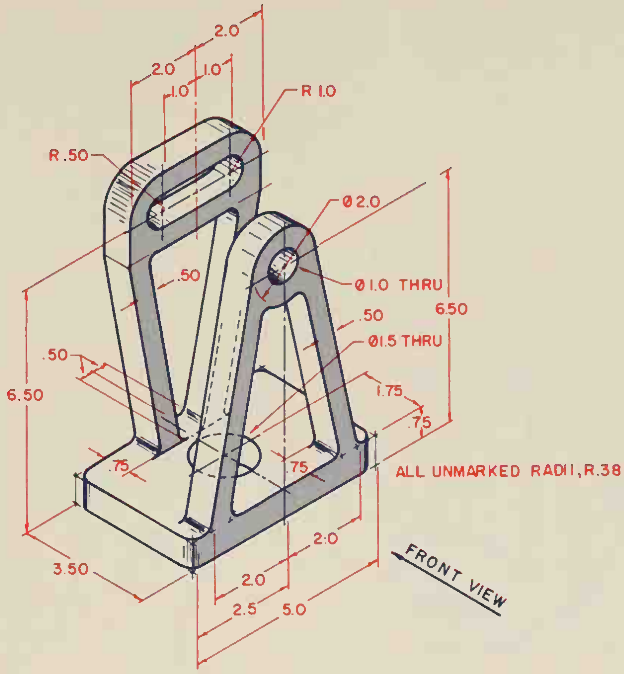
Problem 4-33



Problem 4-34



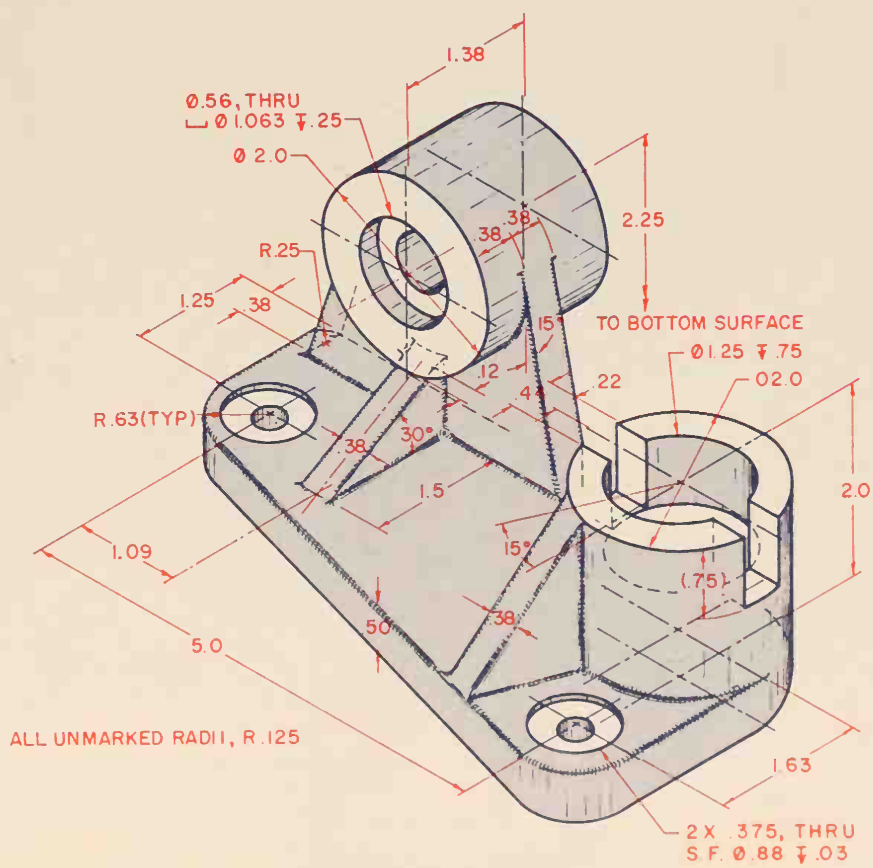
Problem 4-35



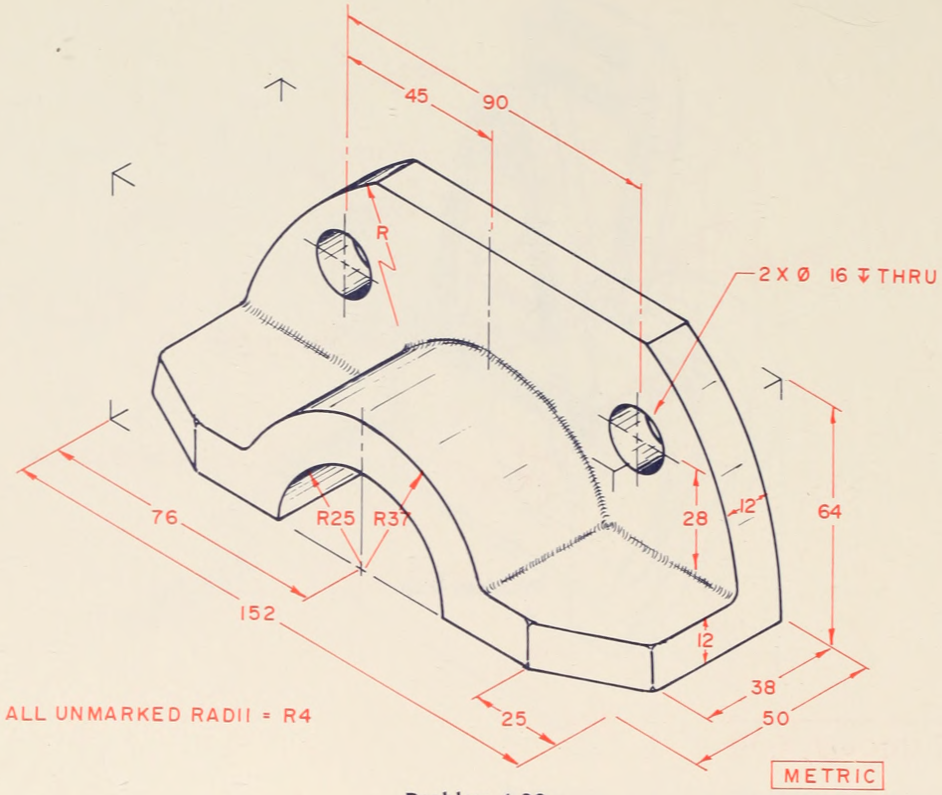
Problem 4-36

Problems 4-37 through 4-50

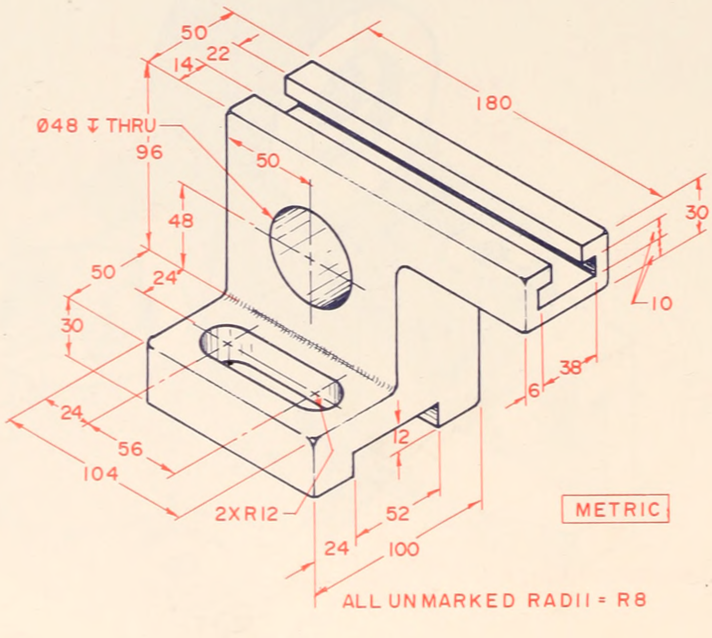
Choose the front view and construct a 3-view drawing of this object, using the listed steps.



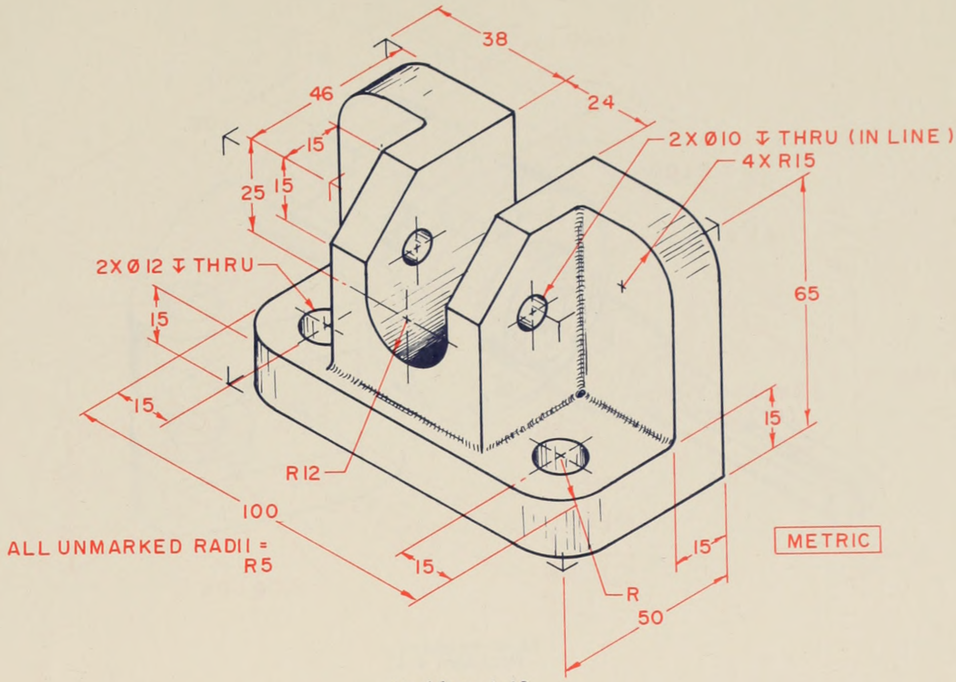
Problem 4-37



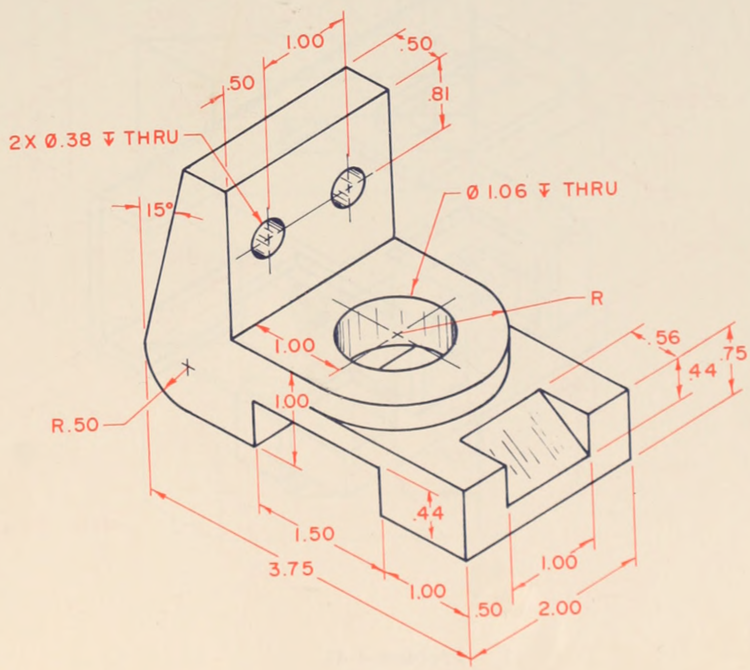
Problem 4-38



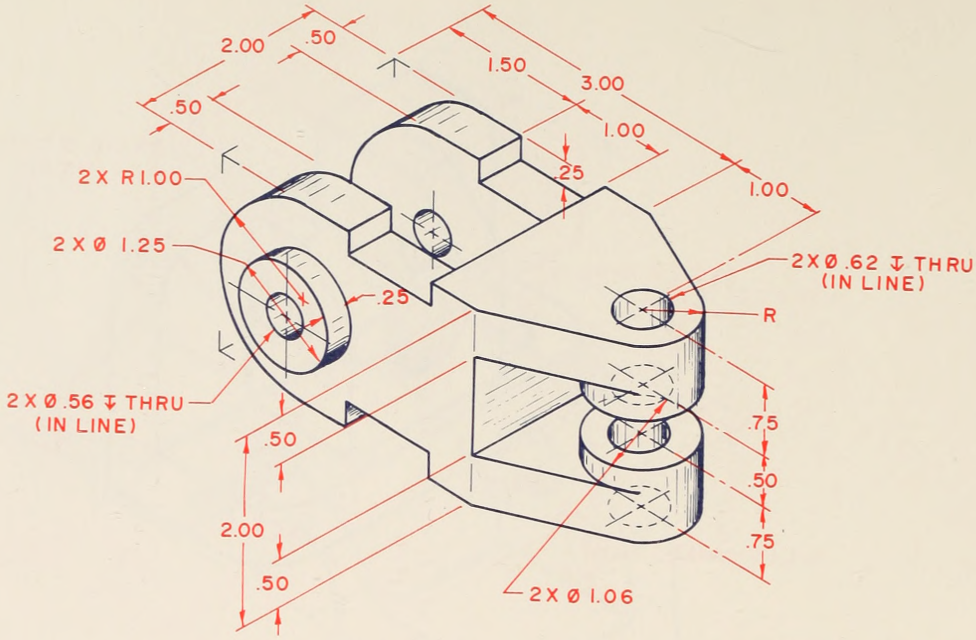
Problem 4-39



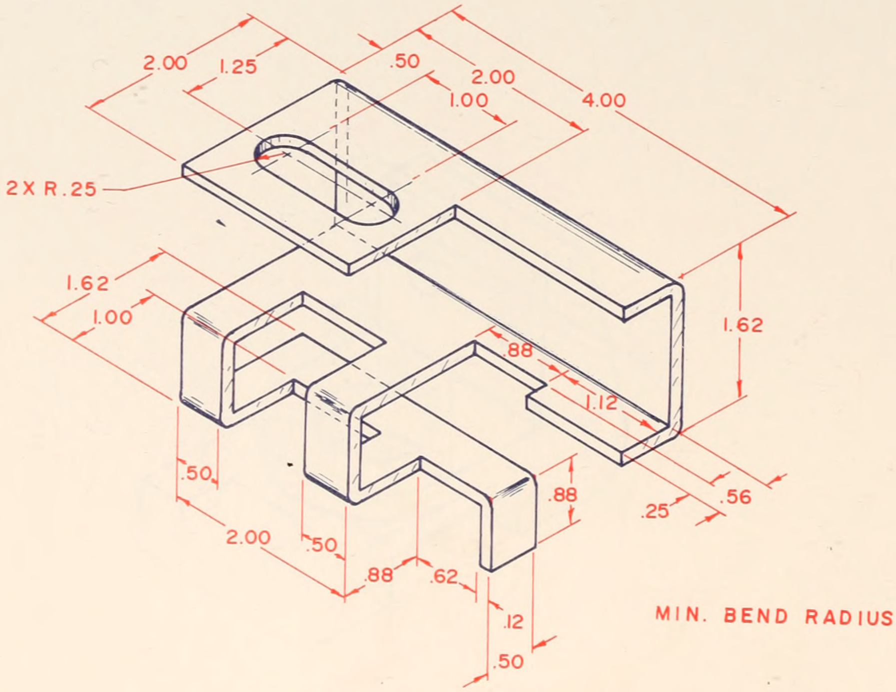
Problem 4-40



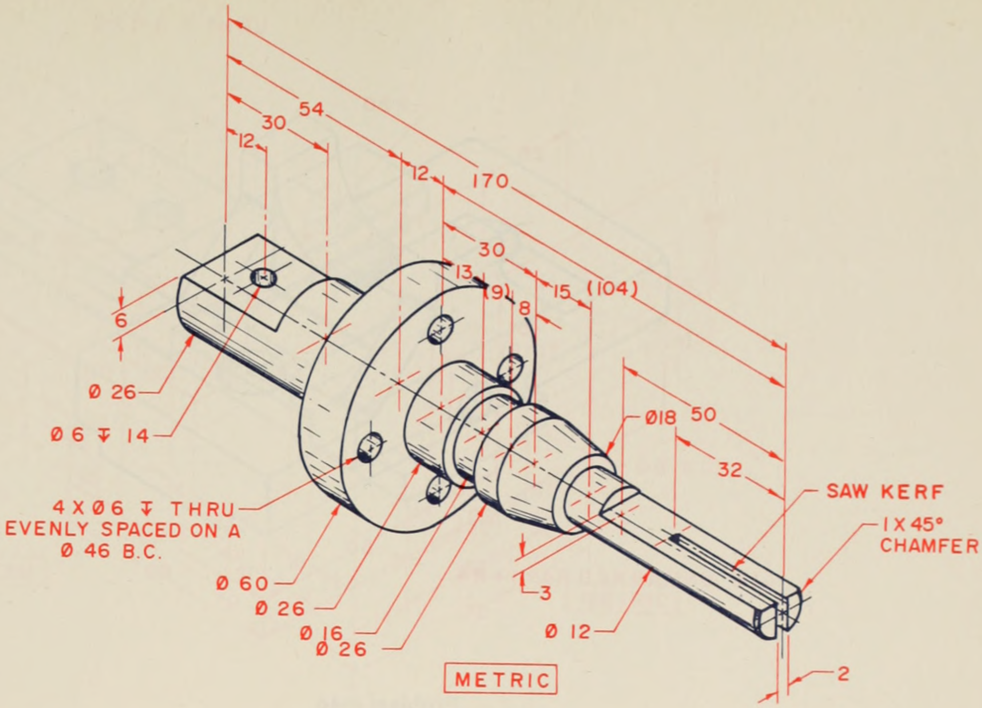
Problem 4-41



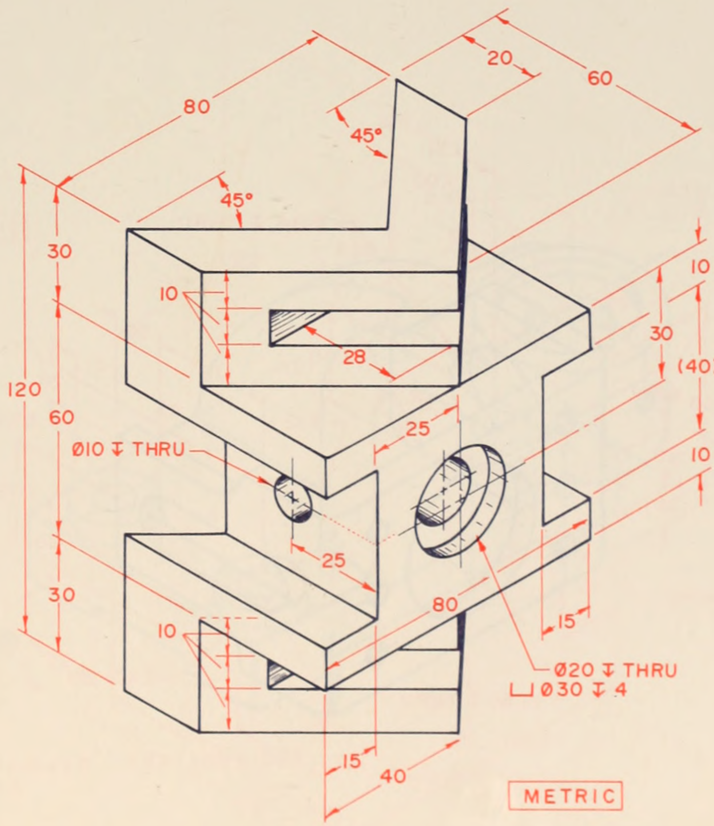
Problem 4-42



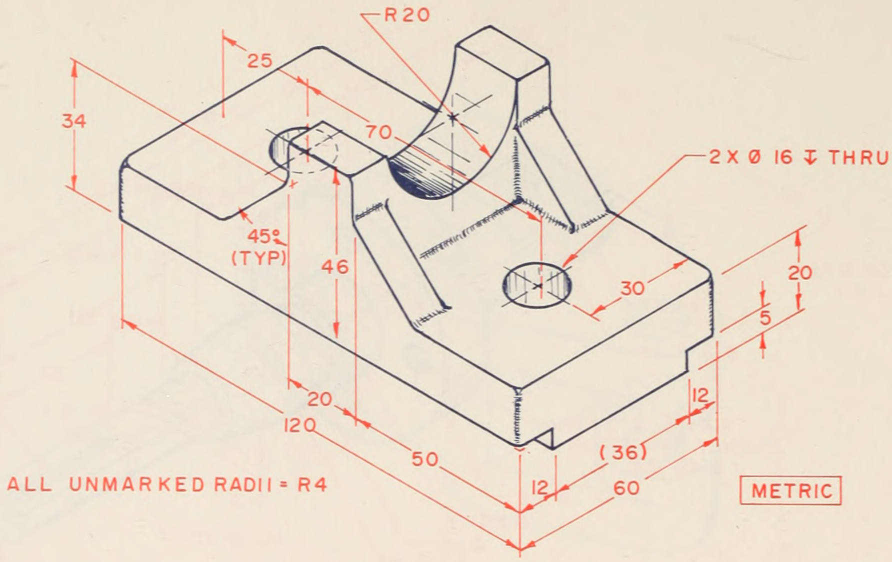
Problem 4-43



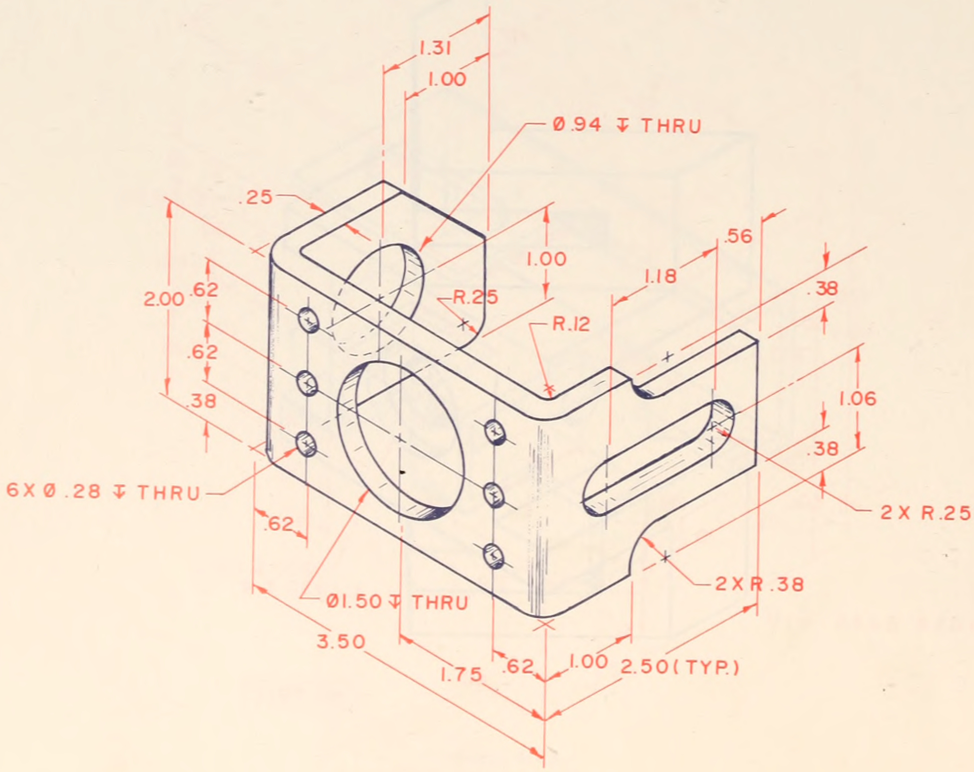
Problem 4-44



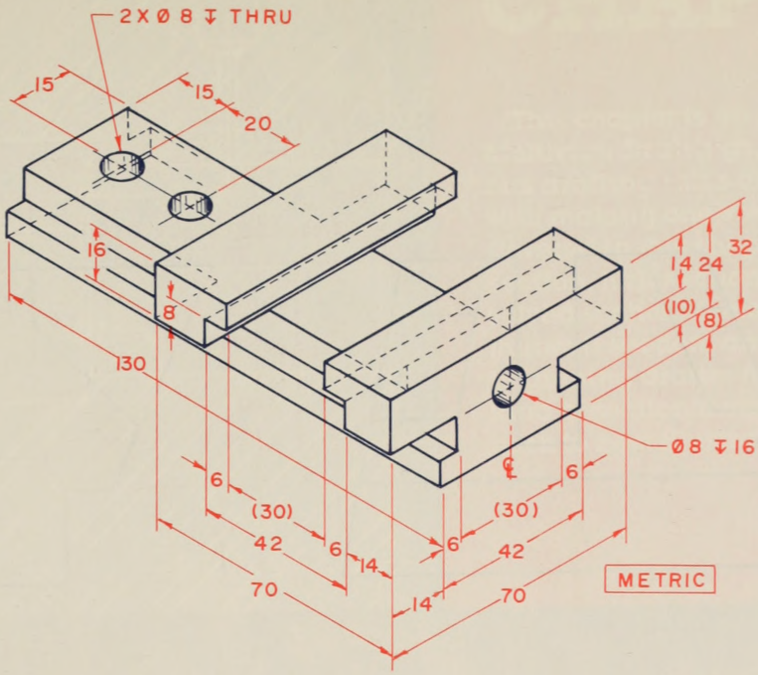
Problem 4-45



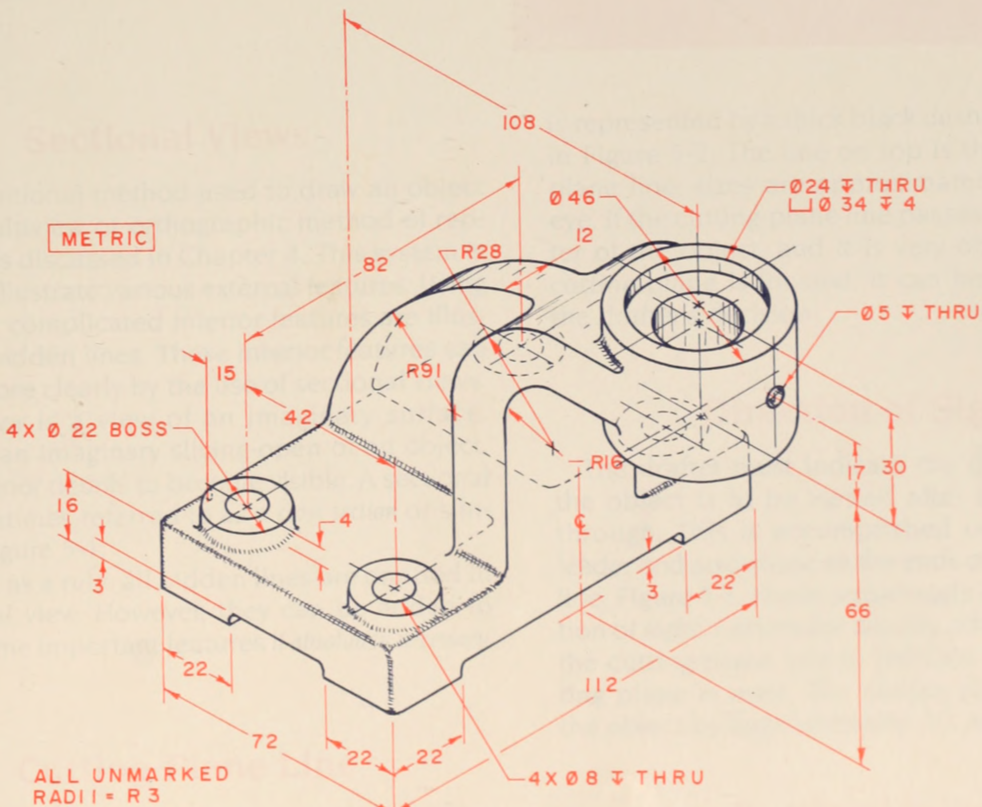
Problem 4-46



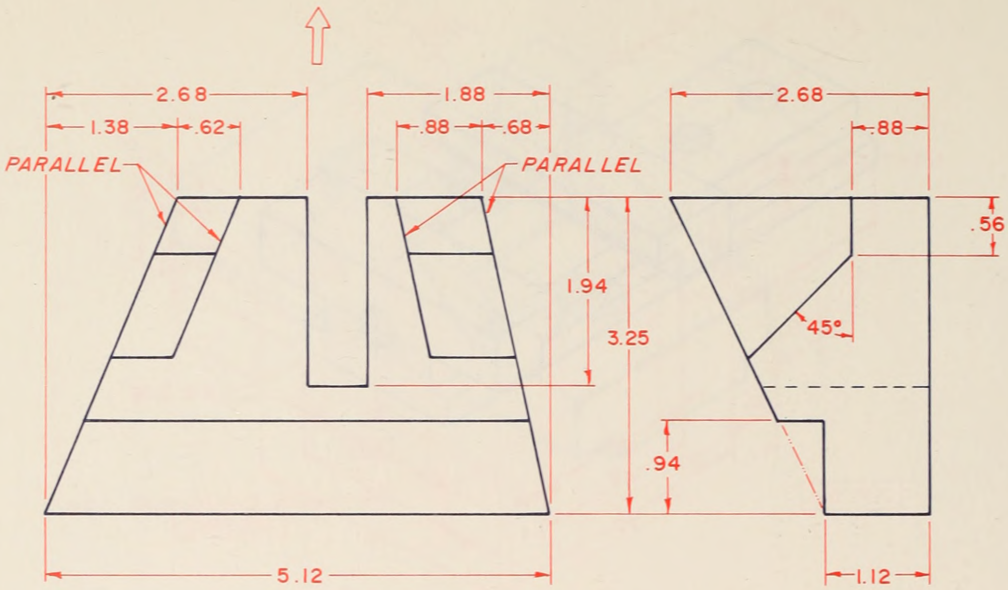
Problem 4-47



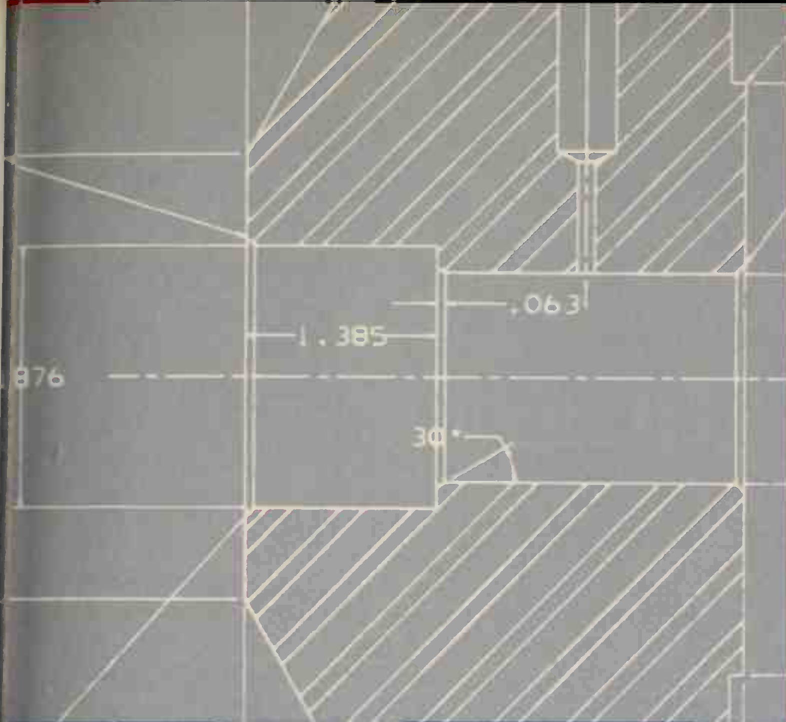
Problem 4-48



Problem 4-49


2.68
1.38
.62
1.88
.88
.68
2.68
.88
PARALLEL
PARALLEL
.56
1.94
3.25
45°
.94
5.12
1.12

Problem 4-50



CHAPTER 5

This chapter is an extension of Chapter 4, Multiview Drawings, with the addition of various drafting rules and practices associated with making one view into a sectional view. Covered in this chapter are full section, offset section, half section, broken-out section, revolved section, removed section, auxiliary view, thinwall section, and assembly section. The beginning drafter must fully understand each kind of sectional view, and know where to use each to best illustrate the object.

SECTIONAL VIEWS

Sectional Views

The conventional method used to draw an object using the multiview or orthographic method of representation is discussed in Chapter 4. This system is excellent to illustrate various external features. Using this method, complicated interior features are illustrated with hidden lines. These interior features can be shown more clearly by the use of sectional views. A *sectional view* is a view of an imaginary surface, exposed by an imaginary slicing-open of an object, allowing interior details to become visible. A sectional view is sometimes referred to as a *cross section* or simply *section*, Figure 5-1.

Note that, as a rule, all hidden lines are omitted in the sectional view. However, they can be added to illustrate some important features *if absolutely necessary*.

Cutting-Plane Line

The *cutting-plane line* indicates the path that an imaginary cutting plane follows to slice through an object. Think of the cutting-plane line as a saw blade that is used to cut through the object. The cutting-plane line is represented by a thick black dashed line, as shown in Figure 5-2. The line on top is the newer cutting-plane line; sizes are approximated and spaced by eye. If the cutting-plane line passes through the center of the object, and it is very obvious where the cutting plane is located, it can be omitted. This is the drafter's decision.

Direction of Sight

The drafter must indicate the direction in which the object is to be viewed after it is sliced or cut through. This is accomplished by adding a short leader and arrowhead to the ends of the cutting-plane line, Figure 5-3. These arrowheads indicate the direction of sight. Letters are usually added to the ends of the cutting-plane line to indicate exactly what cutting plane is used. The cutting plane extends past the object by approximately .50, as shown.

Section Lining

Section lining shows where the cutting plane is sliced or cut and the surface or surfaces touched by

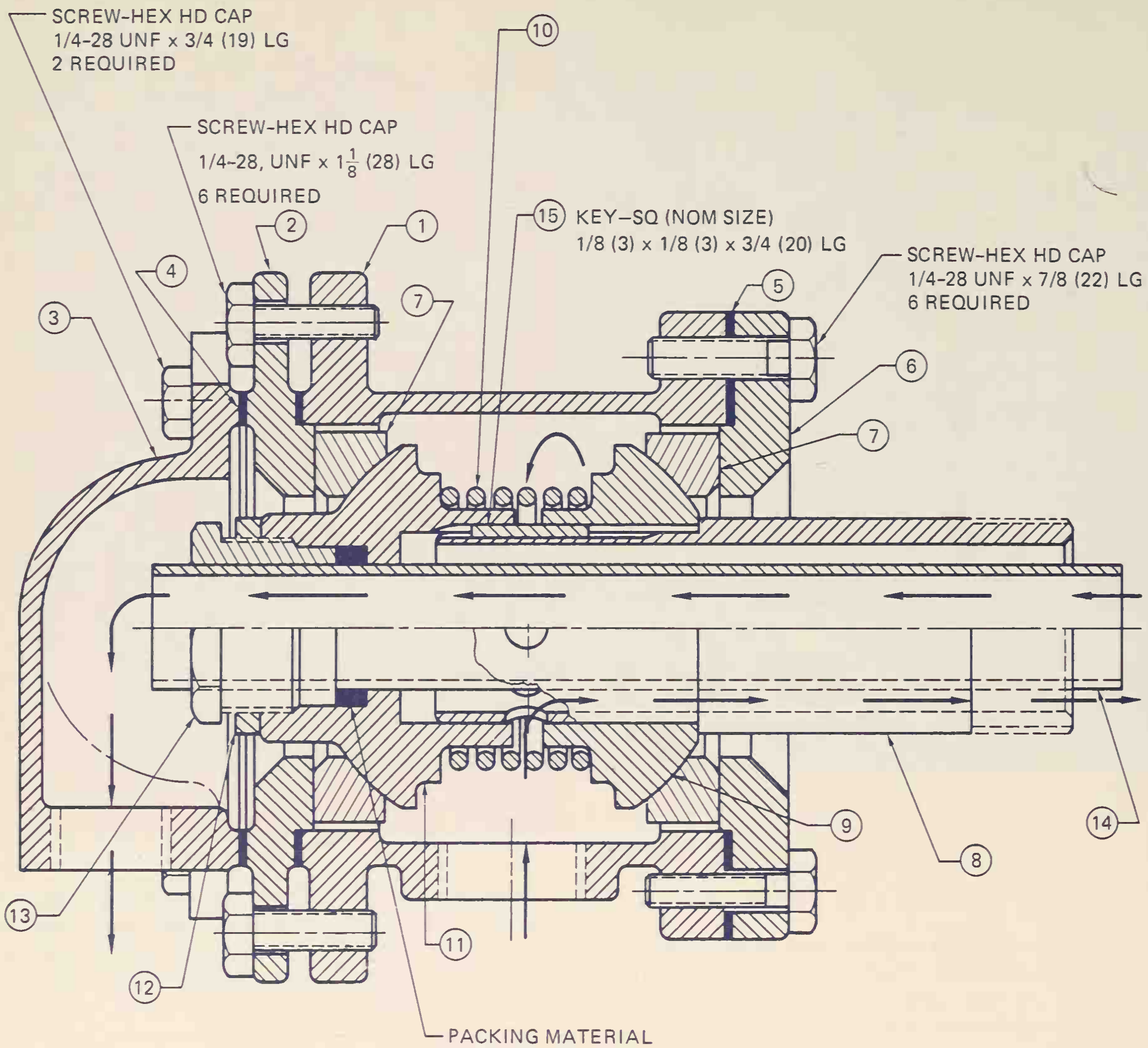


Figure 5-1 Sectional view

the cutting-plane line. Section lining is represented by thin, black lines drawn at 45° to the horizon, unless there is some specific reason for using a different angle. Section lining is spaced by eye from 1/16" (1.5 mm) to 1/4" (6 mm) apart, depending upon the overall size of the object. The average spacing used for most drawings is .13" (3 mm), Figure 5-4. Section lines must be of uniform thickness (thin black) and evenly spaced by eye.

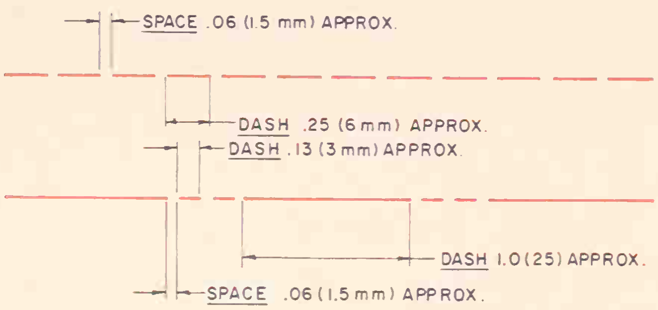


Figure 5-2 Cutting-plane line

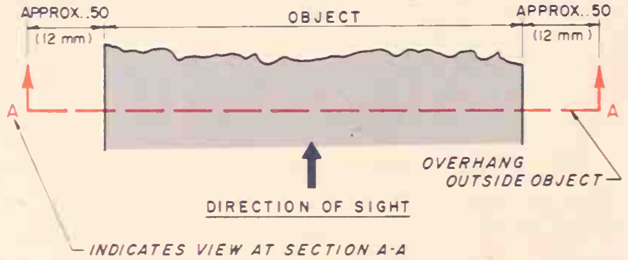


Figure 5-3 The direction of sight

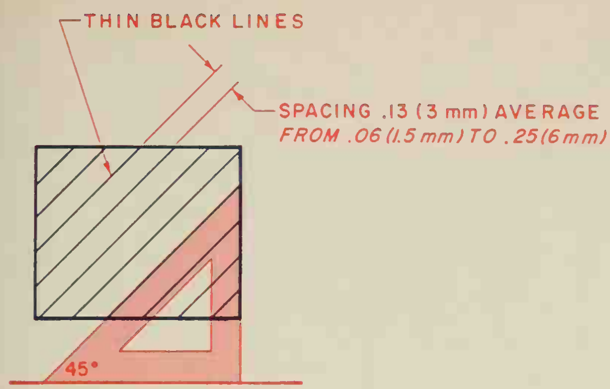


Figure 5-4 Section lining

If a cutting plane passes through two parts, each part has section lines using a 45° angle or other principal angle. These section lines should not be aligned in the same direction, Figure 5-5. If the cutting plane passes through more than two parts, the section lining of each individual part must be drawn at different angles. When an angle other than 45° is used, the angle should be 30° or 60°. Section lining should *not* be parallel with the sides of the object to be section lined, Figure 5-6.

In past years, section lining used various symbols to indicate the type of material used to make the object. These symbols used only such general type identifications as cast iron, steel, brass, aluminum, and so forth. Today, because there are so many different kinds of material, section lining symbols have been eliminated, and a single, all-purpose section lining is used (as illustrated in Figure 5-4). Specific information as to the type of material is given in the title block under "material."

Multisection Views

When an object is very complicated and cut in more than one place, each cutting-plane line must be labeled starting with section A-A, followed by B-B, and so forth, Figure 5-7.

Kinds of Sections

Nine kinds of sections are used today in industry.

- Full section
- Offset section
- Half section
- Broken-out section
- Revolved section (rotated section)
- Removed section
- Auxiliary section
- Thinwall section
- Assembly section

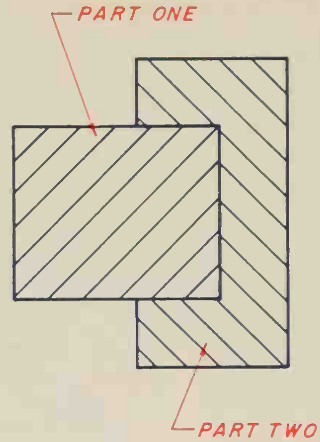


Figure 5-5 Two parts with section lining

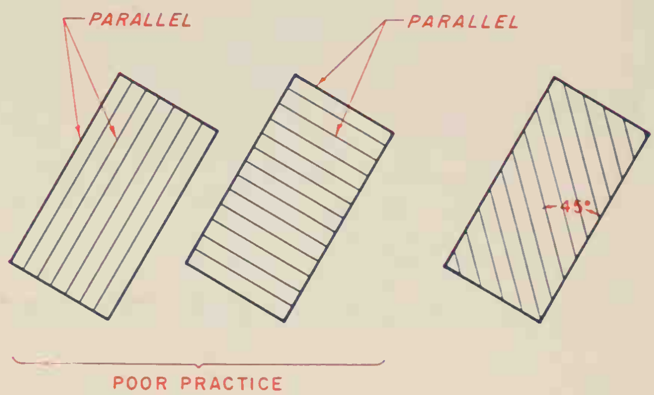


Figure 5-6 Section lining angle

Some sections are made up of a combination of the nine kinds of sections. Each is explained in full detail in the following paragraphs.

Full Section

A *full section* is simply a section of one of the regular multiviews that is sliced or cut completely in two. See the given problem, Figure 5-8, a regular three-view drawing of an object.

Determine which view contains many hard-to-understand hidden lines. In this example, it is the front view. Add a cutting plane to either the top view or right-side view. In this example, the top view is chosen. Indicate how the front view is to be viewed or the direction of sight. After determining where the object is to be sliced or cut and viewed, change the front view into section A-A, Figure 5-9.

Think of the object as a pictorial drawing, Figure 5-10. An imaginary cutting-plane line is passed through the object, Figure 5-11. The front portion is

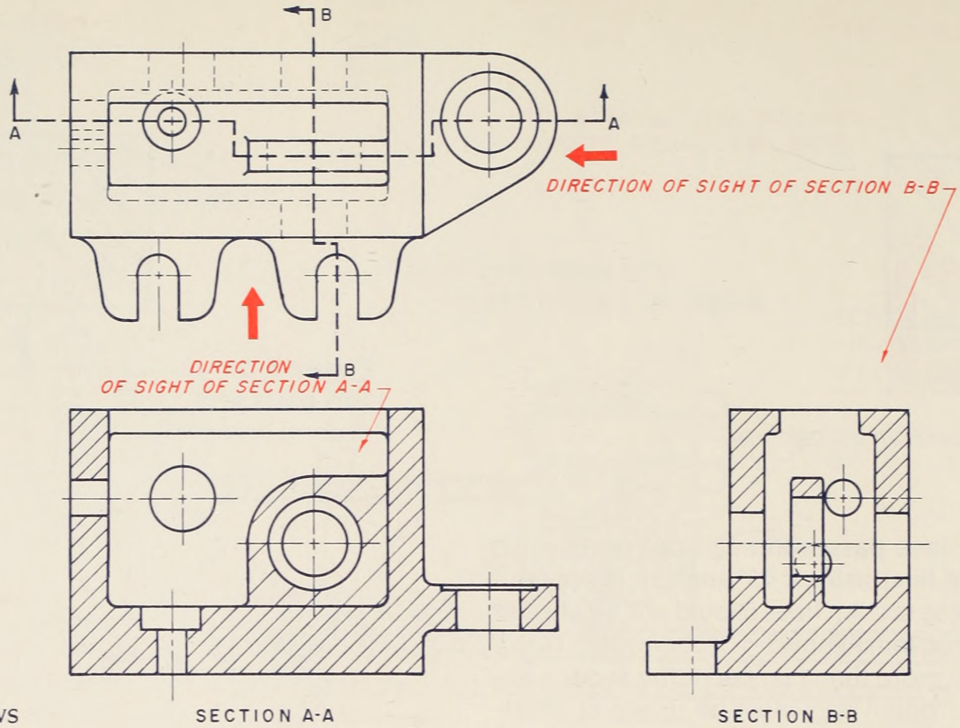


Figure 5-7
Multisection views

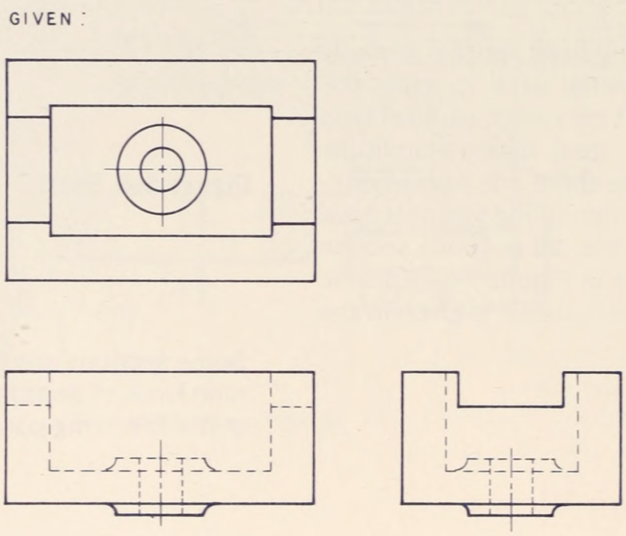


Figure 5-8 Given:
Regular three views of an object

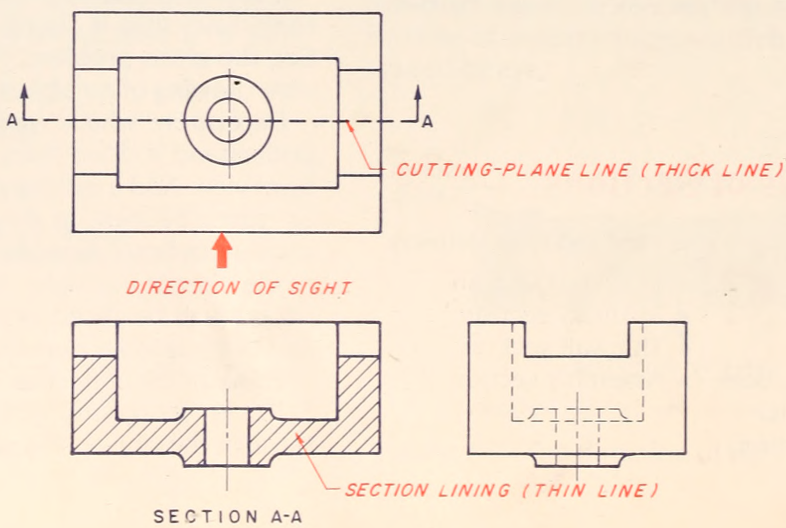


Figure 5-9
Section A-A added

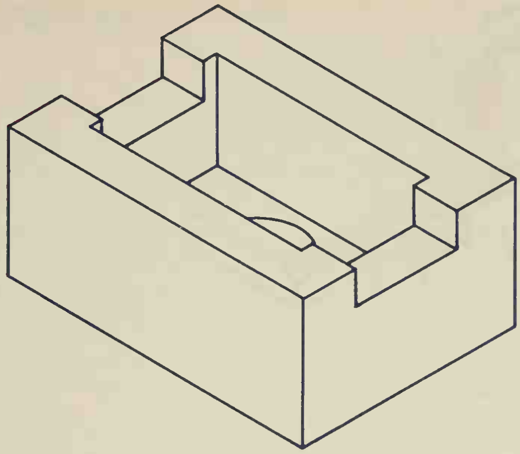


Figure 5-10 Pictorial view of the object

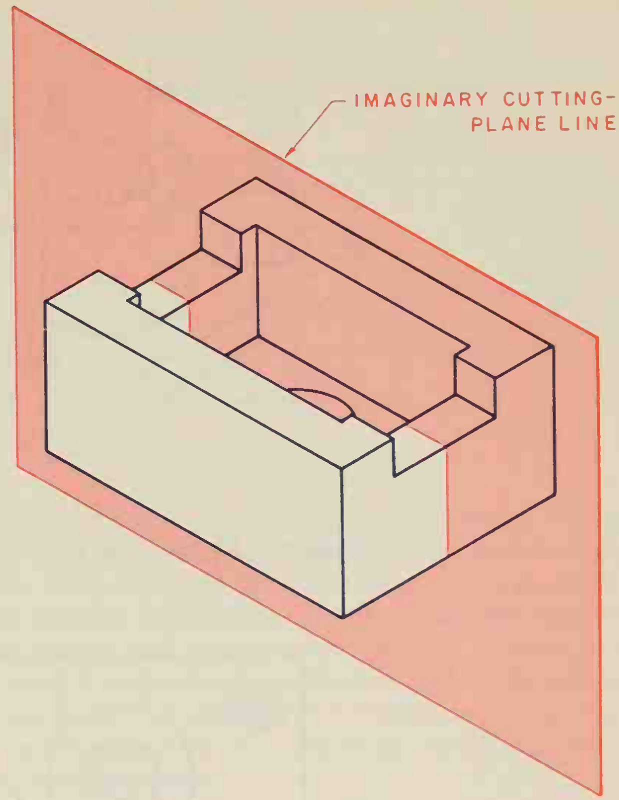


Figure 5-11 Imaginary cutting-plane line added

removed and the remaining section is viewed by the direction of sight, Figure 5-12.

Notice that section lining is applied only to the area the imaginary cutting plane passed through. The back side of the hole and the back sides of the notches are *not* section lined.

Offset Section

Many times, important features do not fall in a straight line as they do in a full section. These important features can be illustrated in an *offset section* by bending or offsetting the cutting-plane line. An offset section is very similar to a full section, except that the cutting-plane line is not straight, Figure 5-13.

Note that the features of the countersunk holes A, projection B with its counterbore, and groove C with a shoulder are not aligned with one another. The cutting-plane line is added, and changes of direction (*staggers*) are formed by right angles to pass through these features. An offset cutting-plane line A-A is added to the top view and the material behind the cutting plane is viewed in section A-A, Figure 5-14. The front view is changed into an offset section, similar to a full-sectional view. The actual bends of the cutting-plane lines are omitted in the offset section, Figure 5-15. By using a sectional view, another view often may be omitted. In this example, the right-side view could have been omitted, as it adds nothing to the drawing and takes extra time to draw.

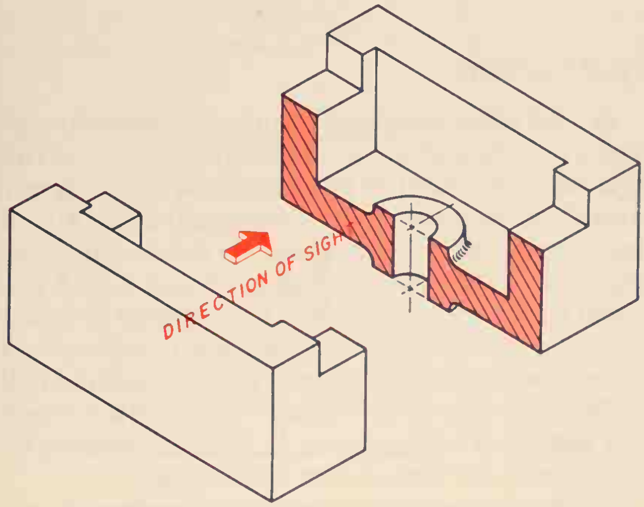


Figure 5-12 Pictorial view of the full section

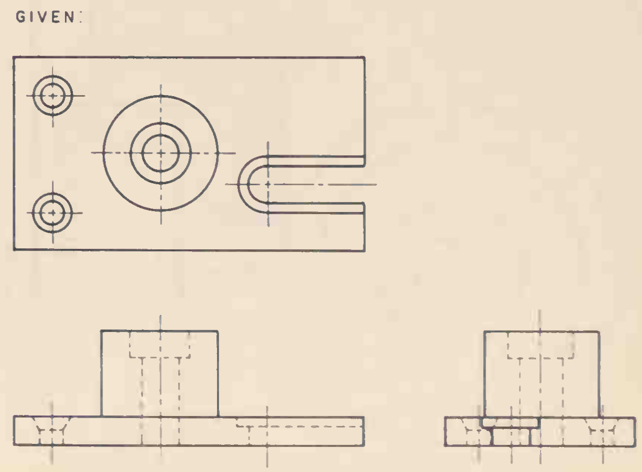


Figure 5-13 Offset section

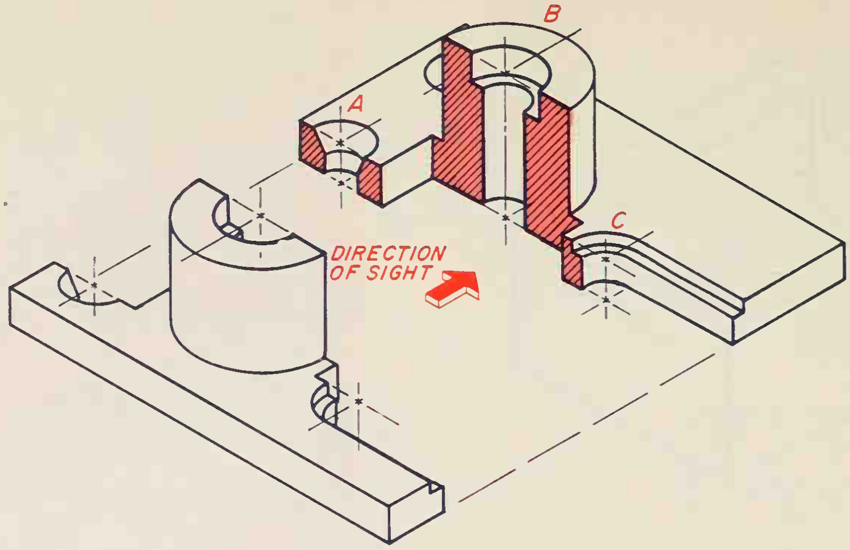


Figure 5-14 Pictorial view of the offset section

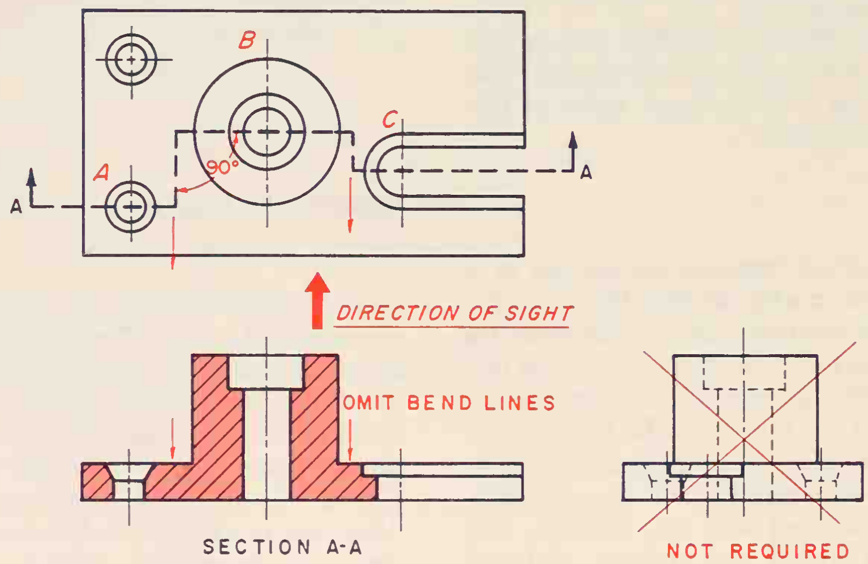


Figure 5-15 Bends omitted from section view

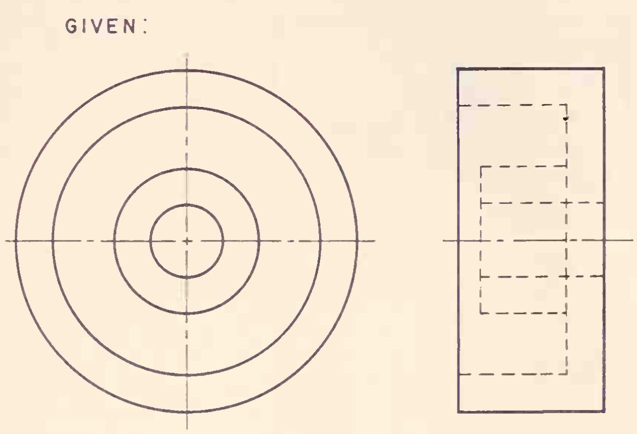


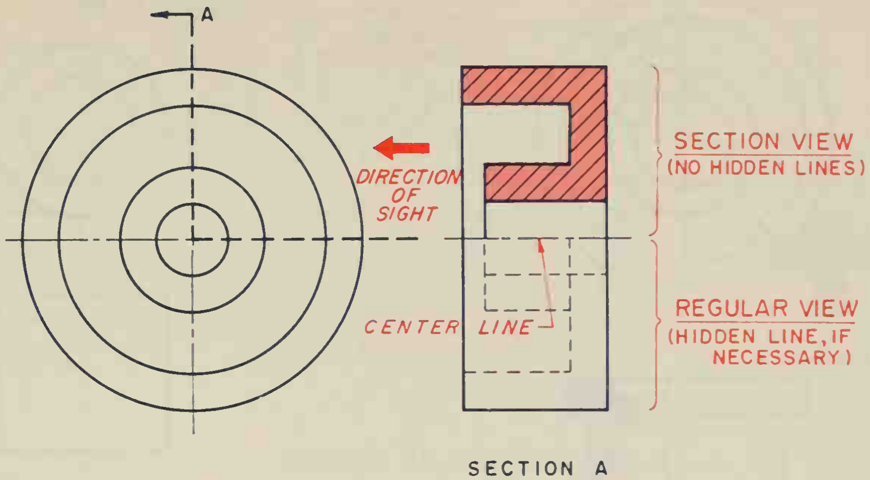
Figure 5-16 Given: Regular two views of an object

Half Section

In a *half section*, the object is cut only halfway through and a quarter section is removed, Figure 5-16. A cutting plane is added to the front view, with only one arrowhead to indicate the viewing direction. Also, a quarter section is removed and, in this example, the right side is sectioned accordingly, Figure 5-17. A pictorial view of this half section is illustrated in Figure 5-18. The visible half of the object that is not removed shows the *exterior* of the object, and the removed half shows the *interior* of the object. The half of the object not sectioned can be drawn as it would normally be drawn, with the appropriate hidden lines.

Half sections are best used when the object is *symmetrical*, that is, the exact same shape and size on both

Figure 5-17 Half section



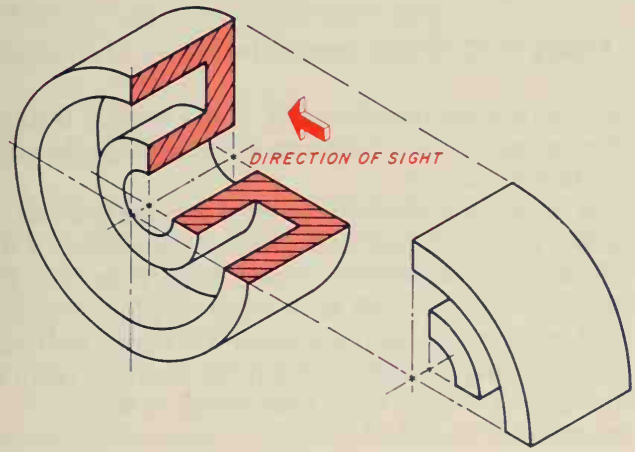


Figure 5-18 Pictorial view of the half section

sides of the cutting-plane line. A half-section view is capable of illustrating both the inside and the outside of an object in the same view. In this example, the top half of the right side illustrates the interior; the bottom half illustrates the exterior. A center line is used to separate the two halves of the half section (refer back to Figure 5-17). A solid line would indicate the presence of a real edge, which would be false information.

Broken-out Section

Sometimes, only a small area needs to be sectioned in order to make a particular feature or features easier to understand. In this case, a *broken-out section* is used. Given: Figure 5-19. As drawn, the top section is somewhat confusing and could create a question. To clarify this area, a portion is removed, Figure 5-20.

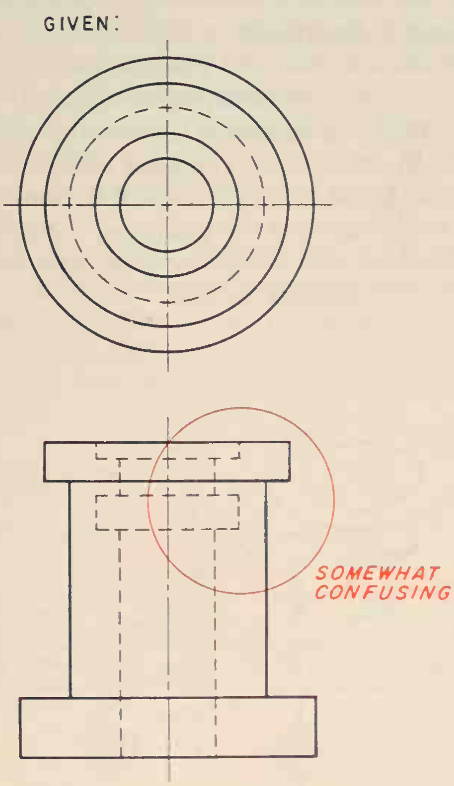


Figure 5-19 Given: Regular two views of an object

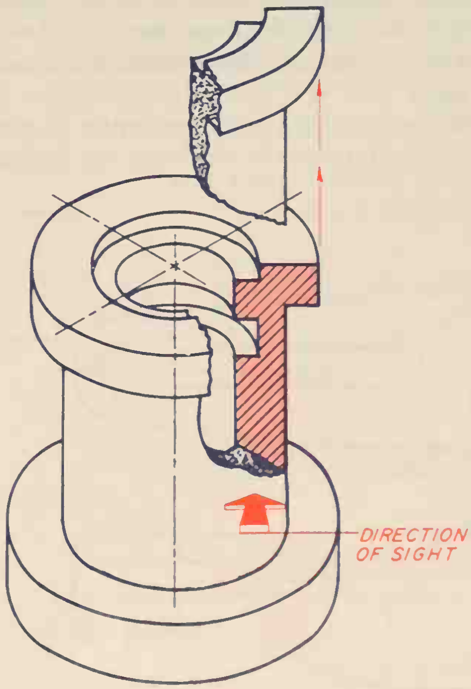


Figure 5-20 Pictorial view of the broken-out section

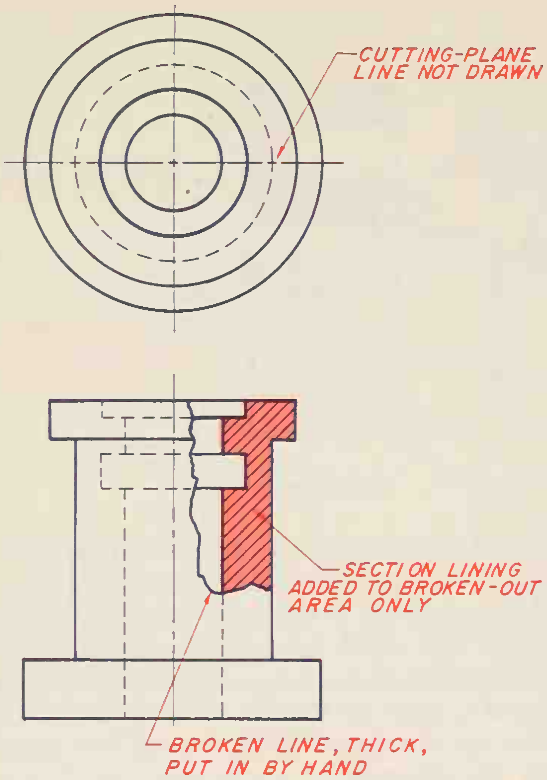


Figure 5-21 Broken-out section

The finished drawing would be drawn as illustrated in Figure 5-21. The broken line is put in freehand, and is drawn as a visible thick line. The actual cutting-plane line is usually omitted.

Revolved Section (Rotated Section)

A *revolved section*, sometimes referred to as a *rotated section*, is used to illustrate the cross section of ribs, webs, bars, arms, spokes or other similar features of an object. Figure 5-22 is a two-view drawing of an arm. The cross-sectional shape of the center portion of the arm is not defined. In drafting, no feature

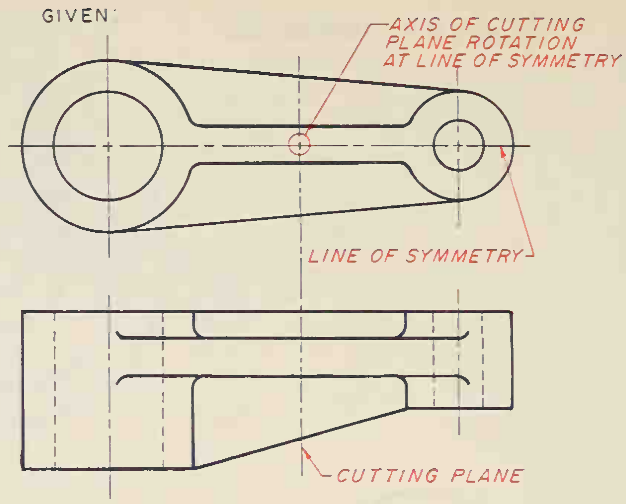


Figure 5-22 Given: Regular two views of an object

should remain questionable, and a section through the center portion of the arm would provide the complete information.

A revolved section is made by assuming a cutting plane perpendicular to the axis of the feature of the object to be described, Figure 5-23. Note that the rotation point occurs at the cutting-plane location and, theoretically, will be rotated 90°. Rotate the imaginary cutting-plane line about the rotation point of the object, Figure 5-24. Notice that dimension X is transferred from the top view to the sectional view of the feature; in this example, the front view. Dimension Y in the top view is also transferred to the front view. The section is now drawn in place. The finished drawing is illustrated in Figure 5-25. Note that the break lines in the front view are on each side of the sectional view, and are put in freehand.

The revolved section is not used as much today as it was in past years. Revolved sections tend to be confusing, and often create problems for the people who must interpret the drawings. Today, it is recommended to use a removed section instead of a revolved or rotated section.

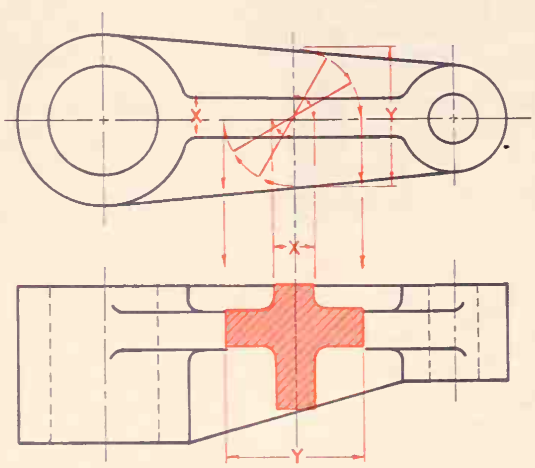


Figure 5-23 Revolved section

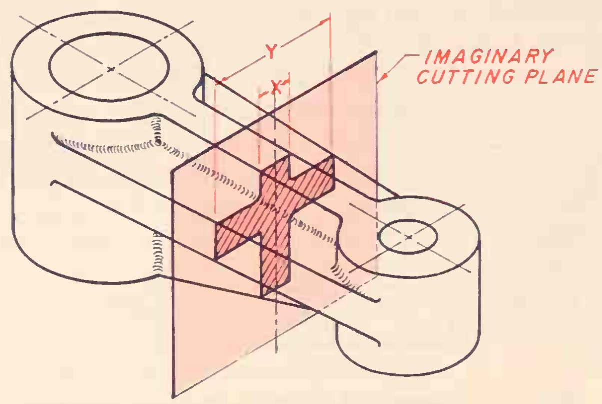


Figure 5-24 Pictorial view of a revolved section

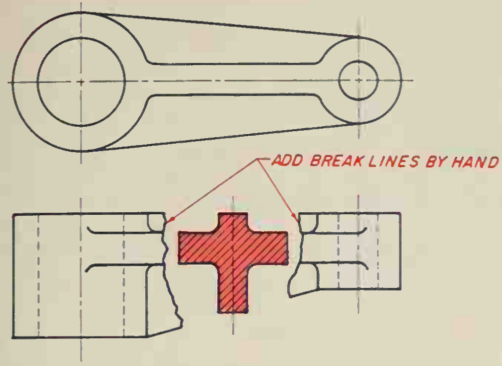


Figure 5-25 Revolved section view

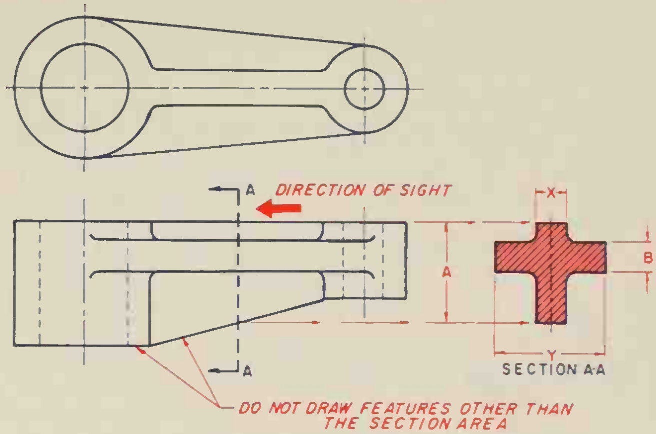


Figure 5-26 Removed section

Removed Section

A *removed section* is very similar to a rotated section except that, as the name implies, it is drawn removed or away from the regular views, Figure 5-26. The removed section, as with the revolved section, is also used to illustrate the cross section of ribs, webs, bars, arms, spokes or other similar features of an object.

A removed section is made by assuming that a cutting-plane, perpendicular to the axis of the feature of the object, is added through the area that is to be sectioned. (Refer back to Figures 5-23 and 5-24.) Transfer dimensions X and Y to the removed views, exactly as was done in the rotated section. Height features, such as dimensions A and B, are transferred from the front view in this example.

Note that a removed section must identify the cutting-plane line from which it was taken. In the sectional view, do not draw features other than the actual section.

Removed sections are labeled section A-A, section B-B, and so forth, corresponding to the letters at the ends of the cutting-plane line. The sections are usually placed on the drawing in alphabetical order from left to right or from top to bottom, away from the regular views.

Sometimes a removed section is simply drawn on a center line that is extended from the object, Figure 5-27. A removed section can be drawn to an enlarged scale if necessary to illustrate and/or dimension a small feature. The scale of the removed section must be indicated directly below the sectional view, Figure 5-28.

In the field of mechanical drafting, the removed section should be drawn on the same page as the regular views. If there is not room enough on the same page and the removed section is drawn on another page, a page number cross reference must be given as to where the removed section may be found. The page where the removed section is located must refer back to the page from which the section is taken. For example, section A-A on sheet 2 of 4.

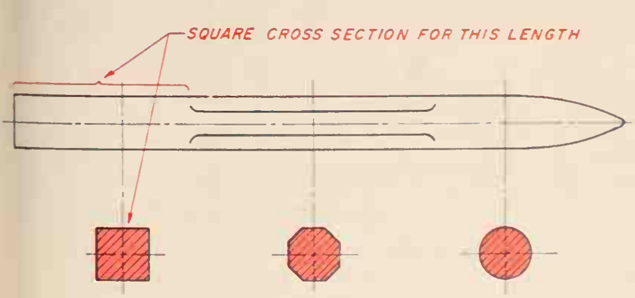


Figure 5-27 Removed section view

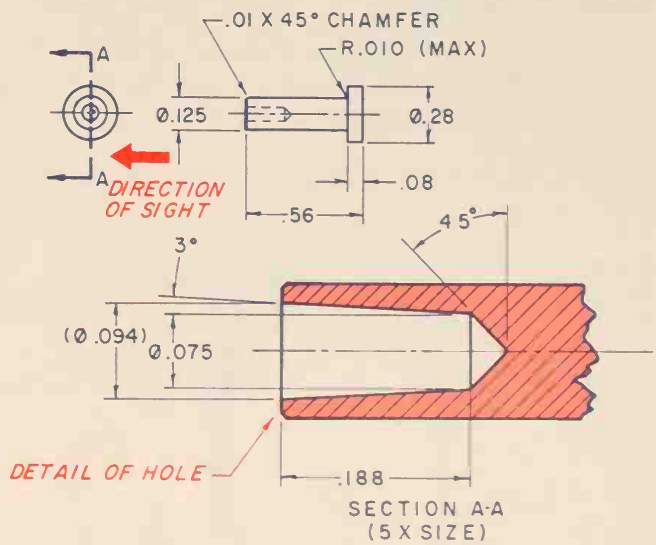


Figure 5-28 Enlarged removed section

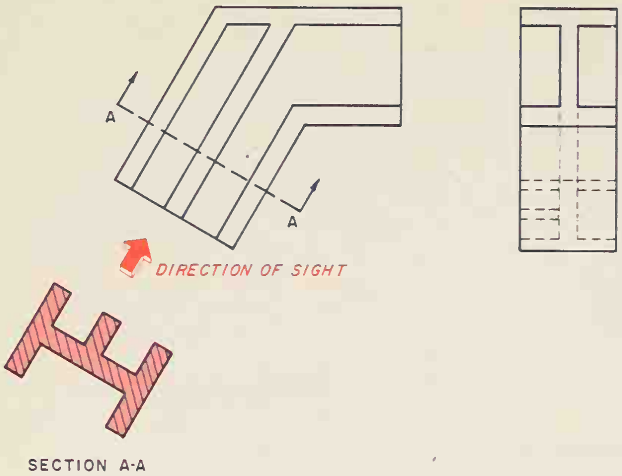


Figure 5-29 Auxiliary section

Auxiliary Section

If a sectional view of an object is intended to illustrate the true size and shape of an object's boundary, the cutting-plane path must be perpendicular to the axis or surfaces of the object. An *auxiliary section* is projected in the same way as any normal auxiliary view, and it provides an option of orienting the cutting plane at any desired angle, Figure 5-29.

Thinwall Section

Any very thin object that is drawn in section, such as sheet metal, a gasket or a shim, should be filled-in solid black, as it is impossible to show the actual section lining. This is called a *thinwall section*, Figure 5-30. If several thin pieces that are filled-in solid black are touching one another, a small white space is left between the solid thinwall section, Figure 5-31.

Assembly Section

When a sectional drawing is made up of two or more parts it is called an *assembly section*, Figure 5-32. An assembly section can be a full section (as it is in

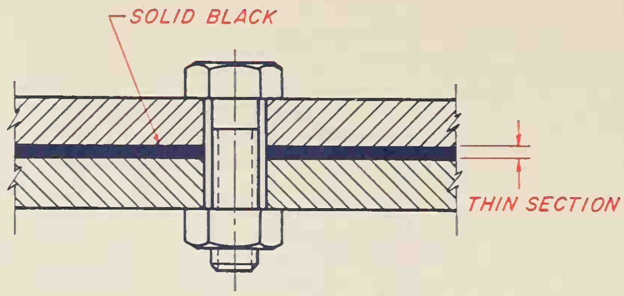


Figure 5-30 Thinwall section

this example), an offset section, a half section or a combination of the various kinds of sectional views. The assembly section shows how the various parts go together.

Each part in the assembly must be labeled with a name, part or plan number, and the quantity required for one complete assembly. If the assembly section does not have many parts, this information is added by a note alongside each part. If the assembly has many parts, and there is not enough room to prevent the drawing from appearing cluttered, each individual part may be identified by a number within a circle called a *balloon*. The balloon callout system is used in this example. A table must be added to the drawing, listing the name, part or plan number, the quantity required for one complete assembly, and a cross reference to the corresponding balloon number. This is called a *parts list*. The exact form of the list varies from company to company. Figure 5-33 is an example of a parts list used with the balloon system of callouts. Notice that entries are sometimes listed in reverse (bottom to top) order, as illustrated.

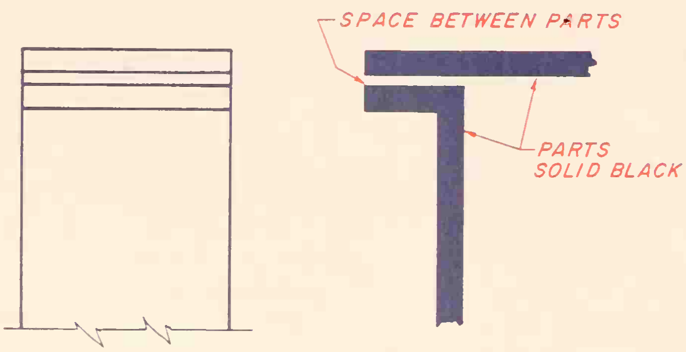


Figure 5-31 Space between thinwall sections

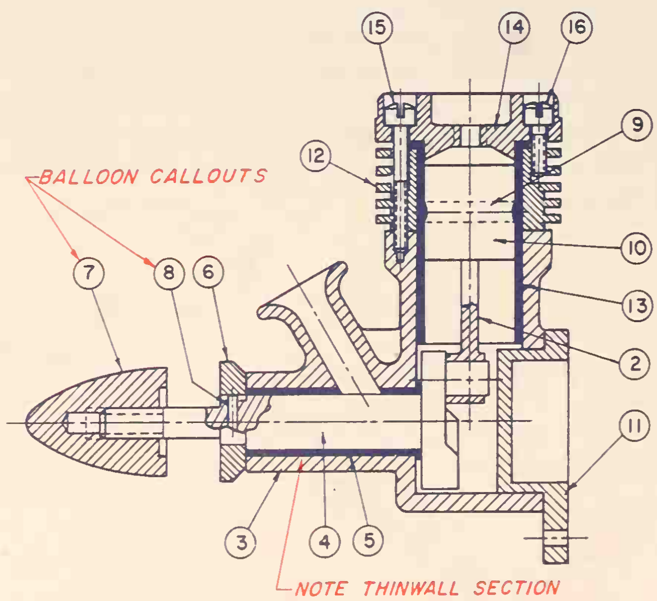


Figure 5-32 Assembly section

CORRESPONDS TO BALLOON NUMBERS

NO	TITLE	PART NO	NO REQ'D
5	PIVOT PIN	A92001	6
4	ARM	B11627	1
3	CENTER SHAFT	A11626	2
2	BASE	C11625	1
1	MAIN FRAME	C11624	1

USUAL CALLOUT INFORMATION

Figure 5-33 Example of a parts list

Sections through Ribs or Webs

True projection of a sectioned view often produces incorrect impressions of the actual shape of the object. Figure 5-34 has a given front view and a right-side view. Its pictorial view would look like Figure 5-35. A full section A-A would appear as it does in Figure 5-36. This is a true projection of section A-A, as the cutting-plane line passes through the rib.

However, such a sectional view gives an incorrect impression of the object's actual shape, and is poor drawing practice. It misleads the viewer into thinking the object is actually shaped as it is in Figure 5-37. The conventional practice used to illustrate this section is to draw the section view as illustrated in Figure 5-38, which is not a true projection. Note that the web or rib is not section lined.

Some companies use another method to compensate for this problem. It is somewhat of a middle ground or a combination of true projection and correct representation, Figure 5-39. This is called *alternate section lining*. Section lining, over the rib or web section, is drawn using every *other* section line, and the actual shape is indicated by hidden lines. However, most companies do not use alternate section lining.

Another example of a cutting-plane passing through a rib or web is shown in Figure 5-40. This example is a true projection, but it is poor drafting practice, as it gives the impression that the center portion is a thick, solid mass. Figure 5-41 is drawn incorrectly, but does not give the false impression of the object's center portion. This is the *conventional practice* used.

Holes, Ribs and Webs, Spokes and Keyways

Holes located around a bolt circle are sometimes not aligned with the cutting-plane line, Figure 5-42. The cutting plane passes through only one hole. This is a true projection of the object, but poor drafting practice. In actual practice, the top hole is theoretically revolved to the cutting-plane line and projected

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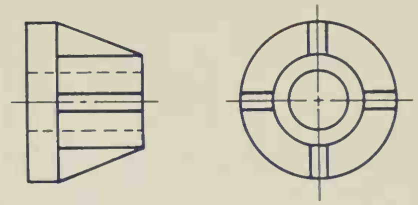
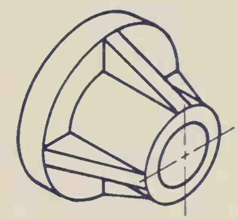


Figure 5-34 Given: Two-view drawing of an object



PICTORIAL VIEW

Figure 5-35 Pictorial view of an object

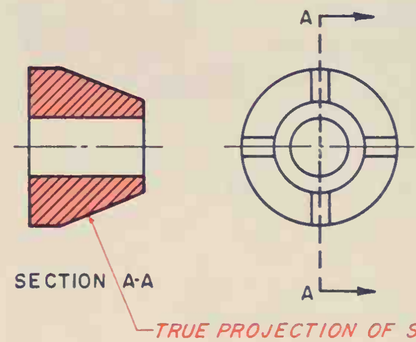
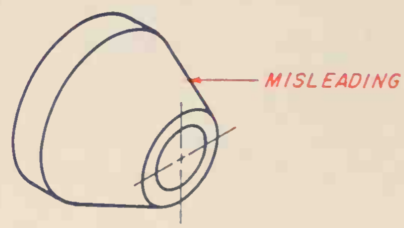


Figure 5-36 True projection of an object



PICTORIAL VIEW

Figure 5-37 True projection can be misleading

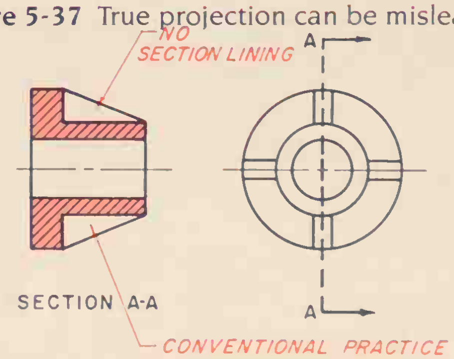


Figure 5-38 Conventional practice — web or rib *not* sectioned

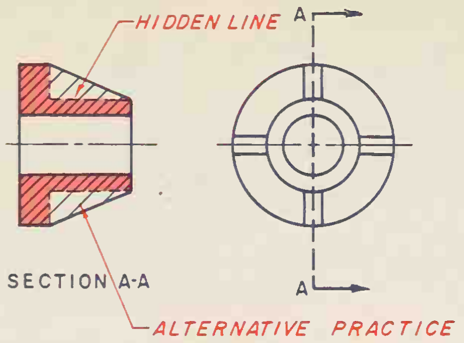


Figure 5-39 Alternate conventional practice

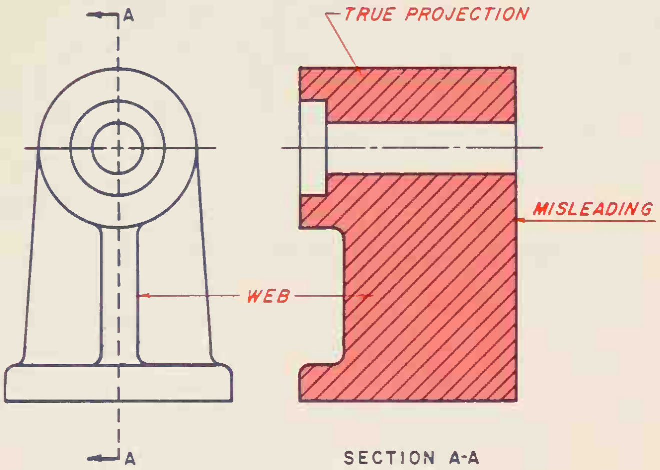


Figure 5-40 Example of true projection

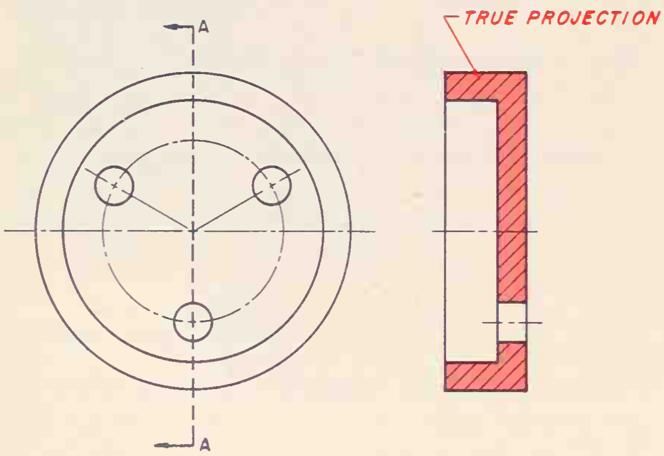


Figure 5-42 Holes using true projection

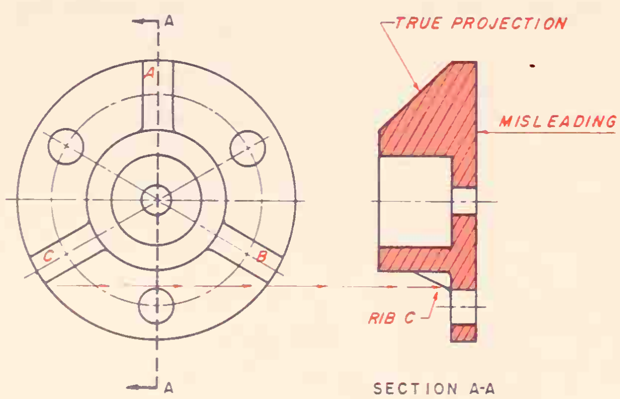


Figure 5-44 Rib or web using true projection

to the sectional view, Figure 5-43. This practice is called *aligning of features.*

Ribs and Webs

Ribs or webs sometimes do not align with the cutting-plane line, Figure 5-44. The cutting plane passes through only one web and only one hole. This is a true projection of the object, but poor drafting practice. In actual practice, one of the webs is theoretically revolved up to the cutting-plane line and projected to the sectional view, Figure 5-45. Notice that

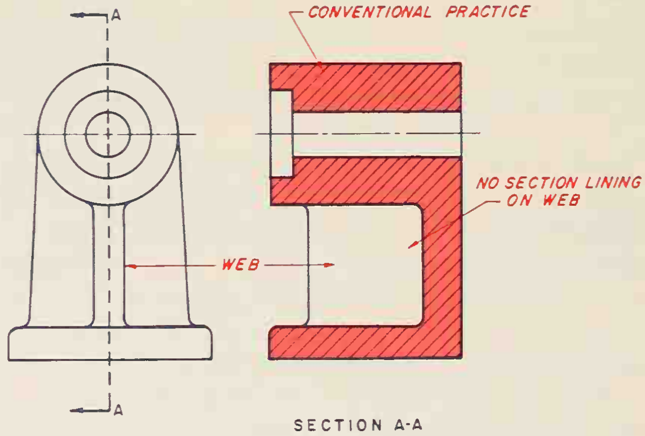


Figure 5-41 Example of conventional practice

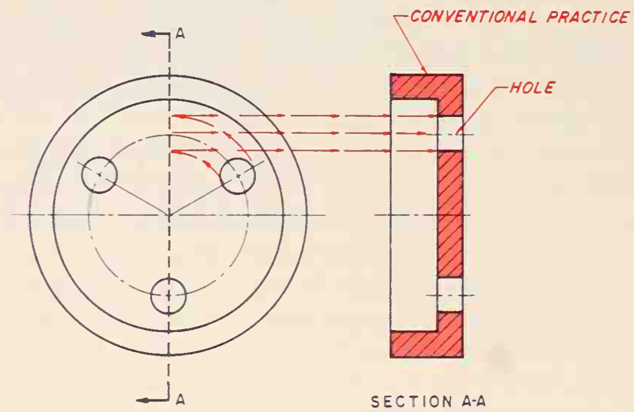


Figure 5-43 Holes using conventional practice (aligning of features)

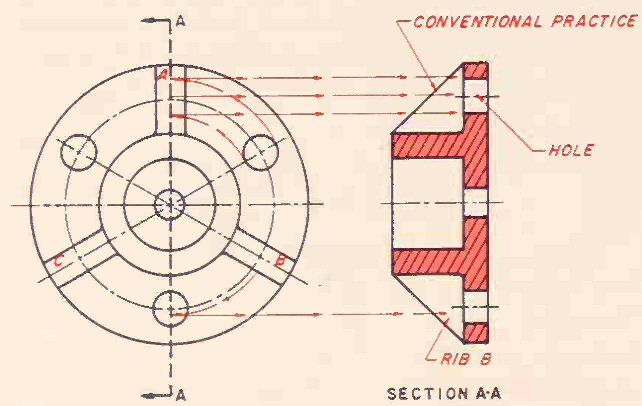


Figure 5-45 Rib or web using conventional practice

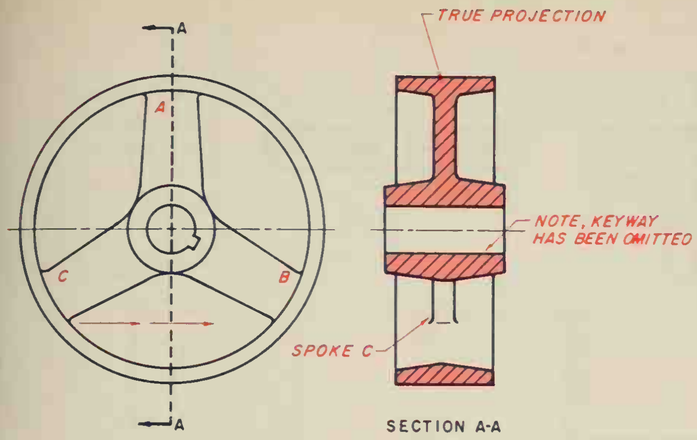


Figure 5-46 Spokes and keyway using true projection

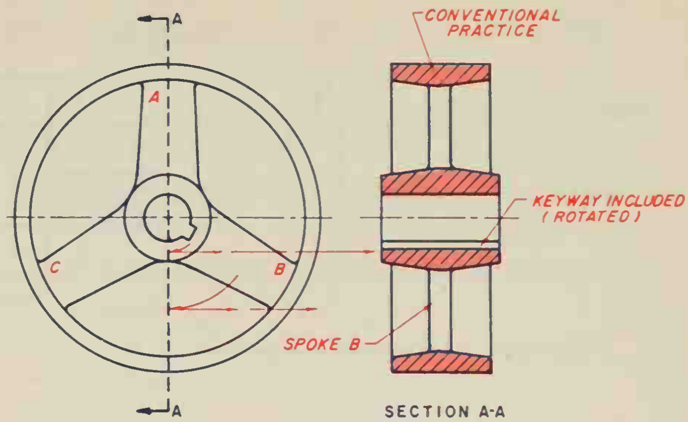


Figure 5-47 Spokes and keyway using conventional practice

the bottom hole is unaffected and is projected normally. This is another example of aligning of features.

Spokes and Keyways

Spokes and keyways and other important features sometimes do not align with the cutting-plane line, Figure 5-46. The cutting-plane line passes through only one spoke and misses the keyway completely. This also is a true projection of the object, but poor drafting practice. In conventional practice, spoke B is revolved to the cutting-plane line and projected to the sectional view, Figure 5-47. The keyway is also projected as illustrated. This is another example of aligning of features.

Aligned Sections

Arms and other similar features are revolved to alignment in the cutting plane, as were spokes in the preceding section. This procedure is used if the cutting-plane line cannot align completely with the object, as illustrated in Figure 5-48.

The arm or feature is now revolved to the imaginary cutting plane, and projected down to the sectional view, Figure 5-49. The actual cutting-plane line is bent and drawn through the arm or feature and then revolved to a straight, aligned vertical position. Notice that section lining is *not* applied to the arm, and is also omitted from the web area.

Fasteners and Shafts in Section

If a cutting plane passes *lengthwise* through any kind of fastener or shaft, the fastener or shaft is *not* sectioned. Section lining of a fastener or shaft would have no interior detail, thus it would serve no purpose and only add confusion to the drawing, Figure

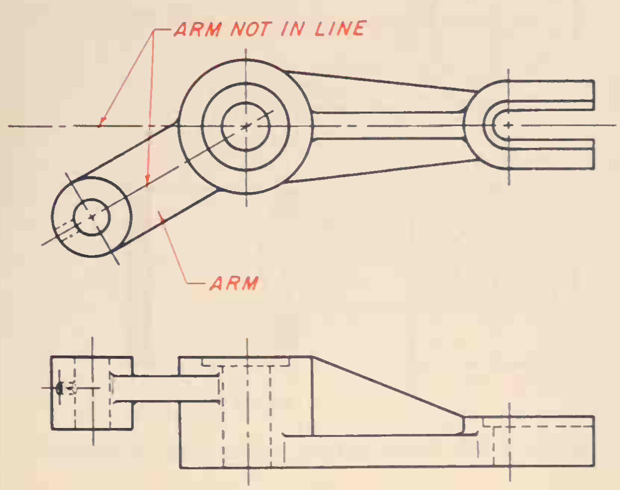


Figure 5-48 Two-view drawing

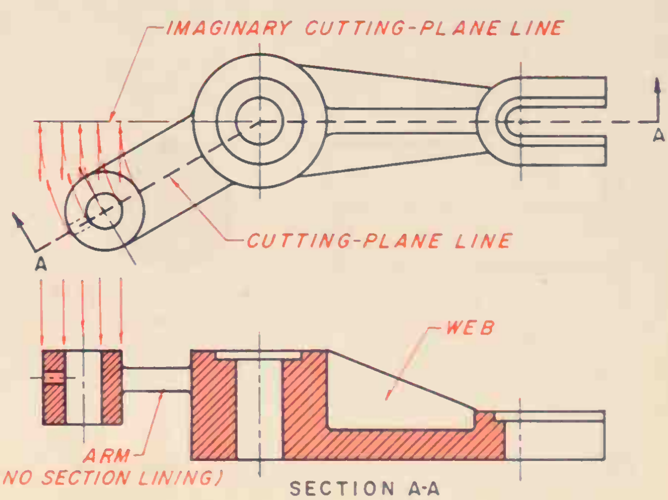


Figure 5-49 Aligned section

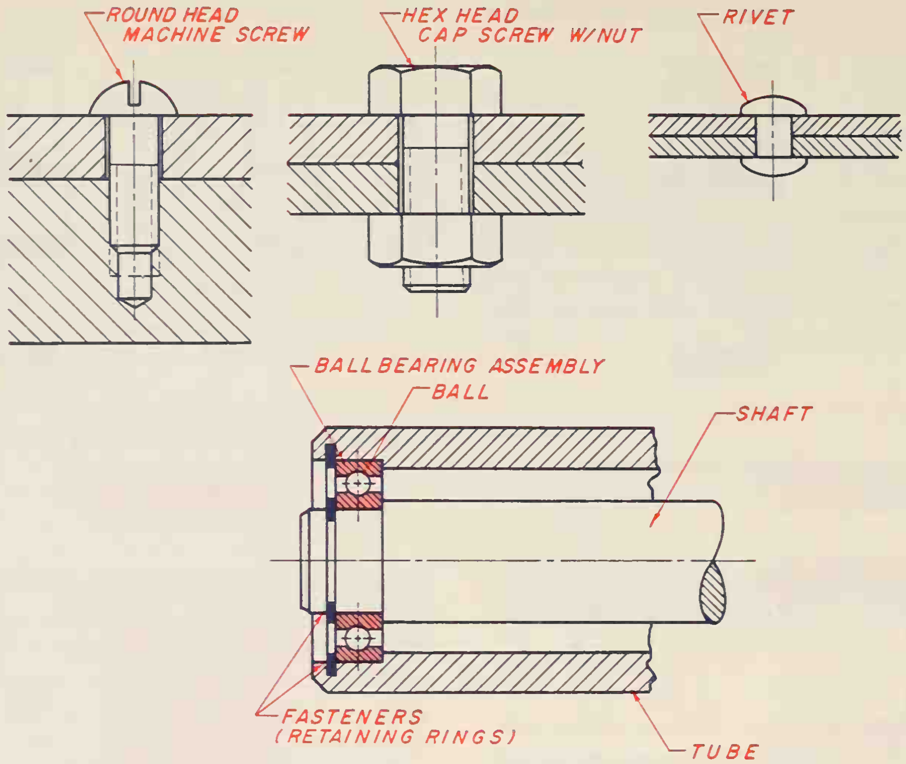


Figure 5-50 Parts *not* sectioned

5-50. The round head machine screw, the hex head cap screw w/nut, and the rivet are not sectioned. The other objects in the figure such as fasteners, ball bearing rollers, and so forth, are also not sectioned.

If a cutting-plane line passes *perpendicularly* through the axis of a fastener or shaft, section lining *is* added to the fastener or shaft, Figure 5-51. The end view has section lining added as shown.

Intersections in Section

Where an intersection of a small or relatively unimportant feature is cut by a cutting-plane line, it is not drawn as a true projection, Figure 5-52. Since a true projection takes drafting time, it is preferred that it be disregarded, and the feature drawn, using conventional practice, as shown in Figure 5-53. This procedure is much quicker and more easily understood.

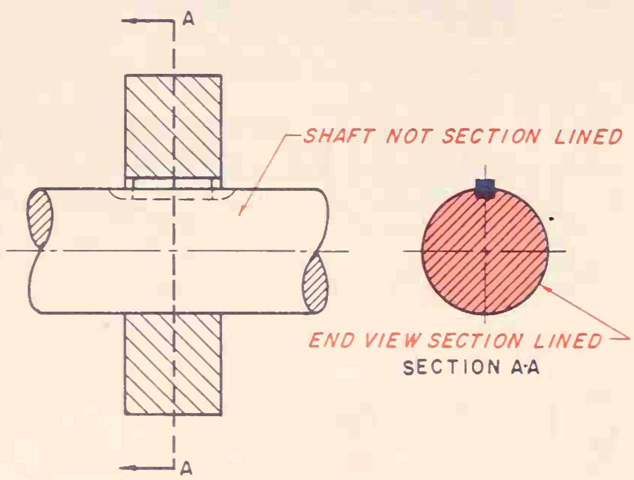


Figure 5-51 Shaft sectioned in end view only

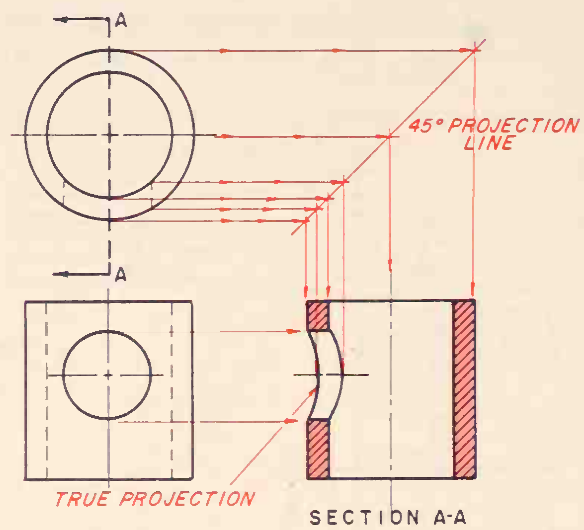


Figure 5-52 Intersection using true projection

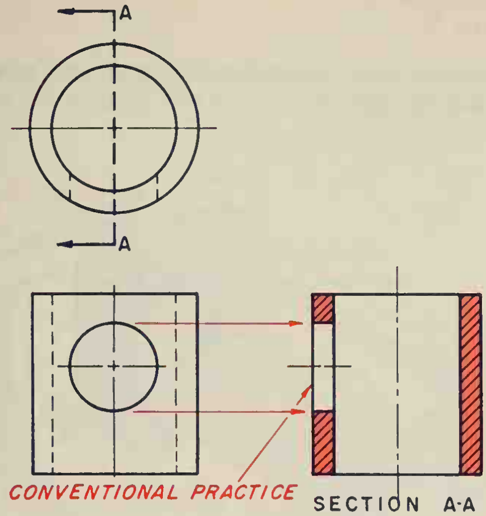


Figure 5-53 Intersection using conventional practice

Review

1. Explain the difference between true projection and conventional practice. Which is used in a sectional view and why?
2. Explain the difference between a revolved section and a removed section. Which is recommended today?
3. Are hidden lines used in a sectional view? Why?
4. Why is a removed section sometimes drawn at a larger scale?
5. List the nine kinds of sectional views and describe the various features of each.
6. What is alternate section lining? Where is it used?
7. List two major functions of an assembly drawing.
8. Explain the practice used for drawing intersections of small or unimportant features that are cut by a cutting-plane line.
9. What kind of sectional view illustrates both the exterior and interior of the object?
10. What must be done if a removed section is placed on another page other than the page on which the cutting-plane line is placed?
11. Explain the two methods used in regard to a cutting-plane line passing through the long dimension and perpendicularly to the center of a fastener or shaft.
12. What must be included for each part in an assembly section? Explain the two methods used to accomplish this.

Chapter Five Problems

The following problems are intended to give the beginning drafter practice in using the various kinds of sectional views used in industry. As these are beginning problems, no dimensions will be used at this time.

The steps to follow in laying out all problems in this chapter are:

Step 1. Study the problem carefully.

Step 2. Choose the view with the most detail as the front view.

Step 3. Position the front view so there will be the least amount of hidden lines in the other views.

Step 4. Make a sketch of all required views.

Step 5. Determine what should be drawn in section, what type of section should be used, and where to place the cutting-plane line.

Step 6. Center the required views within the work area with a 1-inch (25-mm) space between each view.

Step 7. Use light projection lines. Do not erase them.

Step 8. Lightly complete all views.

Step 9. Check to see that all views are centered within the work area.

Step 10. Check to see that there is a 1-inch (25-mm) space between all views.

Step 11. Carefully check all dimensions in all views.

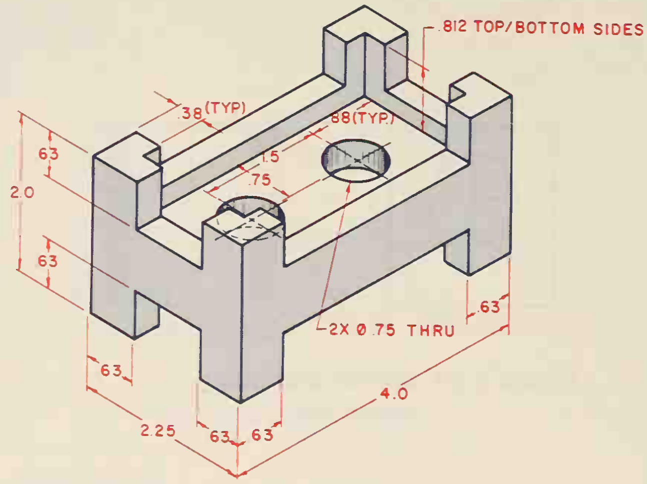
Step 12. Darken in all views using correct line thickness.

Step 13. Add a cutting-plane line and section lining as required.

Step 14. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problem 5-1

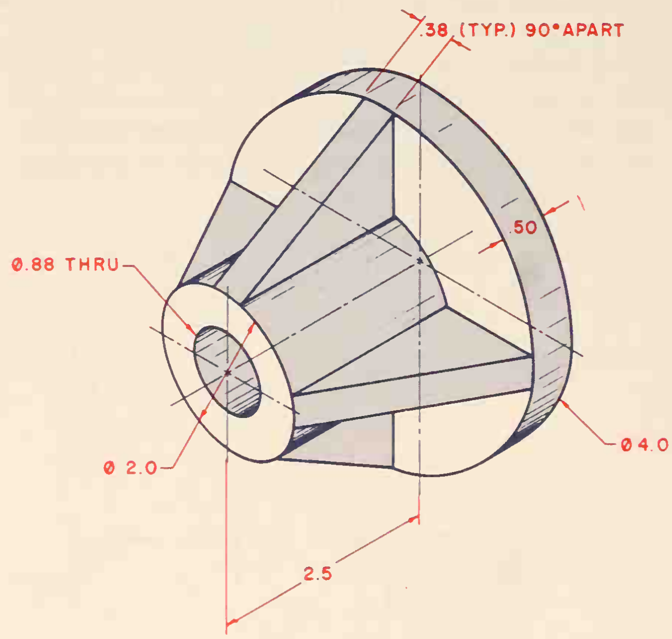
Center three views within the work area, and make the front view a full section.



Problem 5-1

Problem 5-2

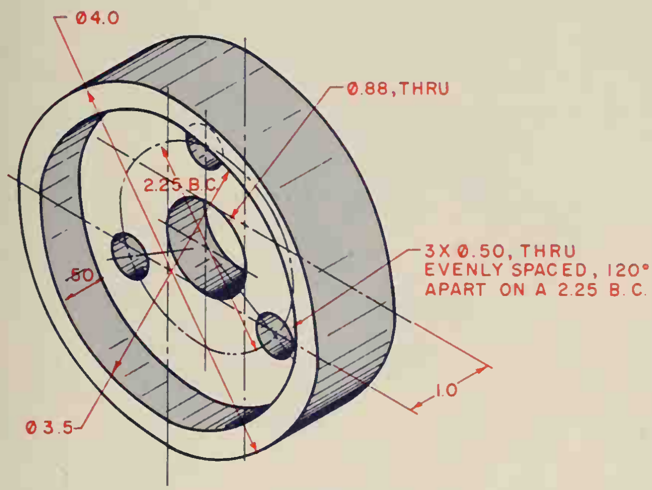
Center two views within the work area, and make one view a full section. Use correct drafting practices for the ribs.



Problem 5-2

Problem 5-3

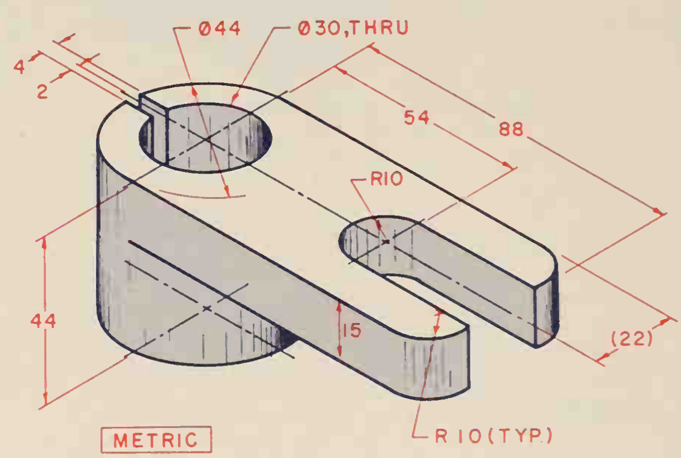
Center two views within the work area, and make one view a full section. Use correct drafting practices for the holes.



Problem 5-3

Problem 5-4

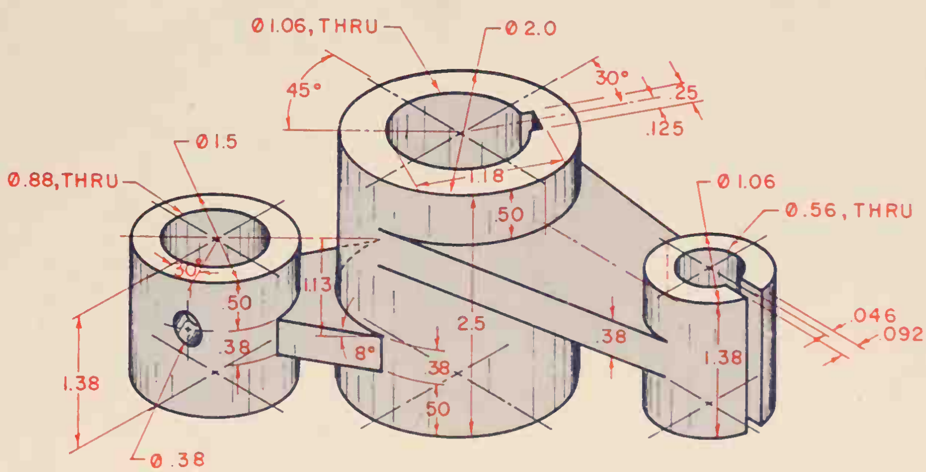
Center the front view and top view within the work area. Make one view a full section.



Problem 5-4

Problem 5-5

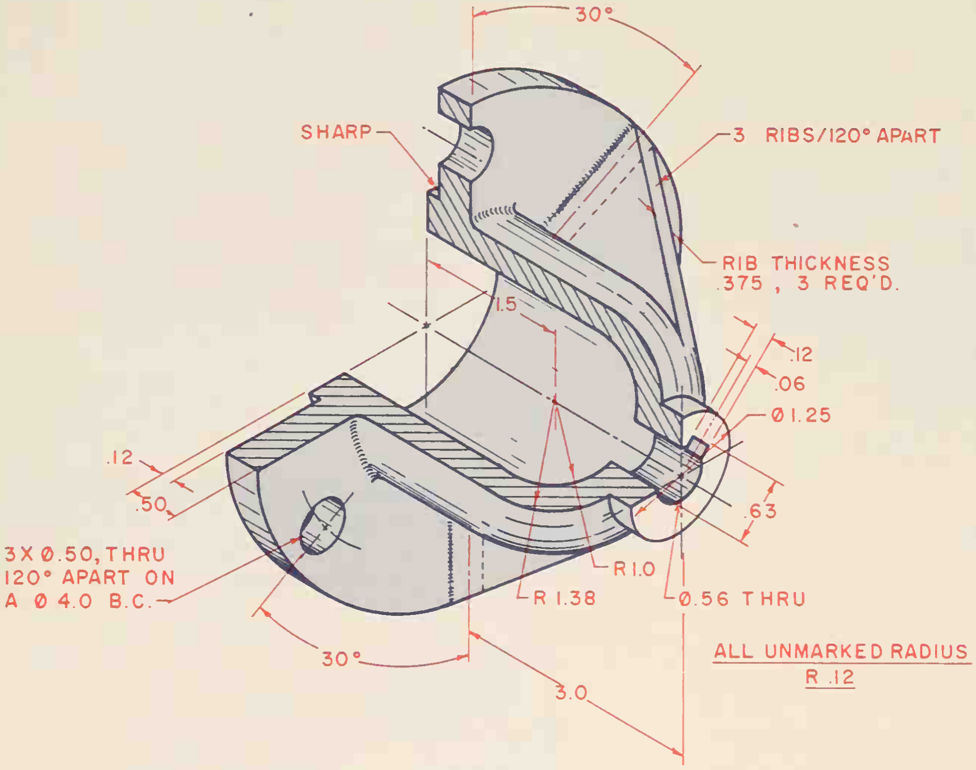
Center two views within the work area, and make one view a full section. Use correct drafting practices for the arms, horizontal hole, and keyway.



Problem 5-5

Problem 5-6

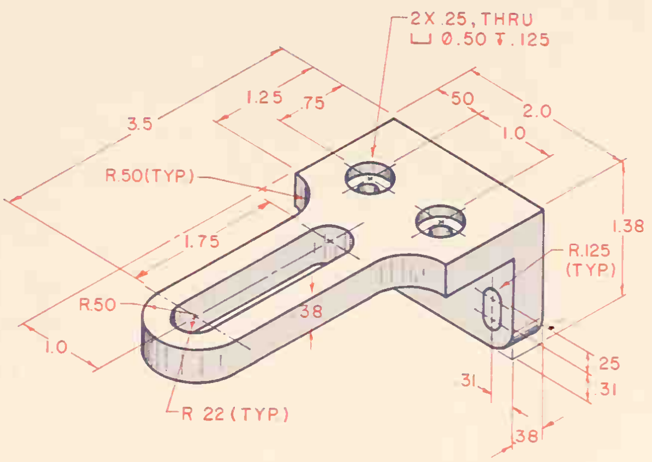
Center two views within the work area, and make one view a full section. Use correct drafting practices for the keyway, ribs, and holes.



Problem 5-6

Problem 5-7

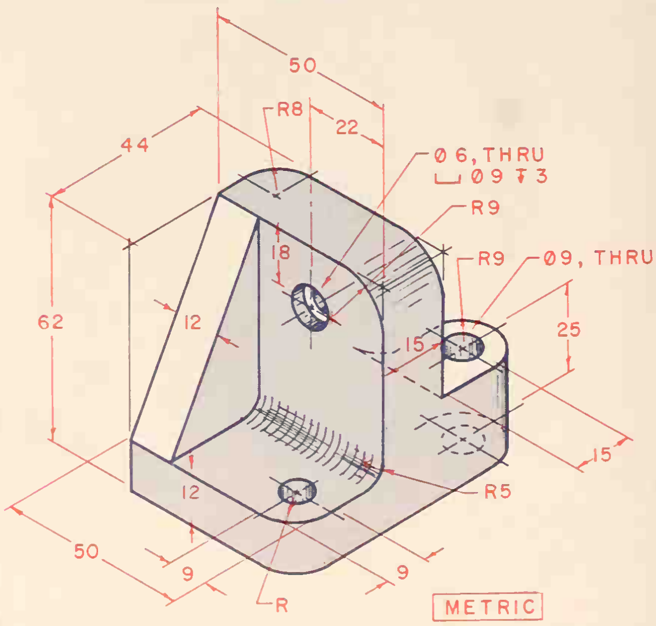
Center three views within the work area, and make one view an offset section. Be sure to include three major features.



Problem 5-7

Problem 5-8

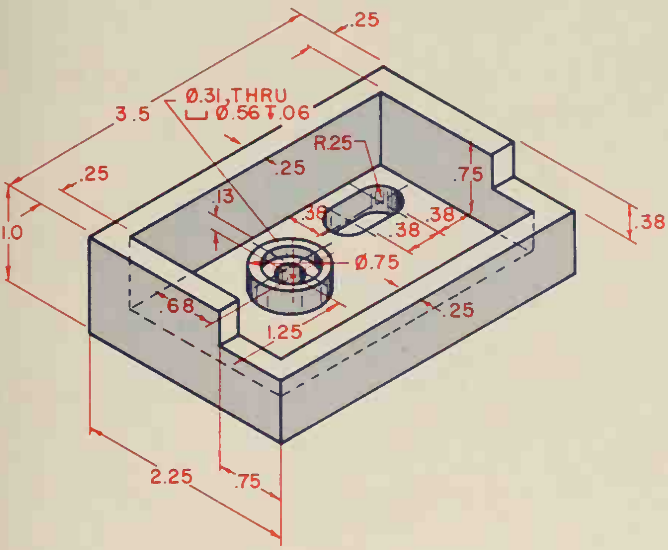
Center three views within the work area, and make one view an offset section. Be sure to include three major features.



Problem 5-8

Problem 5-9

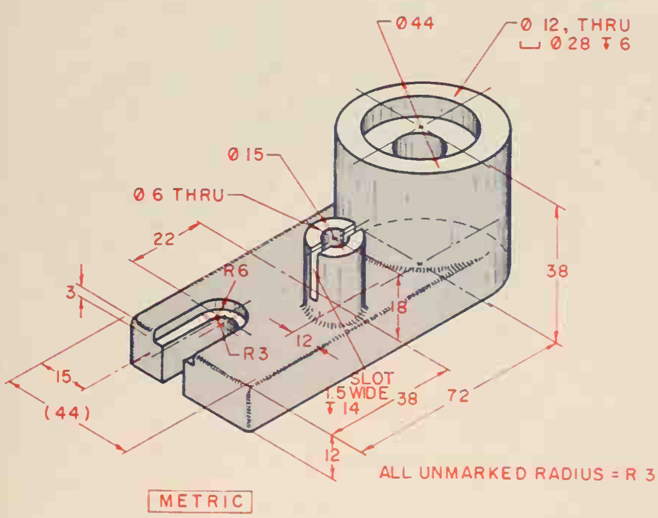
Center three views within the work area, and make one view an offset section. Be sure to include as many of the important features as possible.



Problem 5-9

Problem 5-10

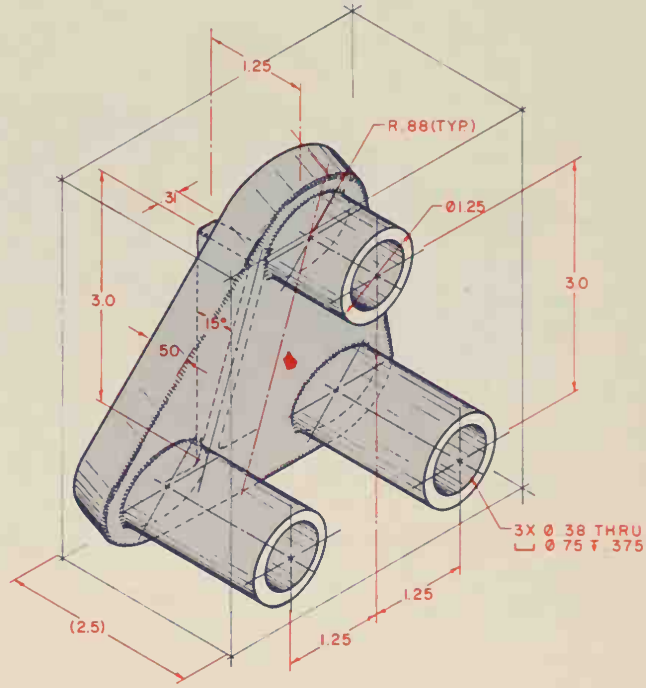
Center three views within the work area, and make one view an offset section. Be sure to include as many of the important features as possible.



Problem 5-10

Problem 5-11

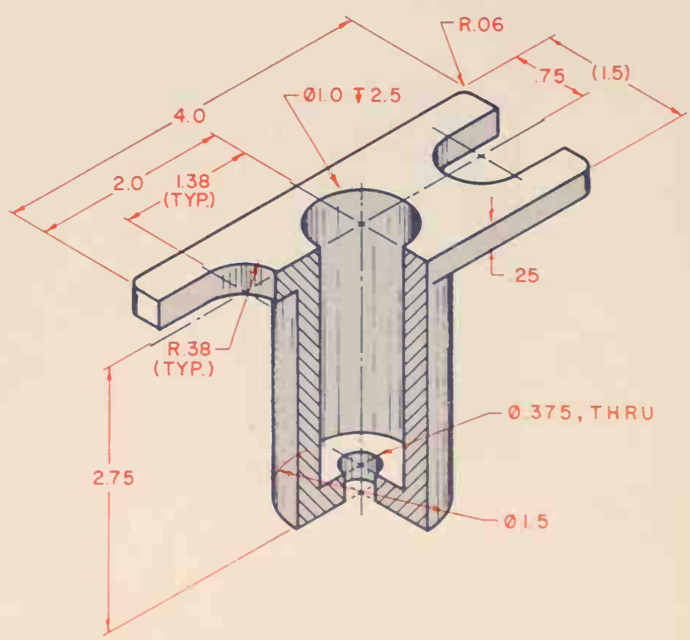
Center two views within the work area, and make one view an offset section. Be sure to include as many of the important features as possible.



Problem 5-11

Problem 5-12

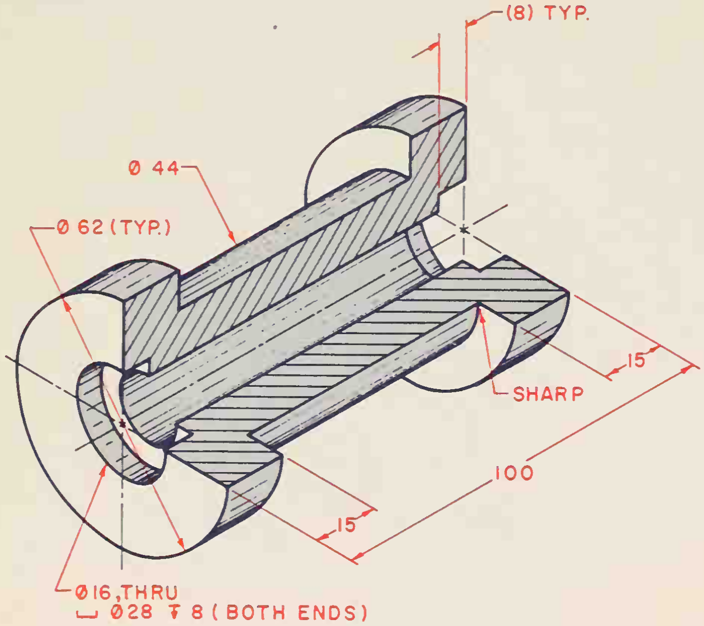
Center the front view and top view within the work area. Make one view a half section.



Problem 5-12

Problem 5-13

Center two views within the work area, and make one view a half section.

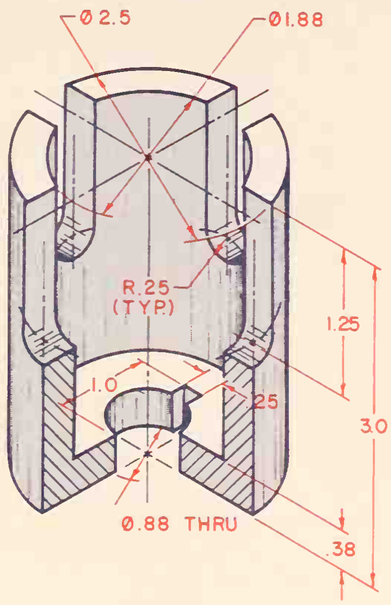


METRIC

Problem 5-13

Problem 5-14

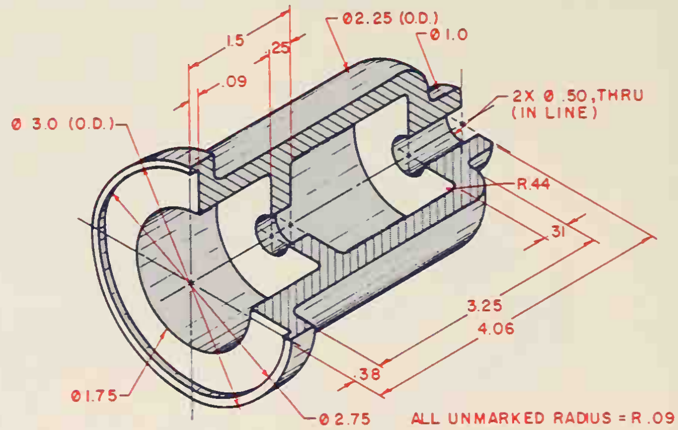
Center the two views within the work area, and make one view a half section.



Problem 5-14

Problem 5-15

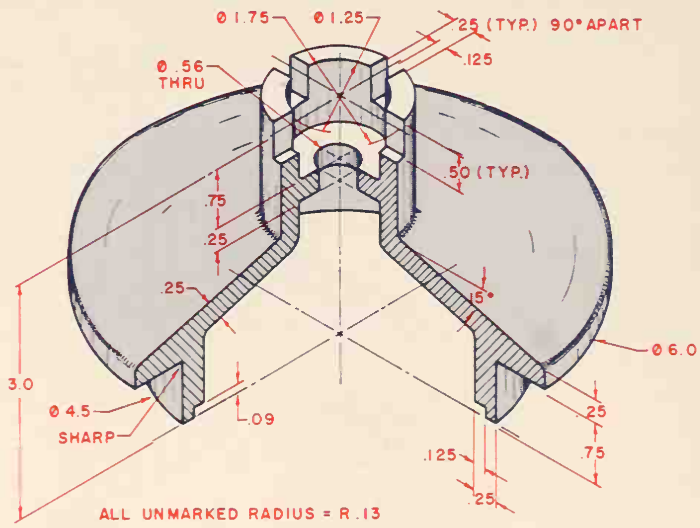
Center two views within the work area, and make one view a half section.



Problem 5-15

Problem 5-16

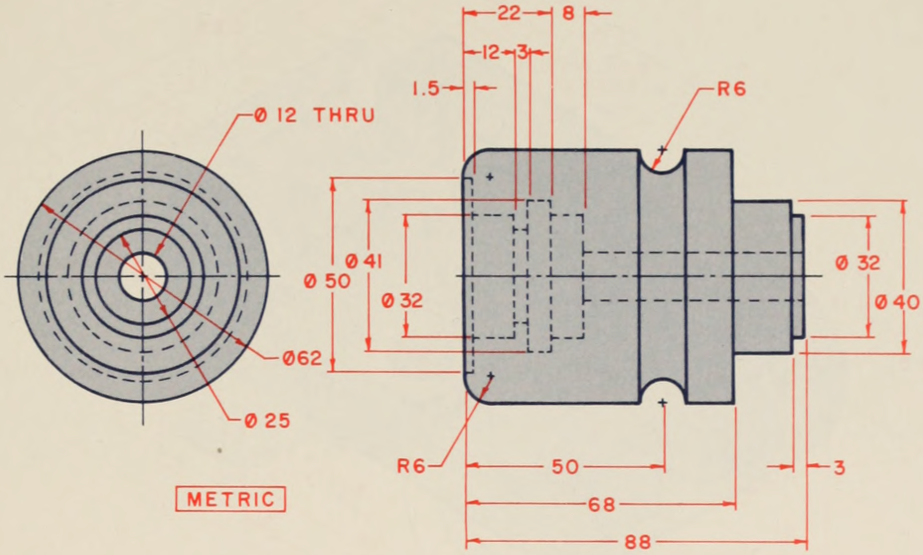
Center two views within the work area, and make one view a half section.



Problem 5-16

Problem 5-17

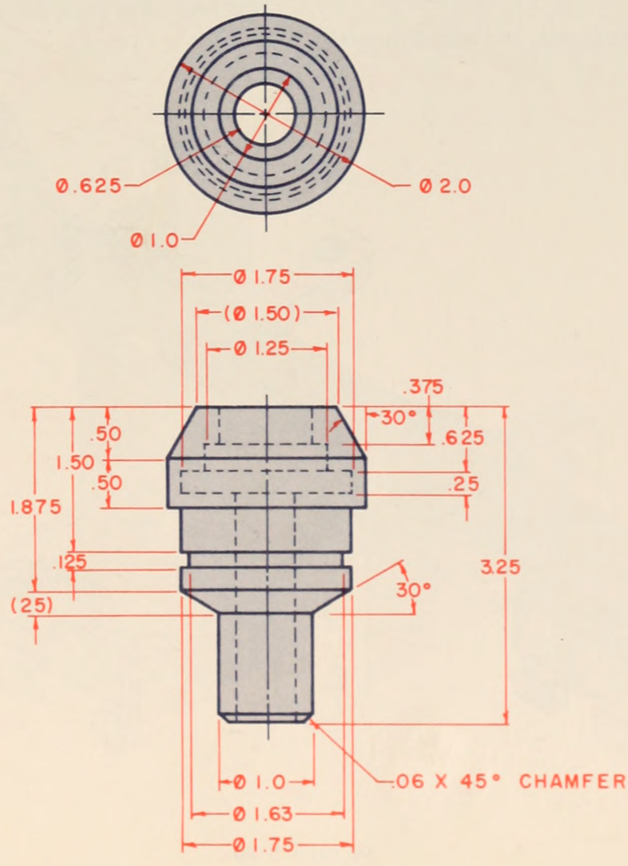
Center the required views within the work area, and make one view a broken-out section to illustrate the complicated interior area.



Problem 5-17

Problem 5-18

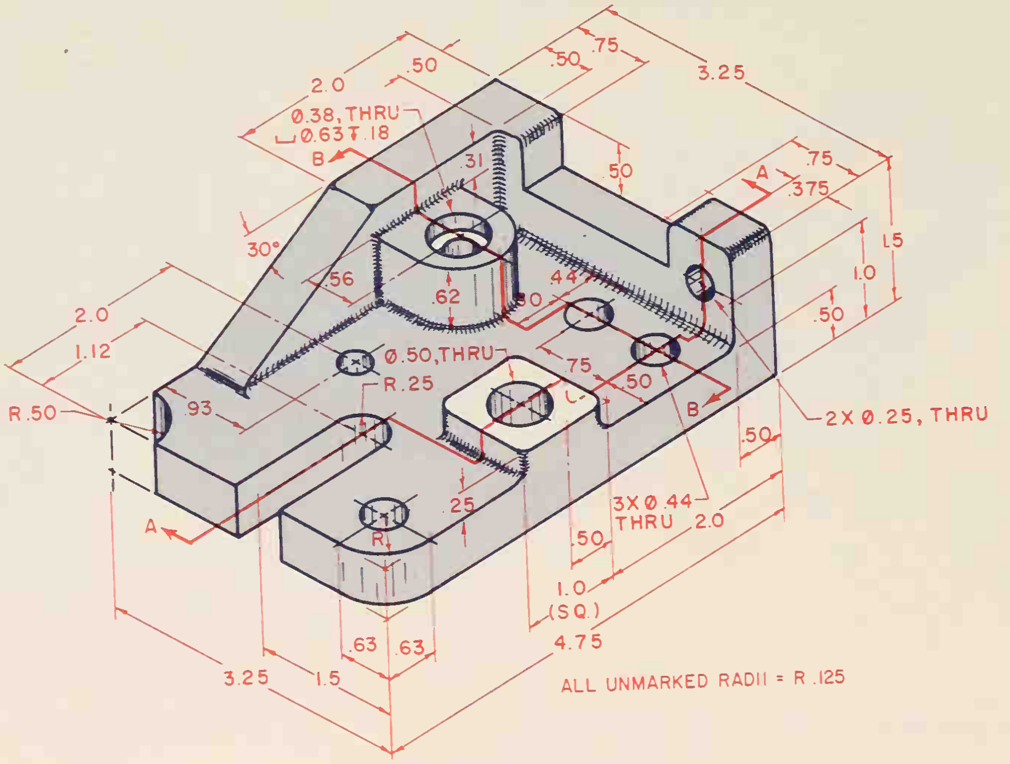
Center the required views within the work area, and make one view a broken-out section as required.



Problem 5-18

Problem 5-19

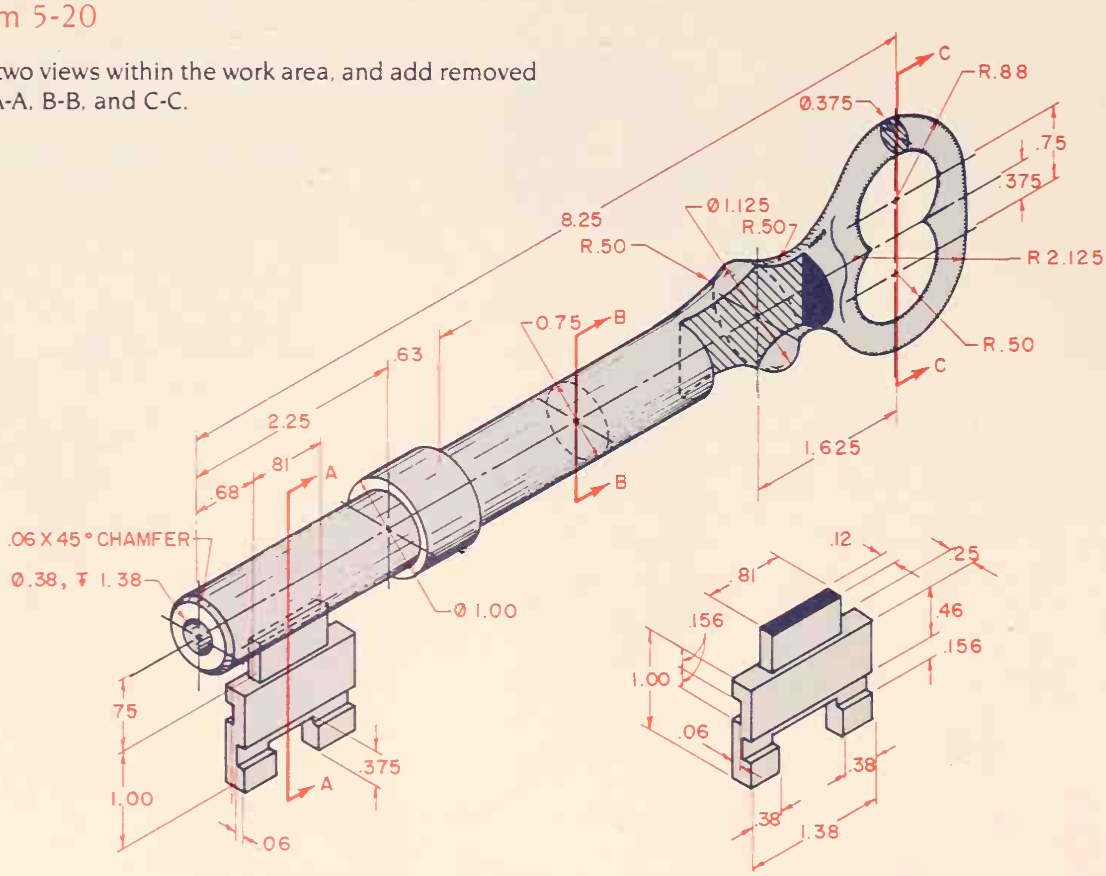
Center three views within the work area, and add removed sections A-A and B-B.



Problem 5-19

Problem 5-20

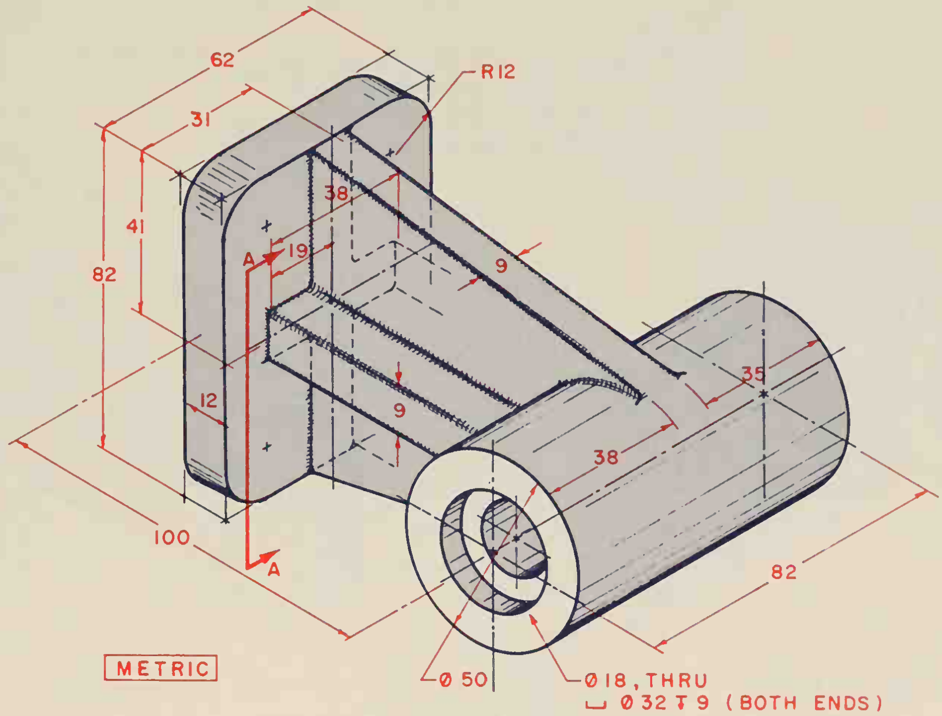
Center two views within the work area, and add removed sections A-A, B-B, and C-C.



Problem 5-20

Problem 5-21

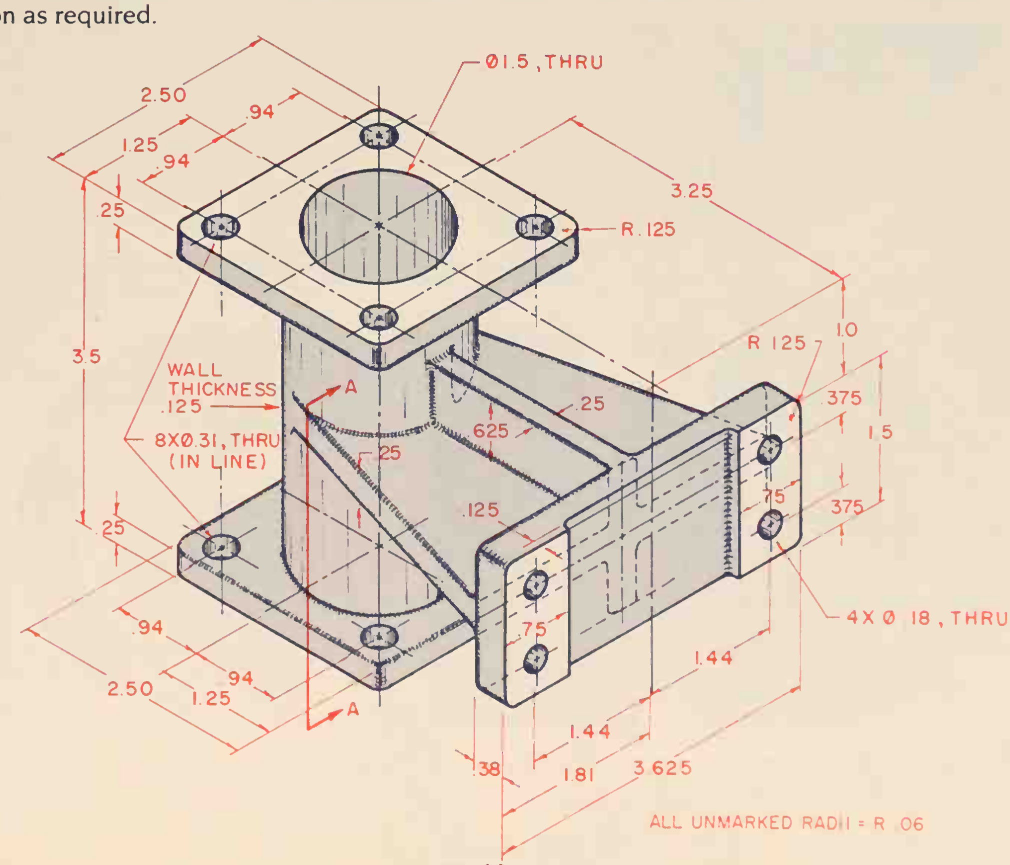
Center the required views within the work area, and add removed section as required.



Problem 5-21

Problem 5-22

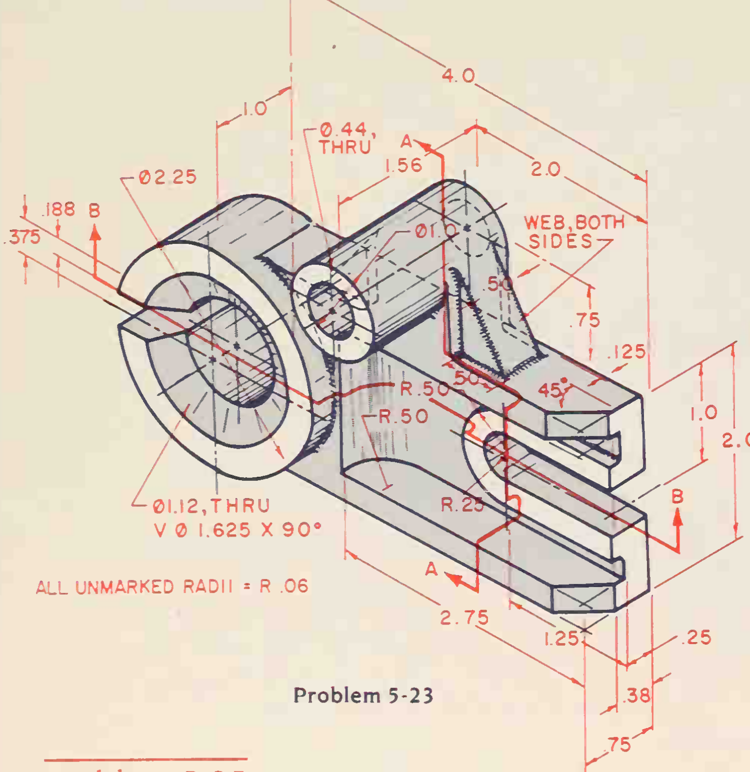
Center the required views within the work area, and add removed section as required.



Problem 5-22

Problem 5-23

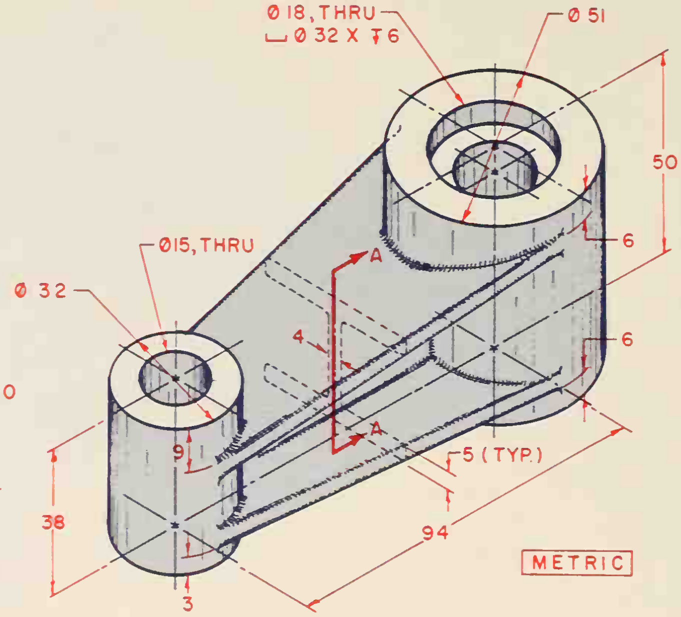
Center the required views within the work area, and add removed sections A-A and B-B.



Problem 5-23

Problem 5-24

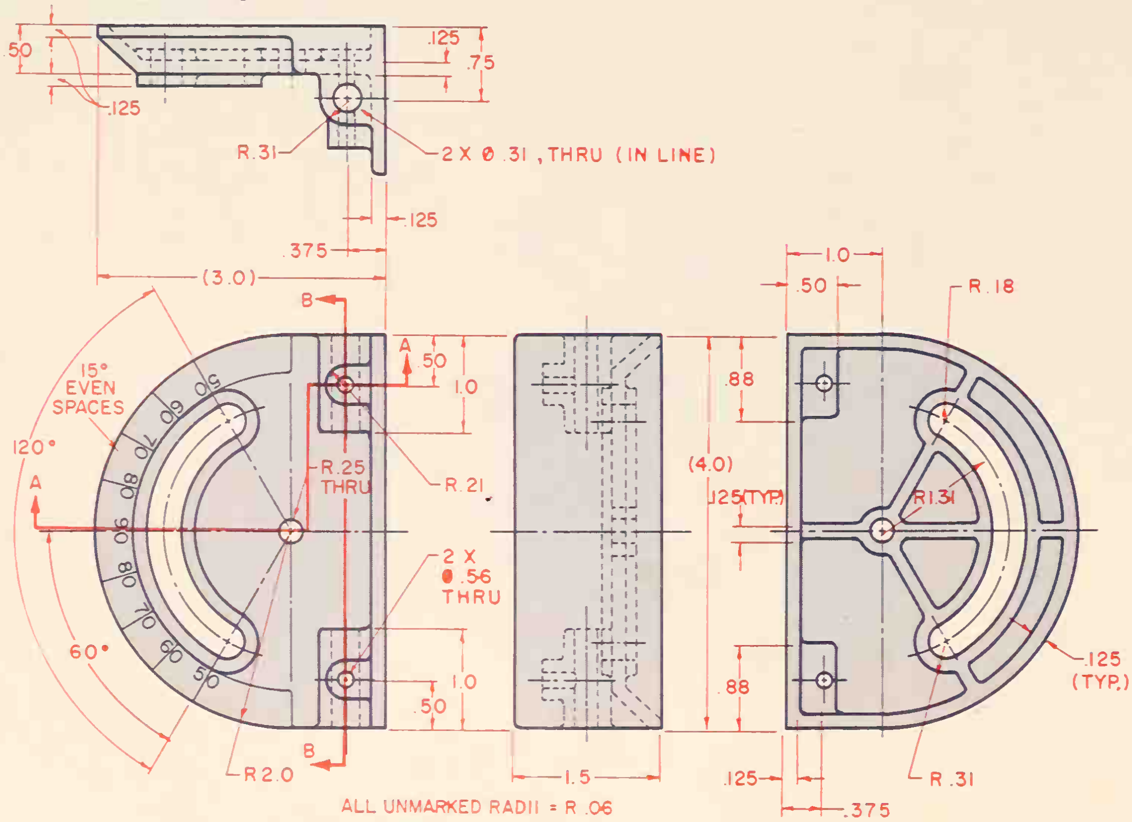
Center the required views within the work area, and add removed section A-A.



Problem 5-24

Problem 5-25

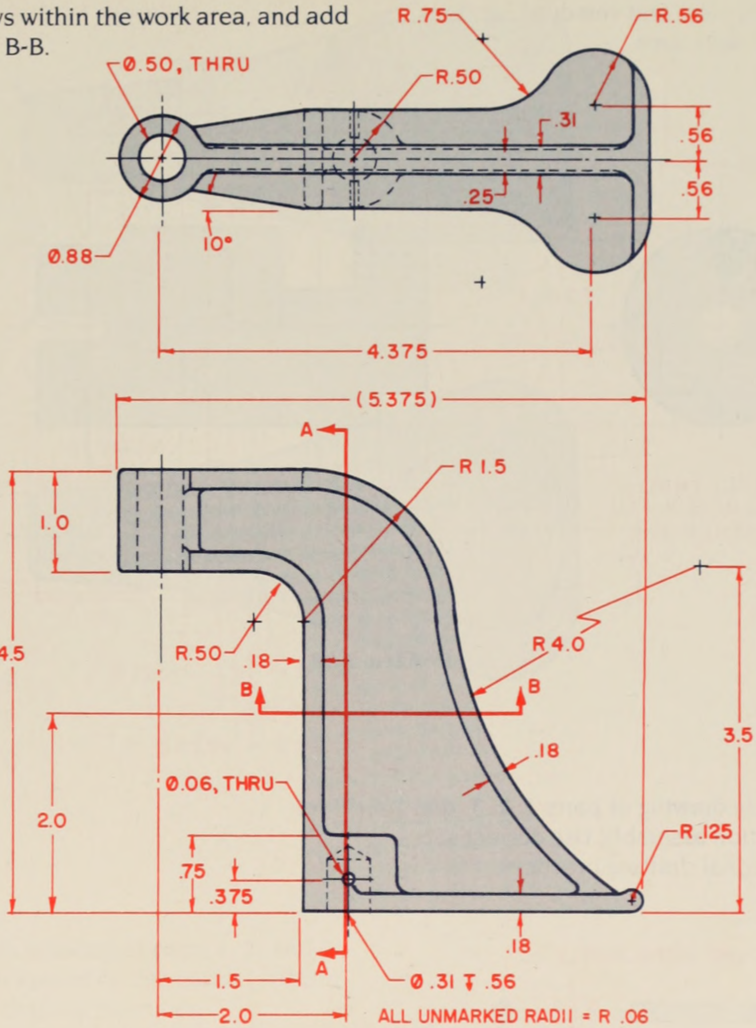
Center the four views within the work area. Make the top view section A-A and the right-side view section B-B.



Problem 5-25

Problem 5-26

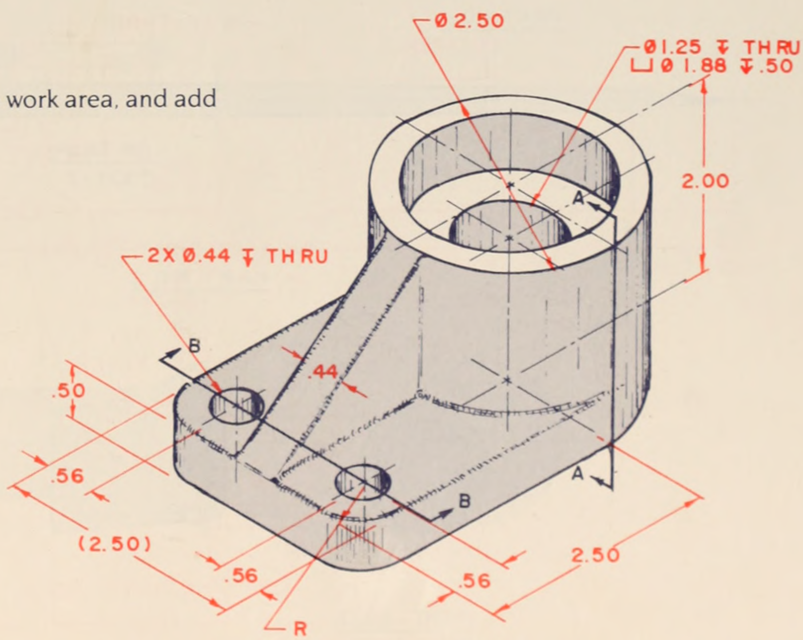
Center the required views within the work area, and add removed sections A-A and B-B.



Problem 5-26

Problem 5-27

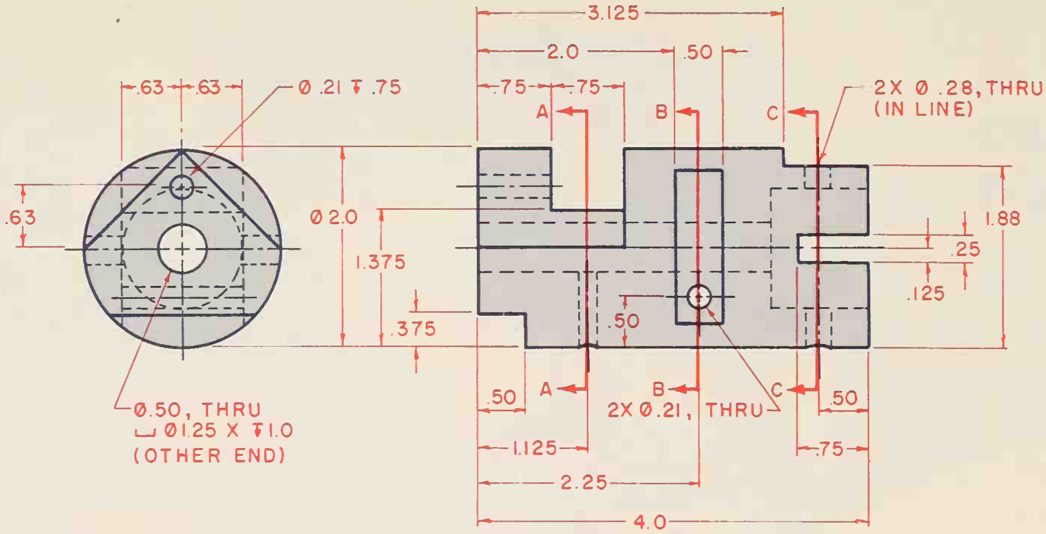
Center the required views within the work area, and add removed sections A-A and B-B.



Problem 5-27 ALL UNMARKED RADII = R .06

Problem 5-28

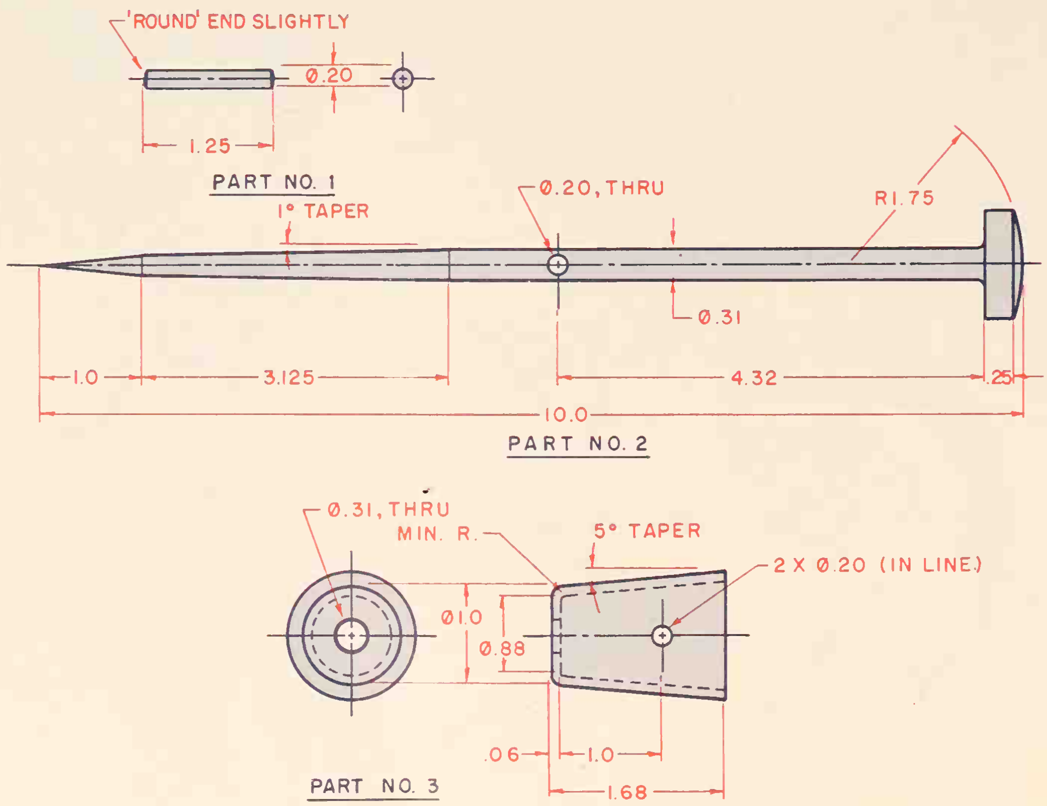
Center the front view, side view and removed sections A-A, B-B, and C-C within the work area.



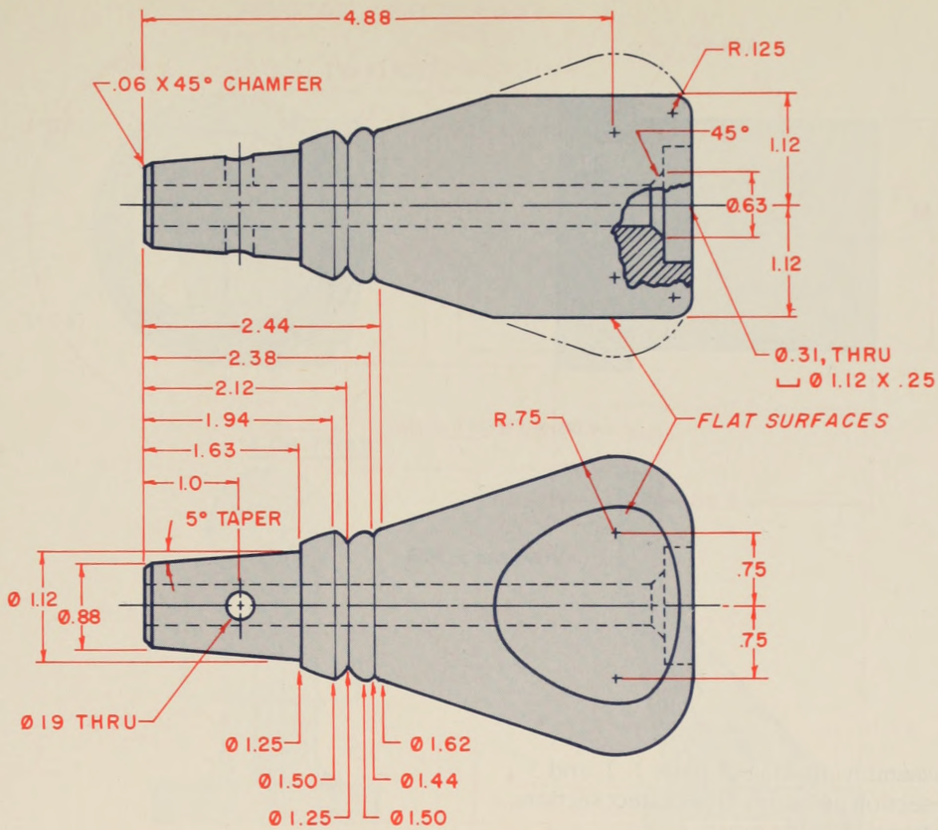
Problem 5-28

Problem 5-29

Make a two-view assembly drawing of parts 1, 2, 3, and 4. Make one view a full-section assembly. Use correct section lining, and all conventional drafting practices.



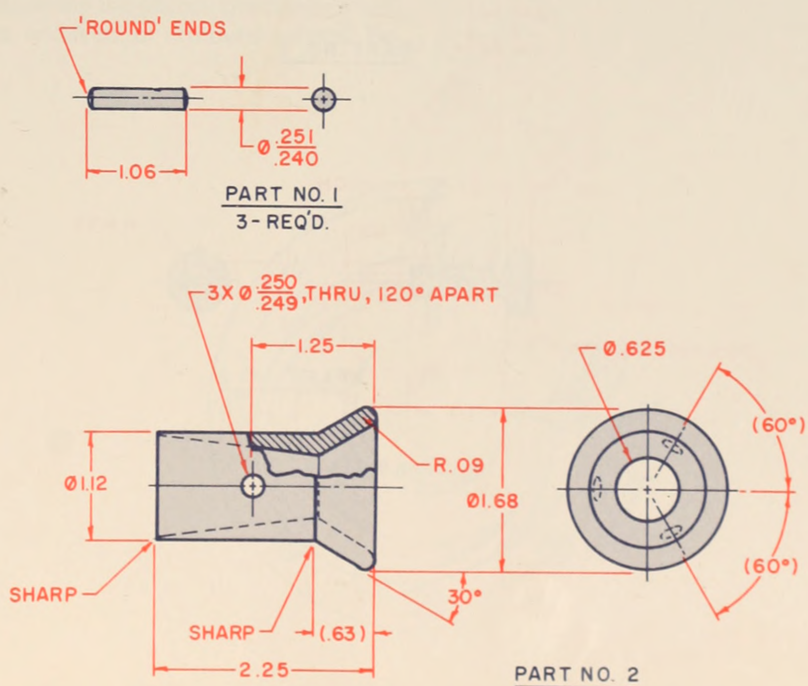
Problem 5-29A



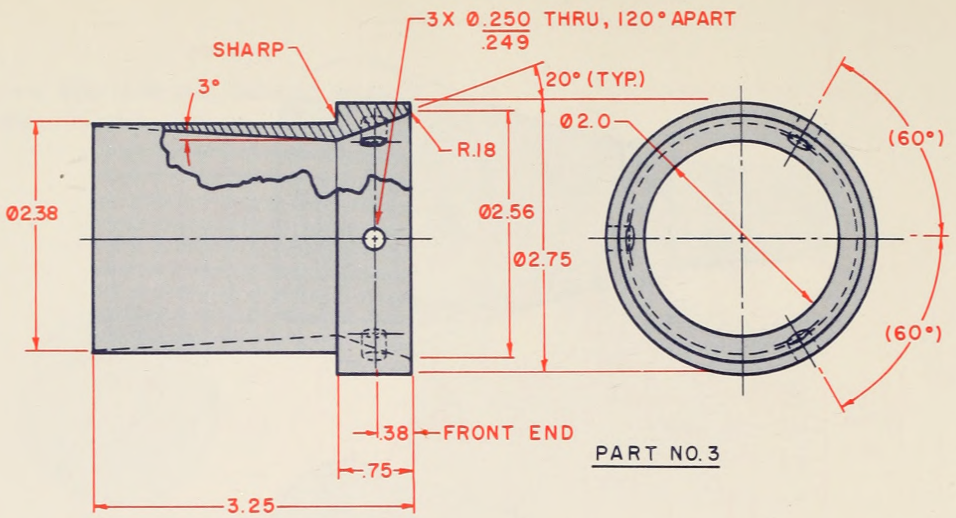
Problem 5-29B

Problem 5-30

Make a two-view assembly drawing of parts 1, 2, and 3. Make one view a full-section assembly. Use correct section lining and all conventional drafting practices.



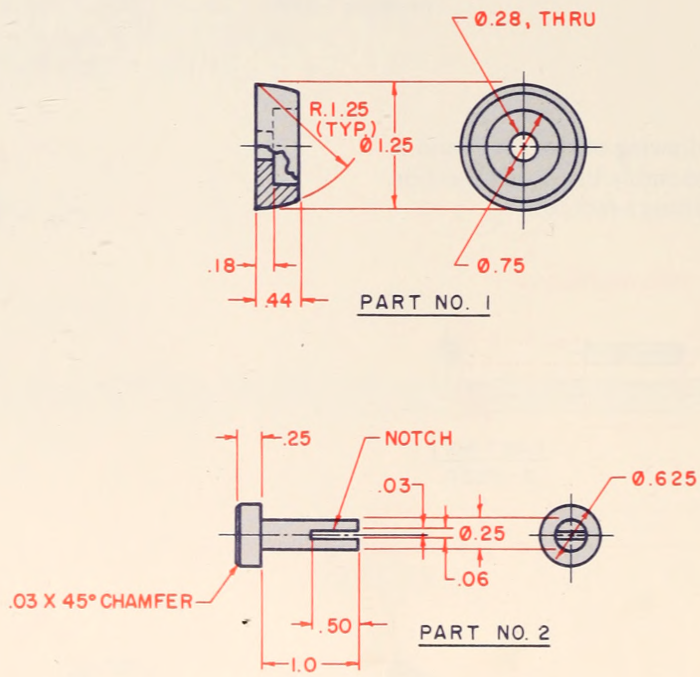
Problem 5-30A



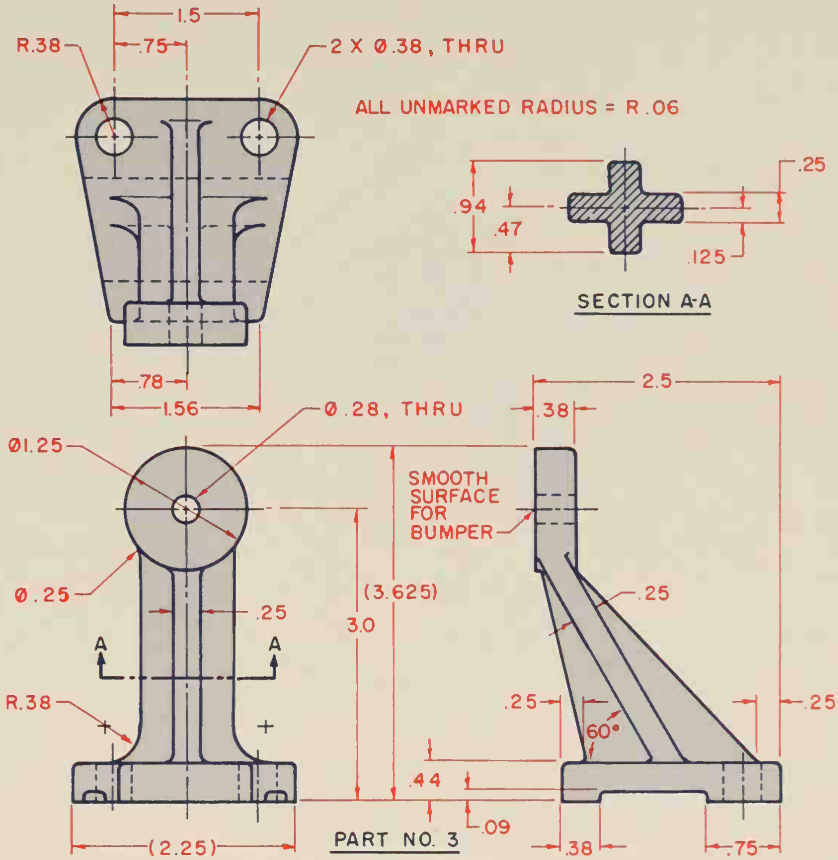
Problem 5-30B

Problem 5-31

Make a two-view assembly drawing of parts 1, 2, and 3. Make one view a full-section assembly. Use correct section lining and all conventional drafting practices.



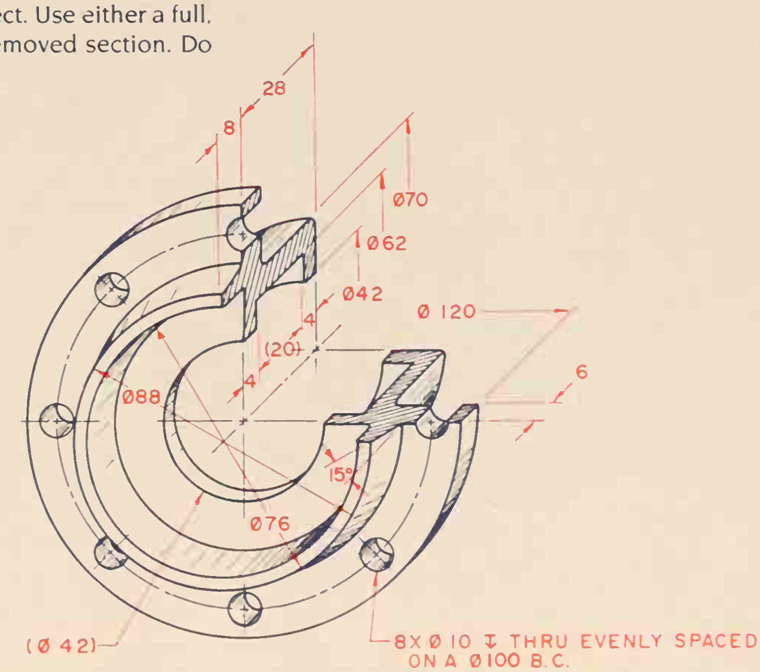
Problem 5-31A



Problem 5-31B

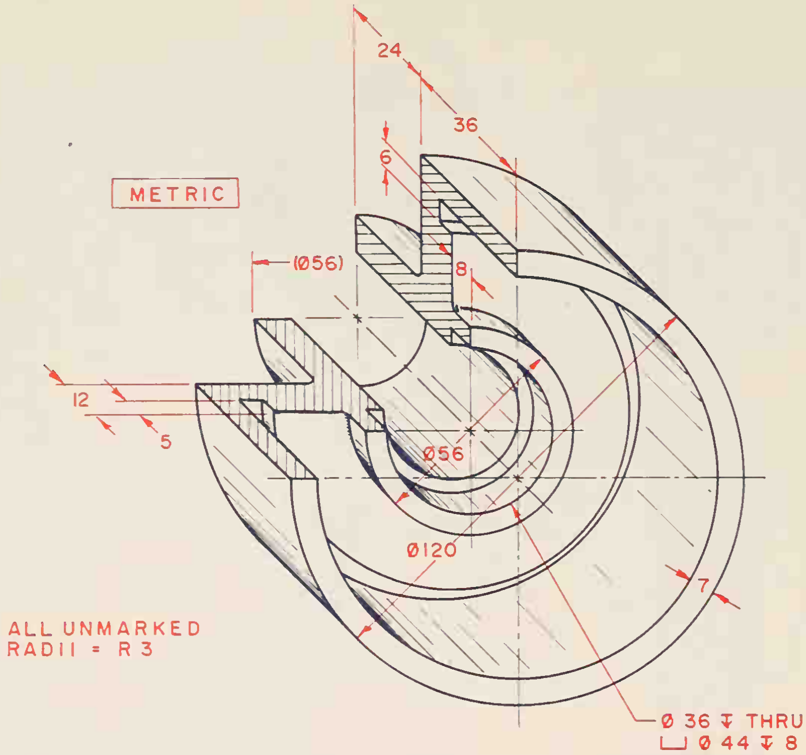
Problems 5-32 through 5-37

Center required views within the work area. Leave a 1-inch or 25-mm space between views. Make one view into a section view to fully illustrate the object. Use either a full, half, offset, broken-out, revolved, or removed section. Do not add dimensions.

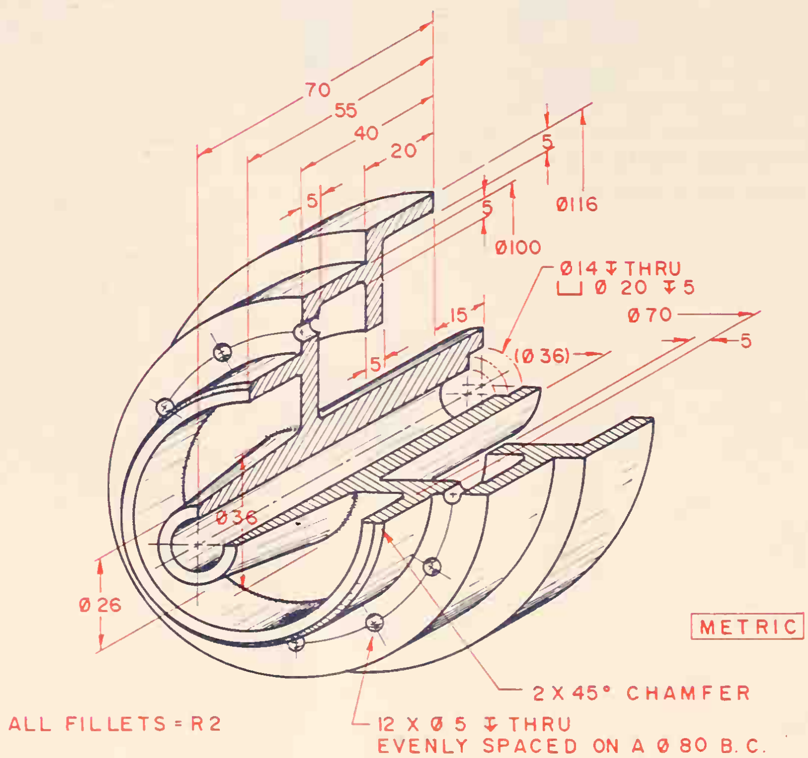


Problem 5-32

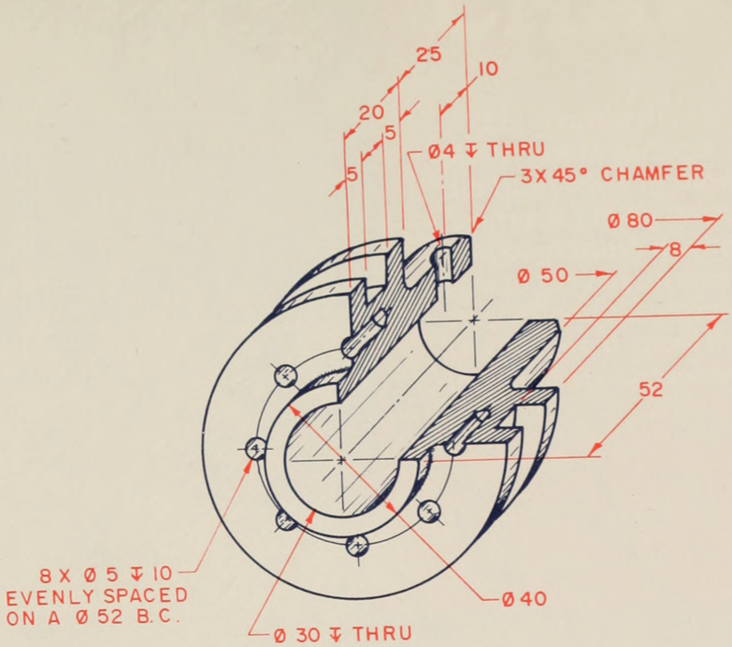
METRIC



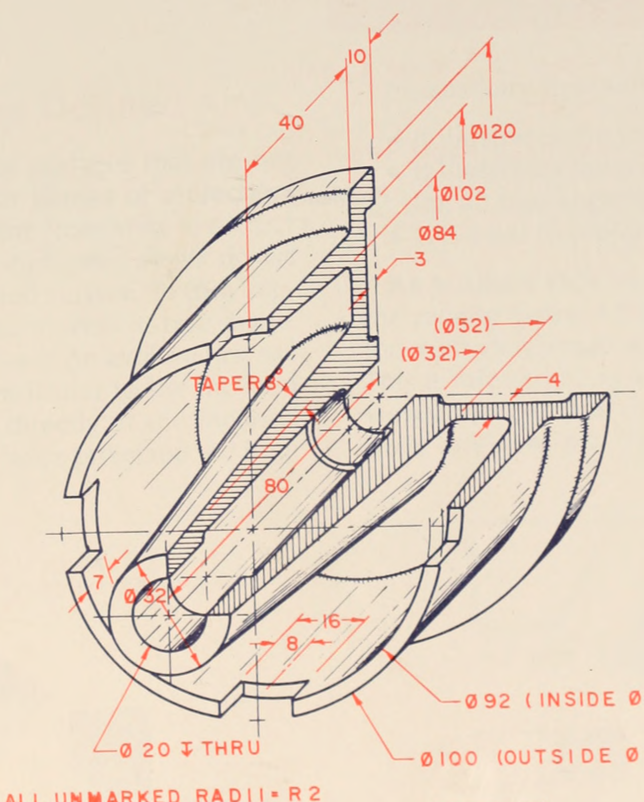
Problem 5-33



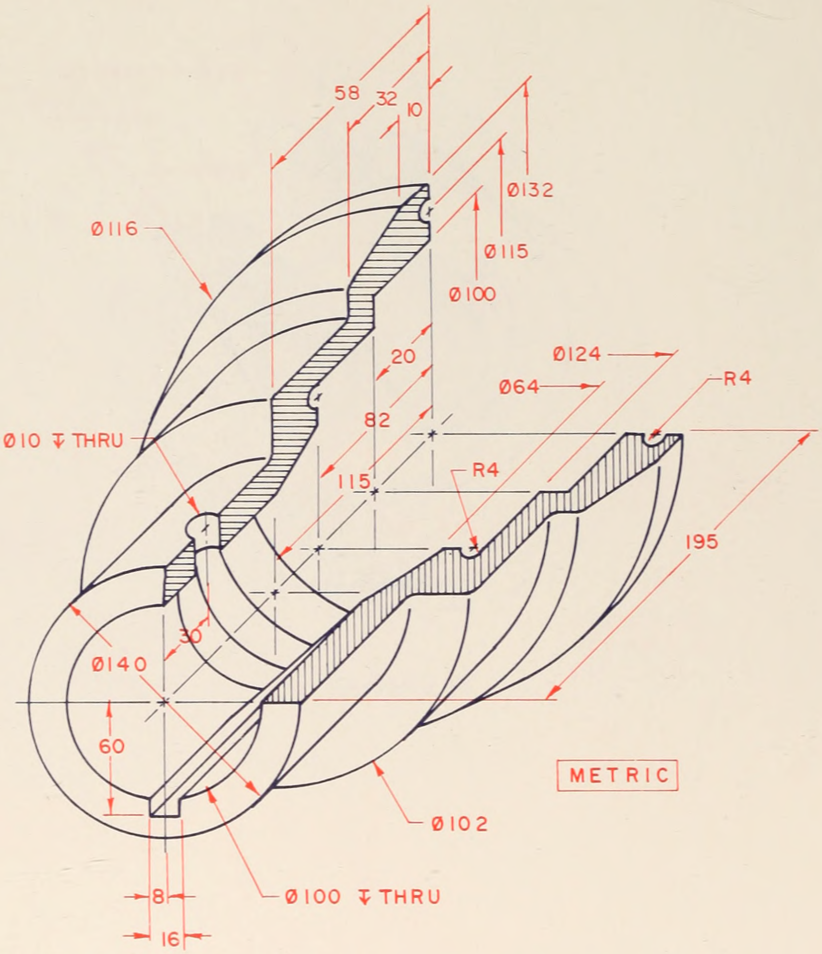
Problem 5-34



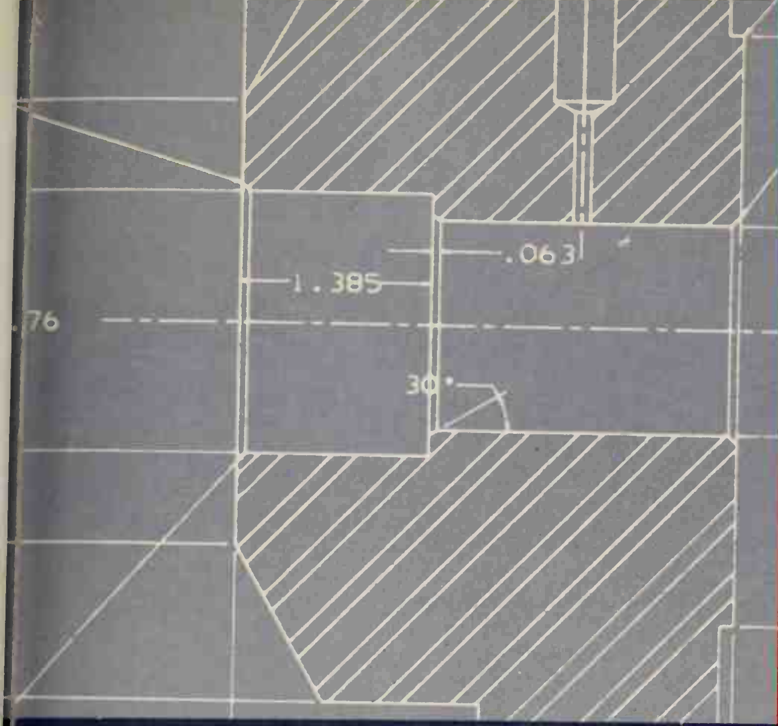
Problem 5-35



Problem 5-36


58
32
10
Ø132
Ø116
Ø115
Ø100
20
Ø124
Ø64
R4
82
Ø10 ↧ THRU
115
R4
195
30
Ø140
60
METRIC
Ø102
8
16
Ø100 ↧ THRU
ALL UNMARKED RADII = R5

Problem 5-37



CHAPTER 6

This chapter also is an extension of Chapter 4, Multiview Drawings, with the addition of an auxiliary view to show the true size and shape of a surface not on the usual planes of projection. The beginning drafter must fully understand how to lay out an auxiliary view and, if necessary, to add a secondary auxiliary view. The student must know the various standard drafting practices associated with auxiliary views.

AUXILIARY VIEWS

Auxiliary Views Defined

Many objects have inclined surfaces that are not always parallel to the regular planes of projection. For example, in Figure 6-1, the front view is correct as shown, but the top and right-side views do *not* correctly represent the inclined surface. To truly represent the inclined surface and to show its true shape, an auxiliary view must be drawn. An *auxiliary view* has a line of sight that is perpendicular to the inclined surface, as viewed looking directly at the inclined surface. Auxiliary views are always projected 90° from the inclined surface.

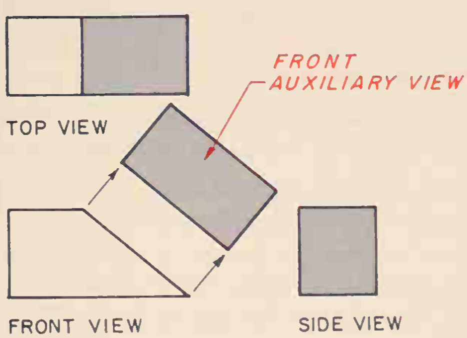


Figure 6-1 Front view auxiliary view

An auxiliary view serves three purposes:

- It illustrates the true size of a surface.
- It illustrates the true shape of a surface, including all true angles and/or arcs.
- It is used to project and complete other views.

An auxiliary view can be constructed from any of the regular views. An auxiliary view projected from the front view would appear as it does in Figure 6-1. This is referred to as a *front view auxiliary*. An auxiliary view projected from the top view would appear as it does in Figure 6-2. This is referred to as a *top view*

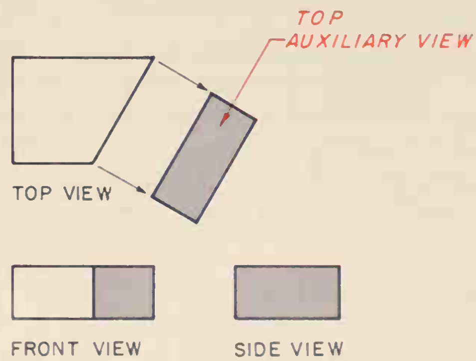


Figure 6-2 Top view auxiliary view

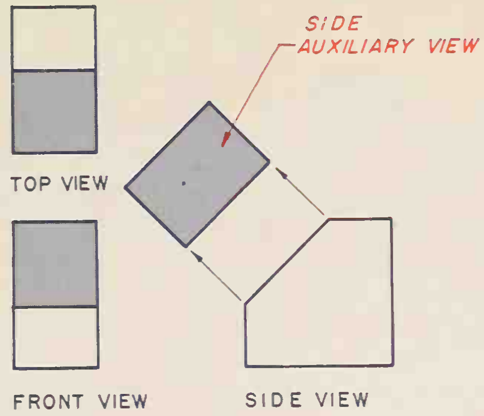


Figure 6-3 Side view auxiliary view

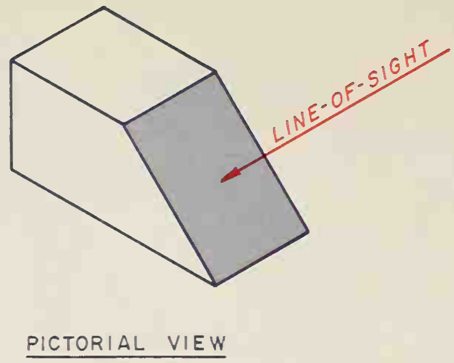


Figure 6-4 Drawing an auxiliary view

auxiliary. An auxiliary view projected from the right-side view would appear as it does in Figure 6-3. This is referred to as a *side view auxiliary.* Note in each case that the auxiliary view is projected 90° from the inclined or slanted surface, and is viewed from a line of sight 90° to the inclined or slanted surface, or as viewed looking directly down upon the inclined surface.

Hidden Lines in an Auxiliary View

Hidden lines should be omitted in an auxiliary view, unless they are needed for clarity. This is the drafter's prerogative or decision.

How To Draw an Auxiliary View

Given: The pictorial view of an object, Figure 6-4. Notice the inclined surface. As the inclined surface is on the front view, this will be a front view auxiliary. The usual three views of an object, front view, top view and right-side view, are shown in Figure 6-5.

Step 1. Label all important points of the auxiliary view, as illustrated in Figure 6-6A.

Step 2. Construct a *reference* line, which is also the edge view of a reference plane, in the right-side view. Always construct a reference line so that it is vertical and passes through as many points as possible. In this example, it passes through points a-d, Figure 6-6B.

Step 3. Draw light projection lines 90° from the inclined surface, and construct a reference line *parallel* to the inclined surface at any convenient distance, as shown in Figure 6-6C. Label all important points established thus far. Notice points a and d are *on* the reference line.

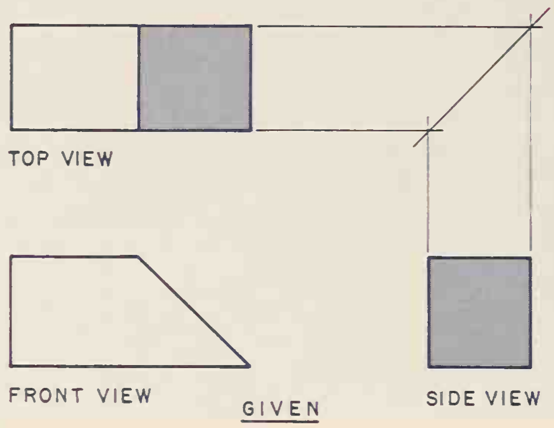


Figure 6-5 Given: Three views of an object

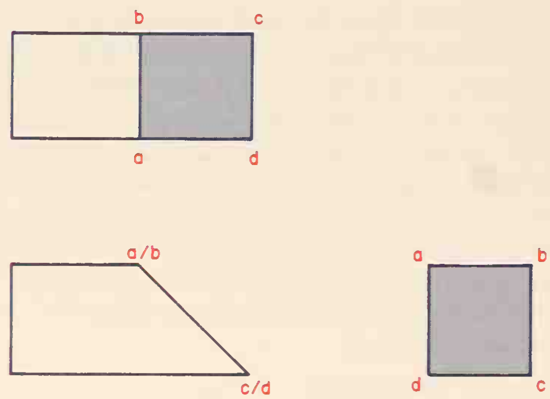


Figure 6-6A Step 1

Step 4. In the right-side view, measure the distance each point is *from* the reference line. Project these distances back to the inclined surface of the front view and up 90° from the inclined surface to the reference line above. Transfer each distance, and lightly label each point as illustrated in Figure 6-6D.

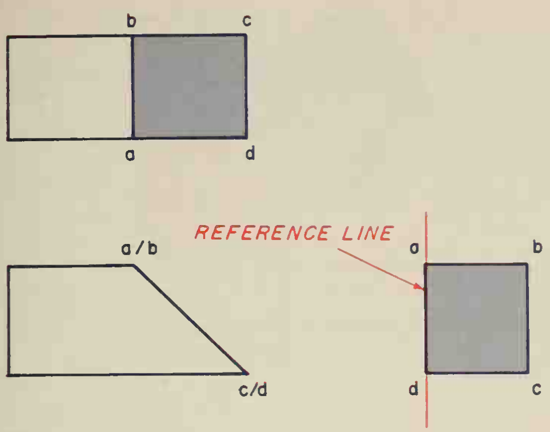


Figure 6-6B Step 2

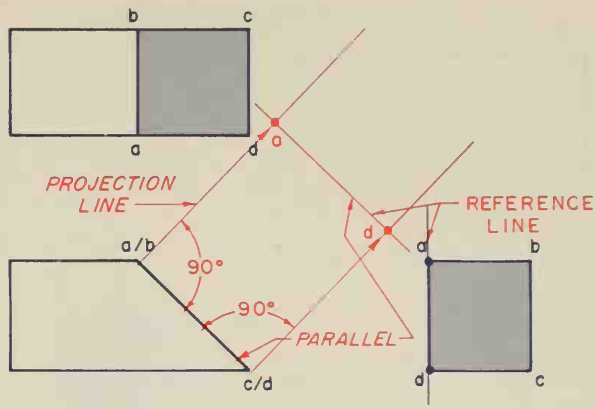


Figure 6-6C Step 3

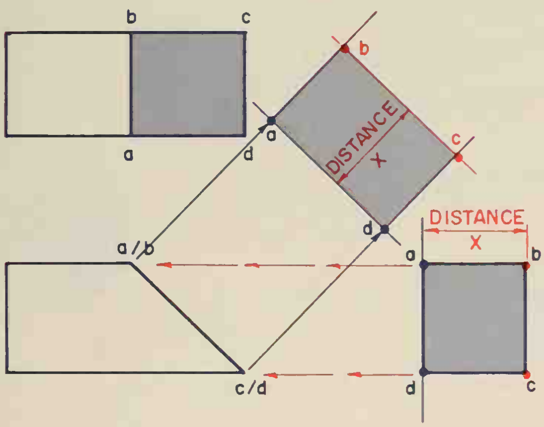


Figure 6-6D Step 4

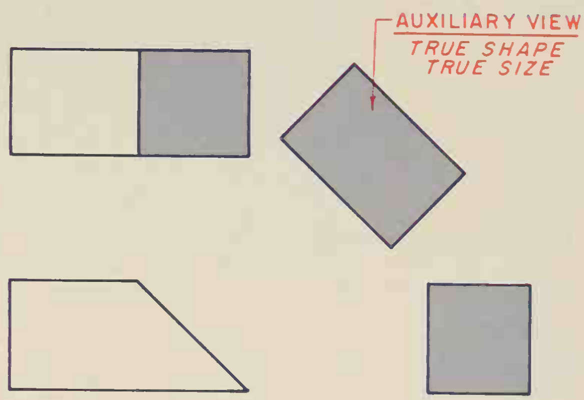


Figure 6-6E Step 5 finished drawing

Step 5. Recheck all work. Be sure:

- The projection is 90° from the inclined surface, in this example the front view.
- The reference line is *parallel* to the inclined surface of the front view.
- All distances have been transferred accurately.

If correct, carefully darken in and complete all views. The final finished drawing will appear as it does in Figure 6-6E. Notice that *only* the inclined surface is projected into the auxiliary view. Anything else would be foreshortened and, thus, not of true size or shape, and therefore of no use. Good drafting practice is to project *only* the surface of the inclined line, Figure 6-7.

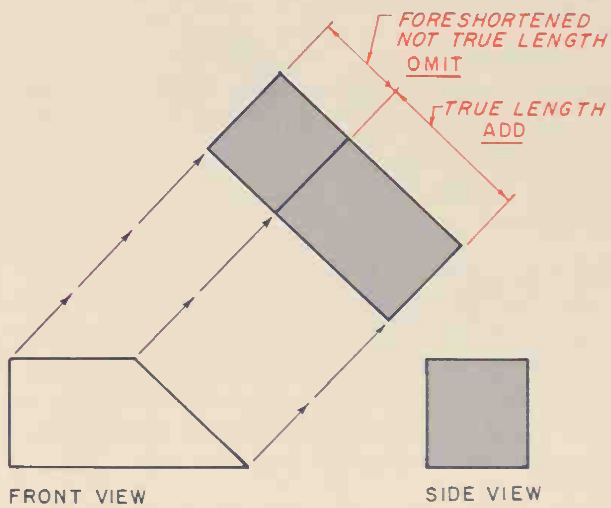


Figure 6-7 Draw only the inclined surface in the auxiliary view

How To Project a Round Surface from an Inclined or Slanted Surface

Given: The usual three views of an object, front view, right-side view and unfinished top view, are shown in Figure 6-8. (The usual 45° projection angle line will be omitted, as a slightly newer projection method will be used to complete the top view.) Refer also to the pictorial drawing of this object, Figure 6-9.

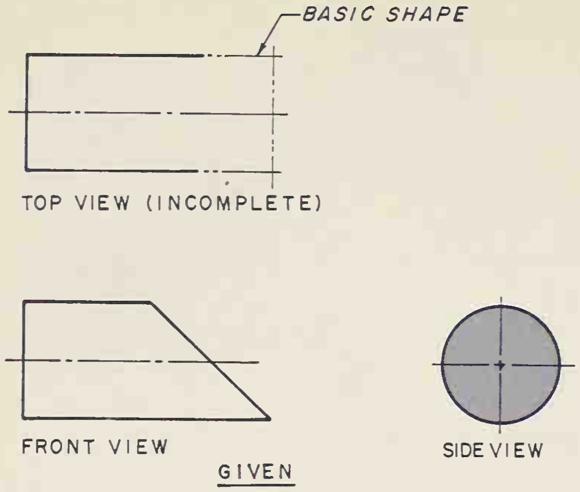


Figure 6-8 Projecting a round surface from an inclined surface

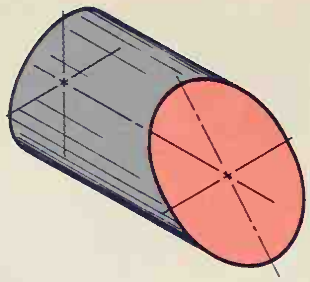


Figure 6-9 Pictorial view of an object

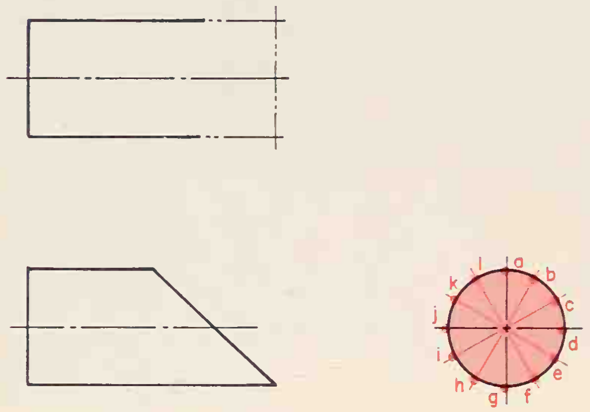


Figure 6-10A Step 1

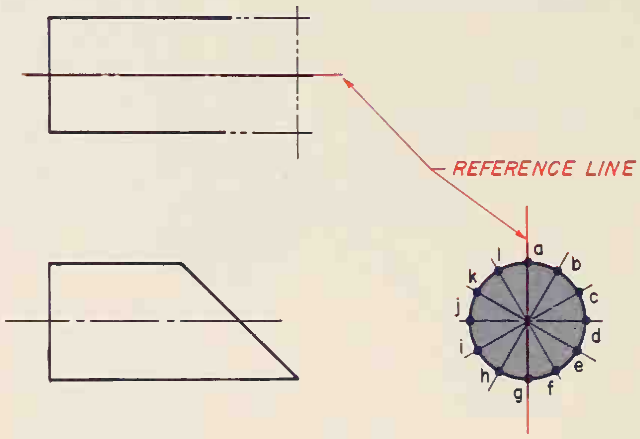


Figure 6-10B Step 2

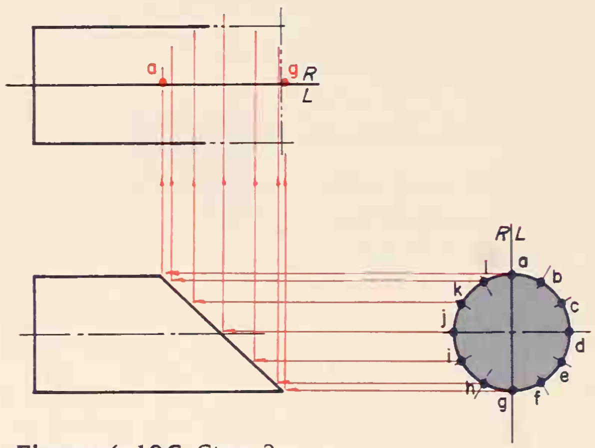


Figure 6-10C Step 3

Step 1. Divide the rounded view into equal spaces. In this example, using a 30° triangle, the right-side view is rounded and divided into 12 equal parts, Figure 6-10A. Letter each point clockwise, as shown in the figure.

Step 2. Construct a vertical reference line in the right-side view so it passes through the center; in this example, through points a and g. (Always place the reference line through the center of any symmetrical object.) Construct a reference line in the top view which runs through the center, as illustrated in Figure 6-10B.

Step 3. Draw light projection lines from the 12 points in the right-side view to the inclined edge in the front view. Project these same 12 points directly up to the top view from the inclined edge in the front view. Notice points a and g are *on* the reference line, Figure 6-10C.

Step 4. In the right-side view, measure the distance each point is *from* the reference line. Transfer each of these distances from the right-side view reference line to the top view reference line. Label each point lightly as each is found, Figure 6-10D.

Step 5. Lightly connect all points and, if correct, darken in all views. This completes the top view, Figure 6-10E. Always darken in the compass and irregular curve layout work first. This completes the top view.

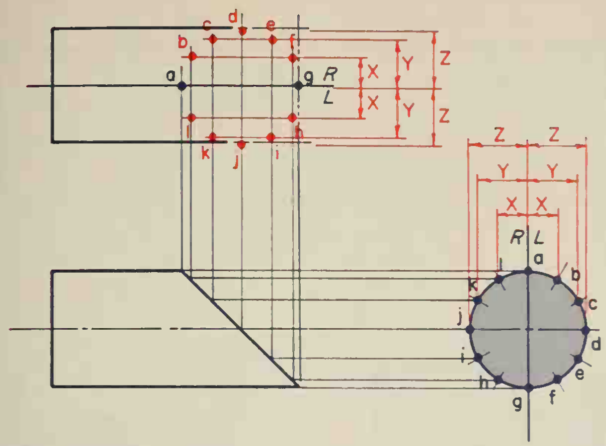


Figure 6-10D Step 4

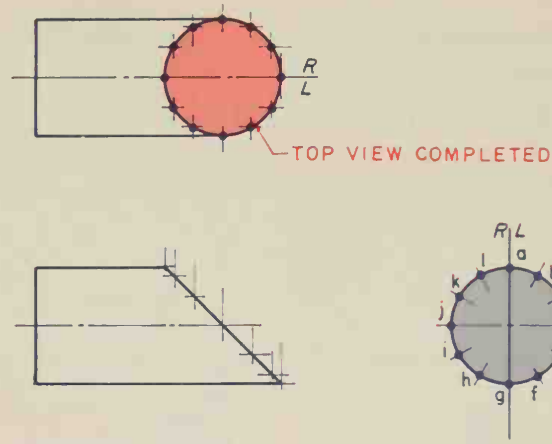


Figure 6-10E Step 5

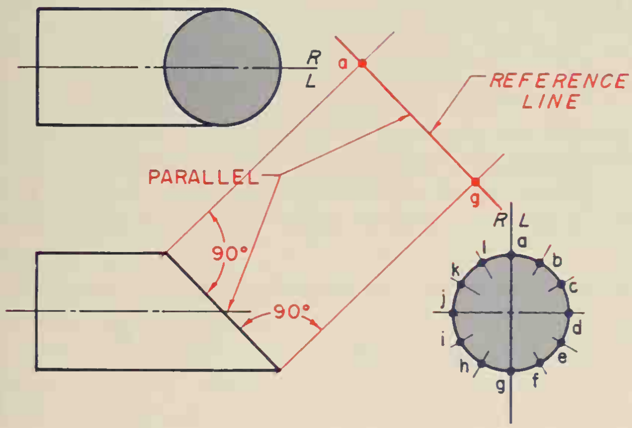


Figure 6-10F Step 6

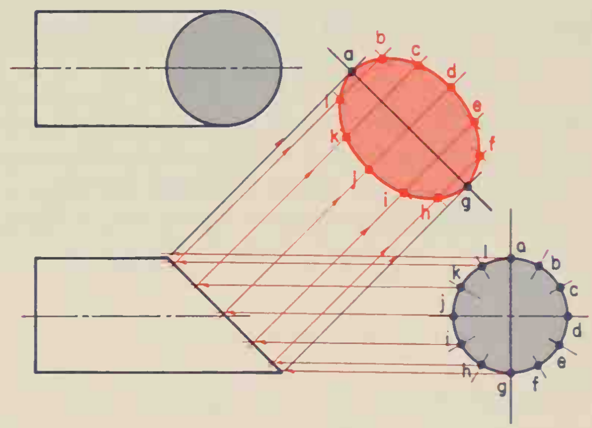


Figure 6-10G Step 7

How to Draw an Auxiliary View of a Round Surface

Step 6. Draw light projection lines 90° from the inclined surface of the front view. Construct the reference line *parallel* to the inclined surface at any convenient distance. Label the points that are on the reference line; in this example, a and g, Figure 6-10F.

Step 7. Draw light projection lines from the 12 points in the right-side view to the inclined edge in the front view (Step 3). Project these same 12 points directly up to the auxiliary view from the inclined edge in the front view. Again, notice points a and g are *on* the reference line, Figure 6-10G. In the right-side view, measure the distance each point is from the reference line. Transfer each of these distances from the right-side view reference line to the auxiliary view reference line. Label each point lightly as each is found.

Step 8. Lightly connect all points and, if correct, darken in the auxiliary view. This completes the auxiliary view, Figure 6-10H. Notice that only the inclined surface has been projected into the auxiliary view.

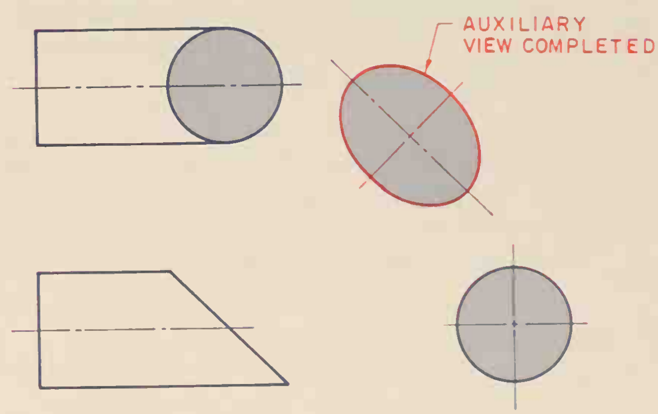


Figure 6-10H Step 8 finished drawing

How to Plot an Irregular Curved Surface

Given: The usual three views: front view (incomplete), top view, and the right-side view, Figure 6-11. This is an example of a top view auxiliary

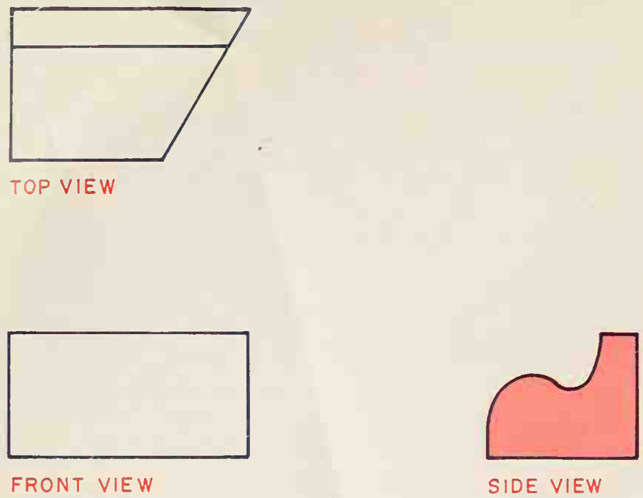


Figure 6-11 Plotting an irregular curved surface

Step 1. Add various points at random along the curved surface. Even spaces are not necessary, but try to choose points that pick up high and low points along the line, Figure 6-12A. Always label the points in a clockwise direction.

Step 2. From the right-side view, project these points *up* to the 45° projection line and over to the top view. Where these points intersect with the inclined surface, project directly down into the front view. Project these same points from the right-side view to the front view. Where the points intersect is where the point actually is. Lightly locate and connect all lines and complete the front view, Figure 6-12B.

Step 3. Establish a reference line in the right-side view. Construct this reference line so it passes through as many points as possible; in this example, points a and j, Figure 6-12C.

Step 4. Add projection lines at 90° from the inclined surface. Add a reference line parallel to the inclined surface. Notice that points a and j again fall *on* the reference line, Figure 6-12D.

Step 5. Project all points from the right-side view up and over to the inclined surface of the top view. Where the points intersect with the inclined surface, project 90° from the inclined surface. Transfer all distances from the reference line in the right-side view to the reference line in the auxiliary view. Lightly connect all points and, if correct, darken in all views, Figure 6-12E.

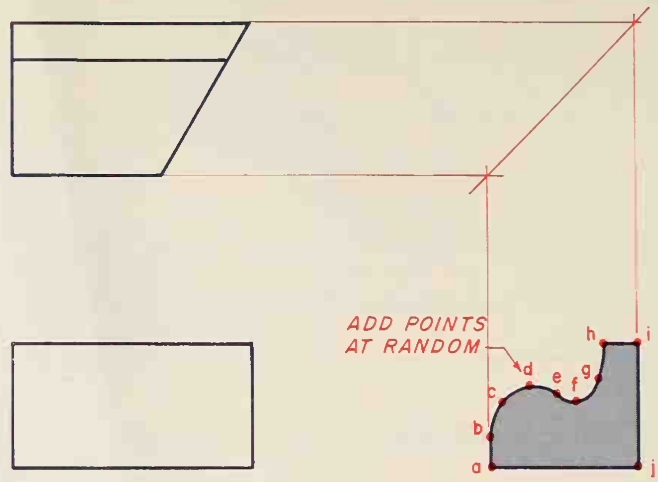


Figure 6-12A Step 1

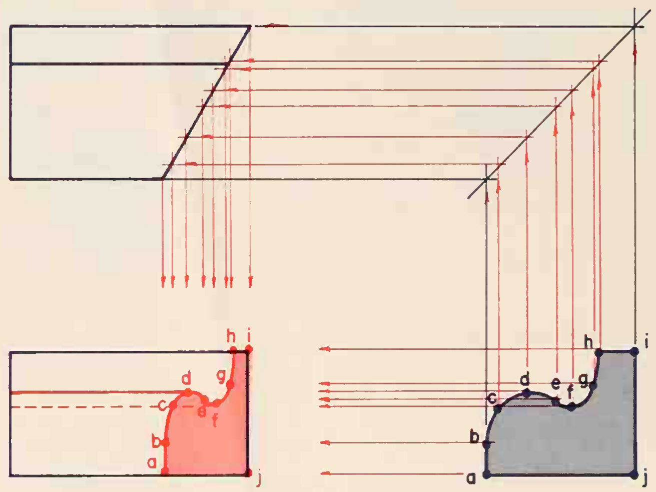


Figure 6-12B Step 2

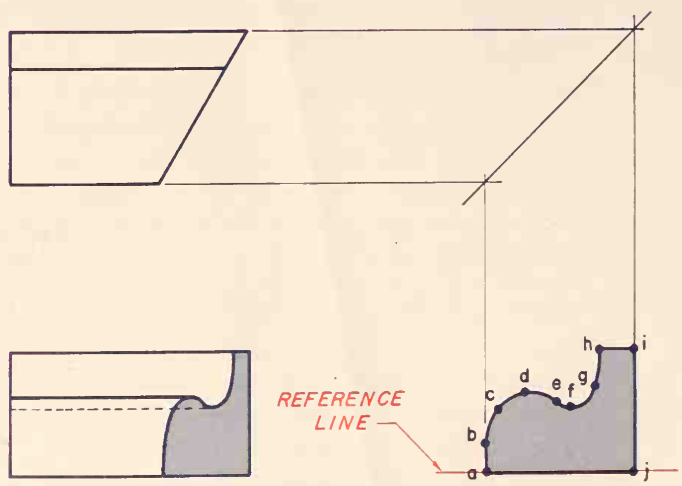


Figure 6-12C Step 3

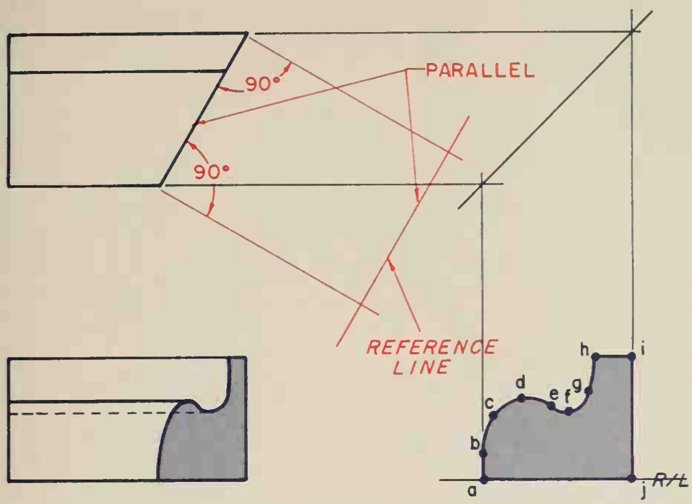


Figure 6-12D Step 4

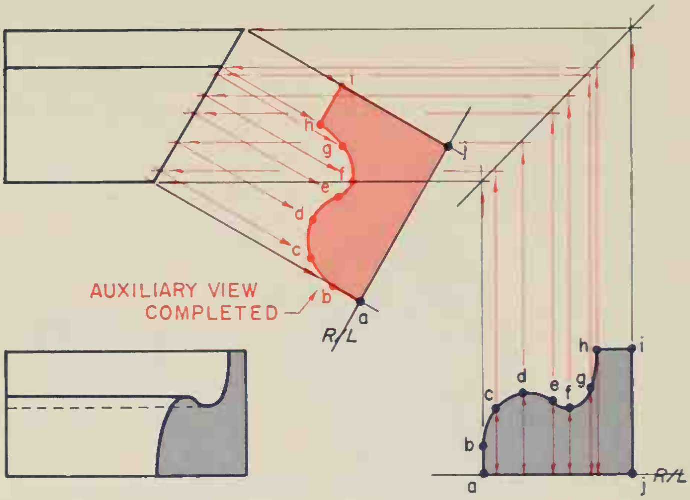


Figure 6-12E Step 5 finished drawing

Secondary Auxiliary Views

Up to this point, primary auxiliary views have been dealt with. A *primary auxiliary view* can be projected from any of the regular views, as has been illustrated thus far.

Sometimes, a primary auxiliary view is not enough to fully illustrate an object; a secondary auxiliary view is needed. A *secondary auxiliary view* is projected directly *from* the auxiliary view. Many times, the auxiliary view and/or some of the other views cannot be fully *completed* until the secondary view has been completed first, Figure 6-13.

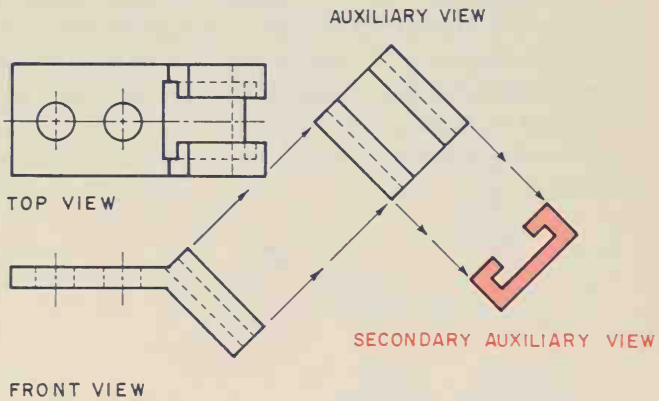


Figure 6-13 Secondary auxiliary view

Partial Views

The use of a *partial auxiliary view* makes it possible to eliminate one or more of the regular views which, in turn, saves drafting time and cost. Figure 6-14 is an example of a front view, top view, right-side view and auxiliary view. Note, the auxiliary view is always drawn partial; only the *inclined* surface is drawn on the auxiliary view. By using a partial top and right-side view in conjunction with the particular auxiliary view, the drawing can be simplified without detracting from its clarity; in fact, in most cases, these partial views make the drawing easier to read, Figure 6-15.

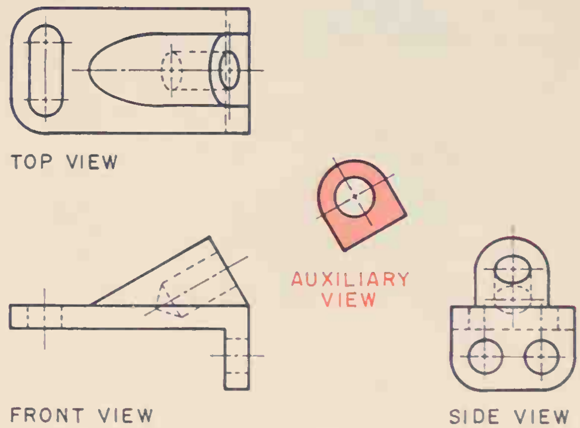


Figure 6-14 Given: Regular three views

Auxiliary Section

An *auxiliary section*, as its name implies, is an auxiliary view in section. An auxiliary section is drawn exactly as is any removed sectional view, and is projected in exactly the same way as any auxiliary view, Figure 6-16. All the usual auxiliary view rules apply, and generally only the surface cut by the cutting-plane line is drawn.

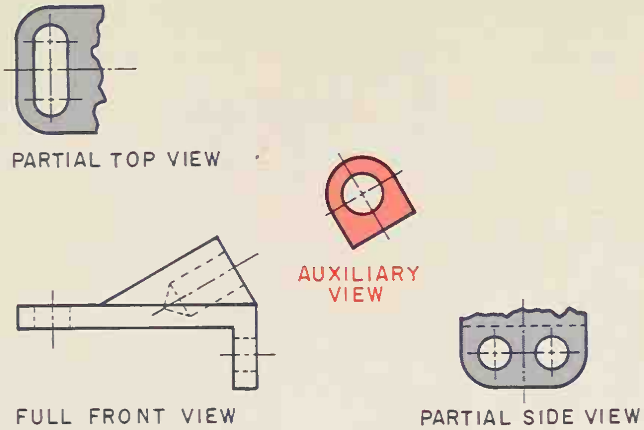


Figure 6-15 Partial auxiliary views

Half Auxiliary Views

If an auxiliary view is symmetrical, and space is limited, it is permitted to draw only half of the auxiliary view, Figure 6-17. Use of the half auxiliary view saves some time, but it should only be used as a last resort, as it could be confusing to those interpreting the drawing. Always draw the *nearest* half, as shown in the figure.

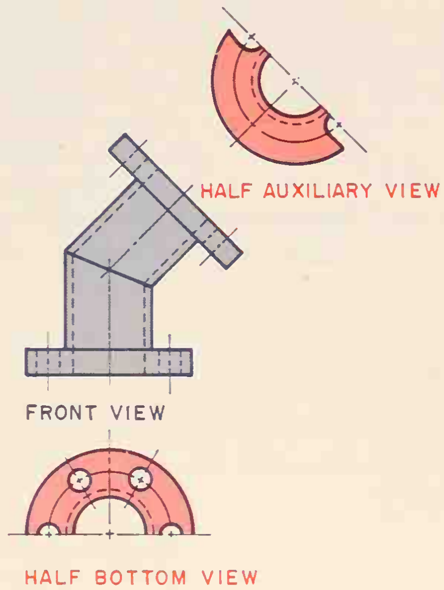


Figure 6-17 Half auxiliary view

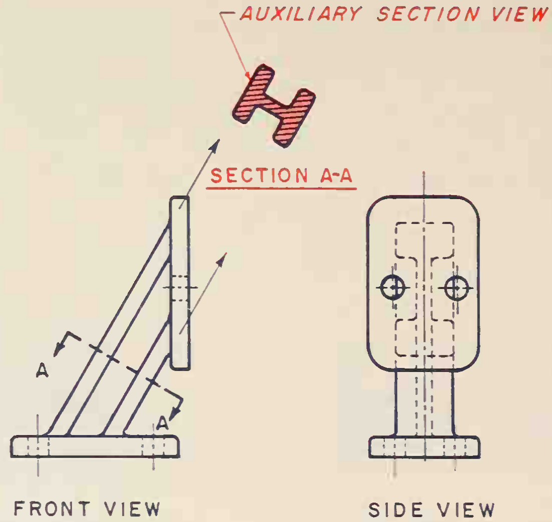


Figure 6-16 Auxiliary section

Review

1. What three purposes does an auxiliary view serve?
2. Name the three major kinds of auxiliary views.
3. What must be done first if the projected surface is round or has a radius?
4. Explain the use of partial views as used in conjunction with an auxiliary view.
5. What is the practice for the use of hidden lines in an auxiliary view?
6. How should the regular views and the auxiliary view be placed within the work area?
7. Explain the use of a reference line. Where should it be drawn, and at what angle?
8. Projection lines *must* be drawn at what angle from the edge view?
9. When and why is a half auxiliary view used?
10. What is an auxiliary sectional view?
11. Explain the use of a secondary auxiliary view.

Chapter Six Problems

The following problems are intended to give the beginning drafter practice in sketching and laying out multiviews with an auxiliary view.

The steps to follow in laying out any drawing with an auxiliary view are:

Step 1. Study the problem carefully.

Step 2. Choose the view with the most detail as the front view.

Step 3. Position the front view so there will be the least number of hidden lines in the other views.

Step 4. Determine which view from which to project the auxiliary view.

Step 5. Make a sketch of all views, including the auxiliary view.

Step 6. Center the required views within the work area with approximately 1-inch (25-mm) space between the views. Adjust the regular views to accommodate the auxiliary view.

Step 7. Use light projection lines. Do *not* erase them.

Step 8. Lightly complete all views.

Step 9. Check to see that all views are centered within the work area.

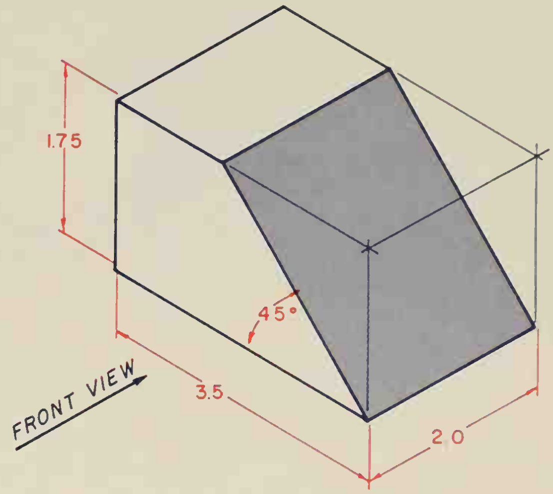
Step 10. Carefully check all dimensions in all views.

Step 11. Darken in all views using correct line thickness.

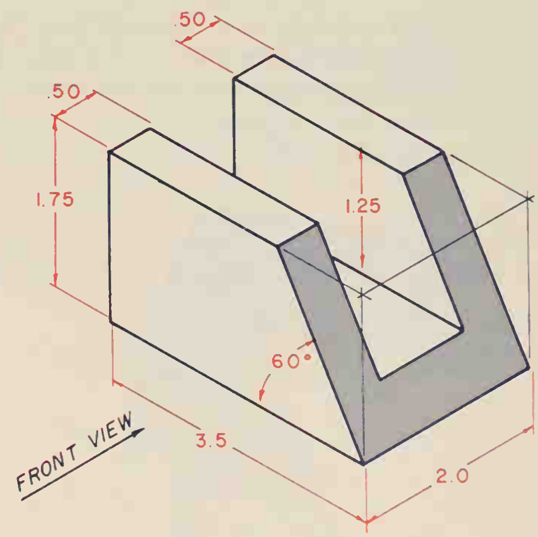
Step 12. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problems 6-1 through 6-4

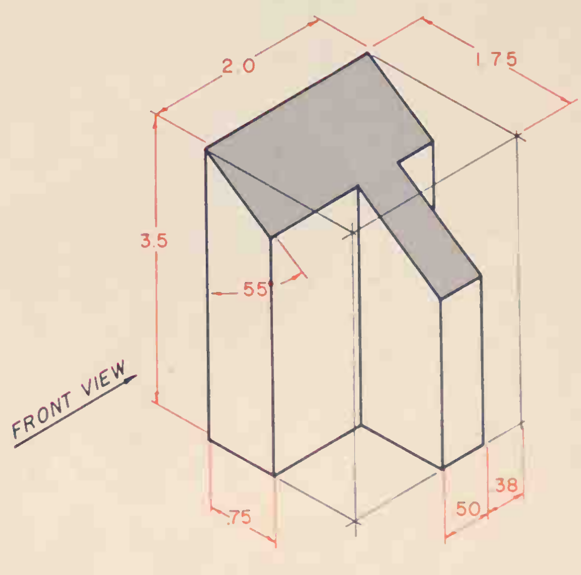
Draw the front view, top view, right-side view and auxiliary view. Complete all views using the listed steps.



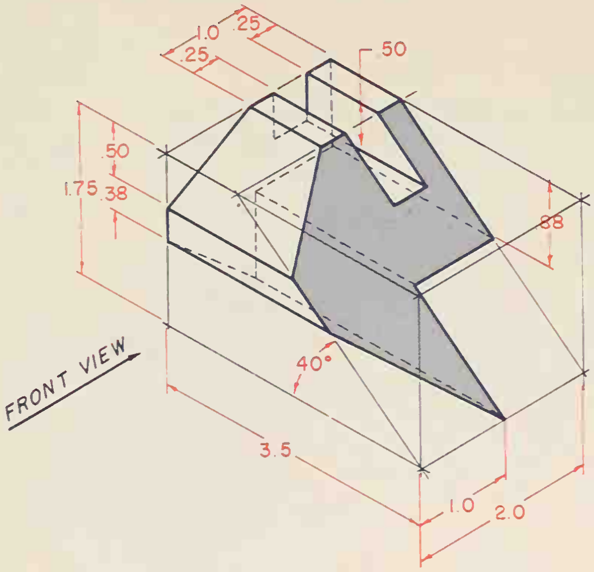
Problem 6-1



Problem 6-2



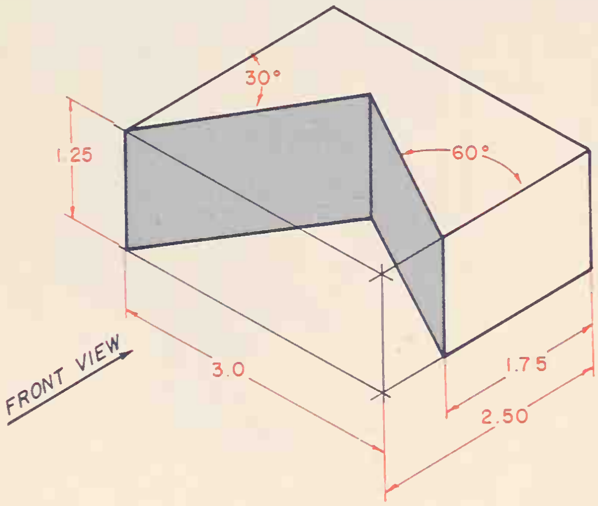
Problem 6-3



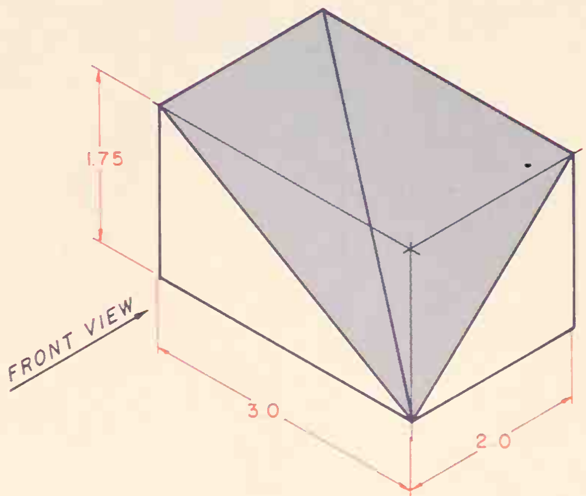
Problem 6-4

Problems 6-5 and 6-6

Draw the front view, top view, right-side view and *two* auxiliary views to illustrate the true size and shape of the slanted surfaces. Complete all views using the listed steps.



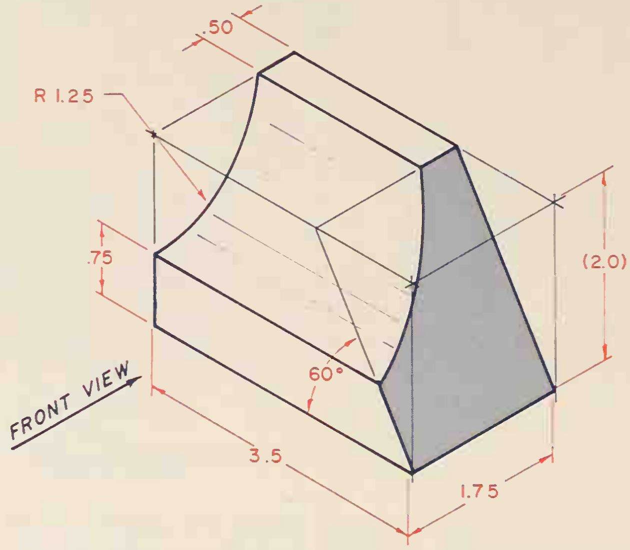
Problem 6-5



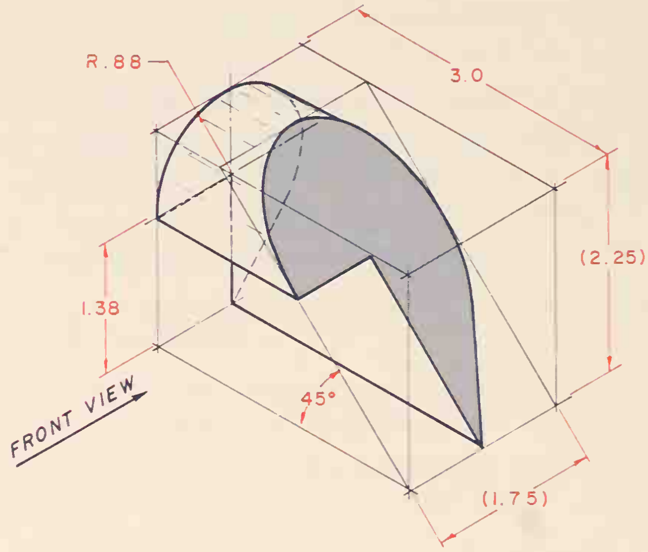
Problem 6-6

Problems 6-7 through 6-13

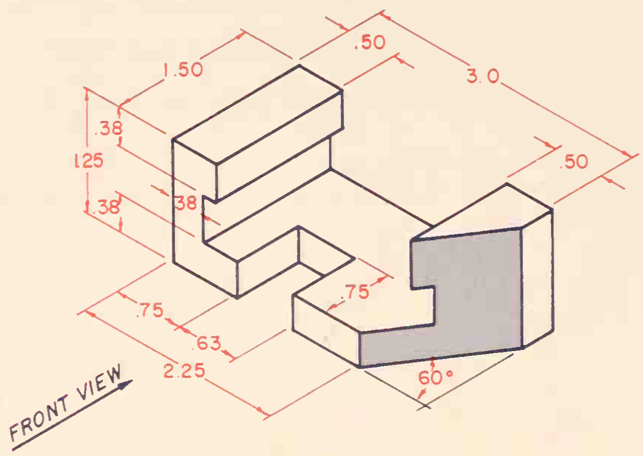
Draw the front view, top view, right-side view and auxiliary view. Complete all views using the listed steps.



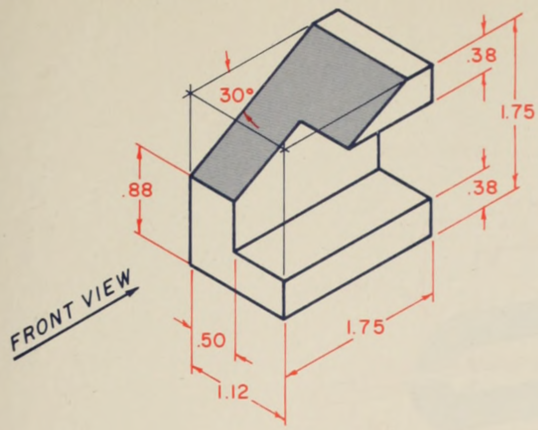
Problem 6-7



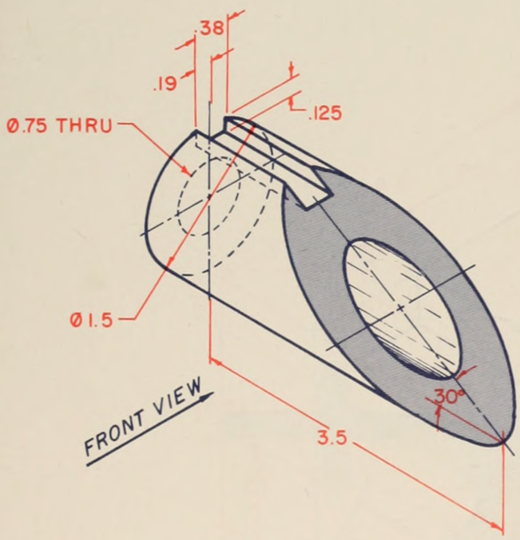
Problem 6-8



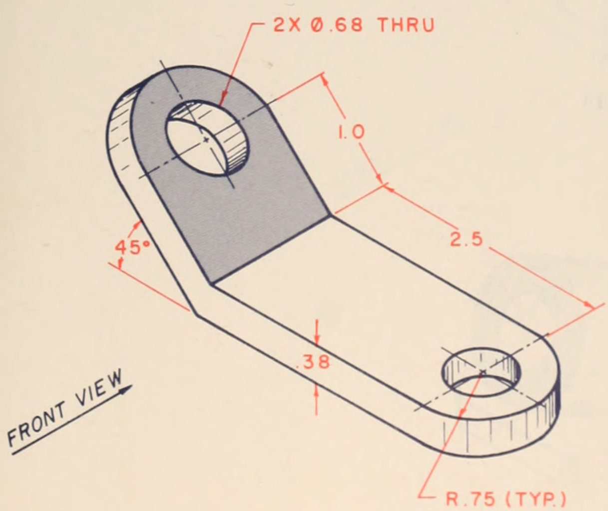
Problem 6-9



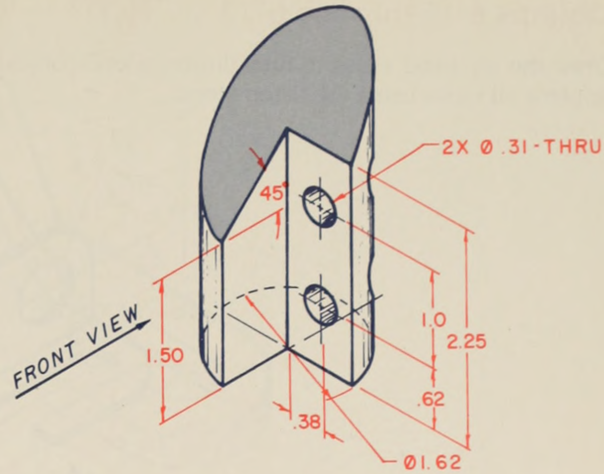
Problem 6-10



Problem 6-11



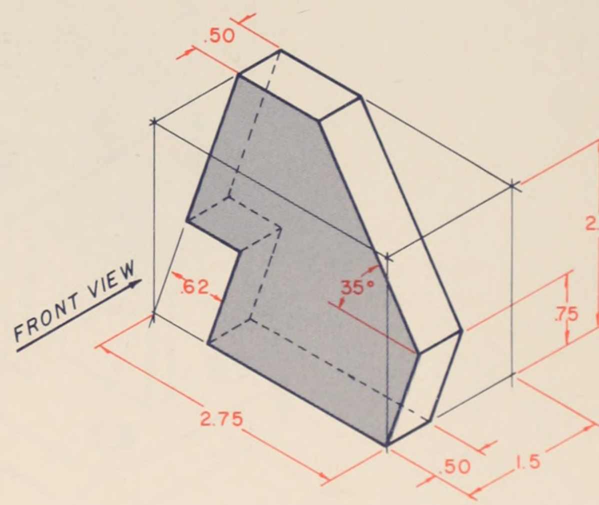
Problem 6-12



Problem 6-13

Problem 6-14

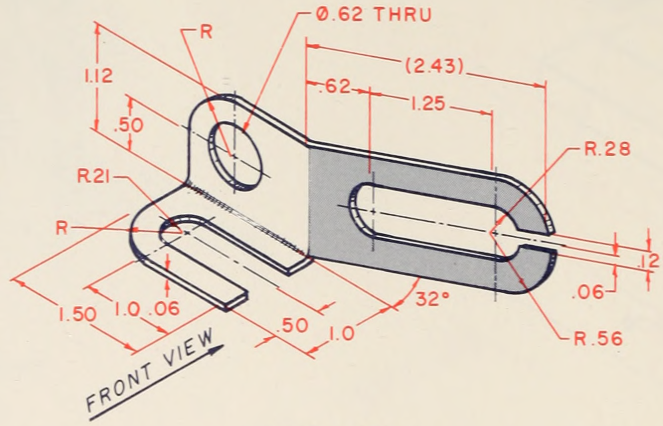
Draw the front view, top view, right-side view and *two* auxiliary views to illustrate the true size and shape of all surfaces. Complete all views using the listed steps.



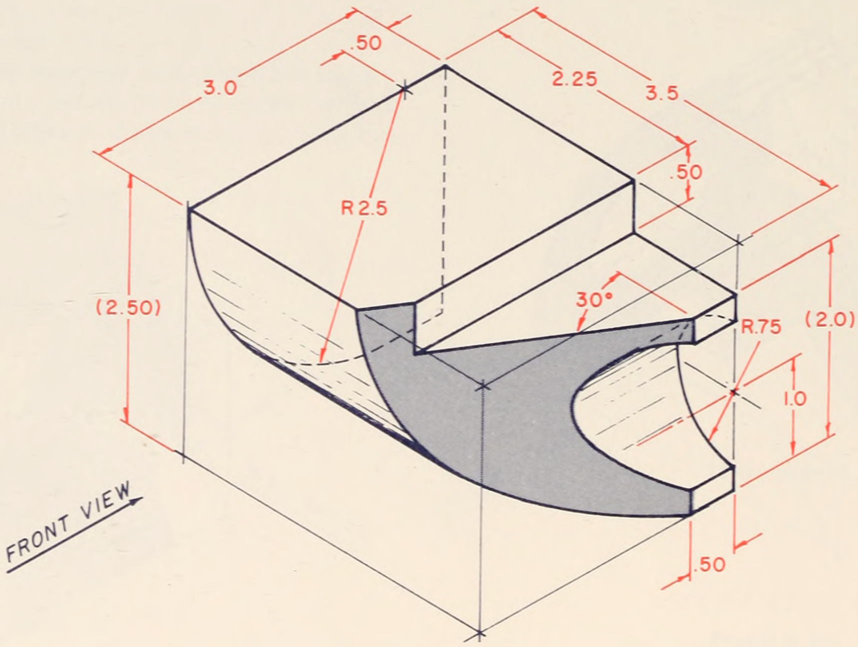
Problem 6-14

Problems 6-15 through 6-22

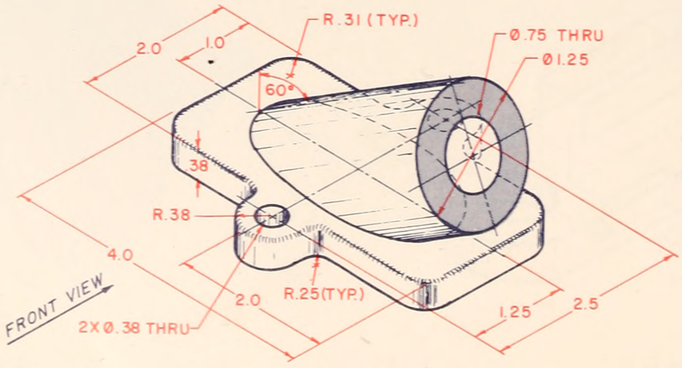
Draw the required views to fully illustrate each object. Complete all views using the listed steps.



Problem 6-15



Problem 6-16



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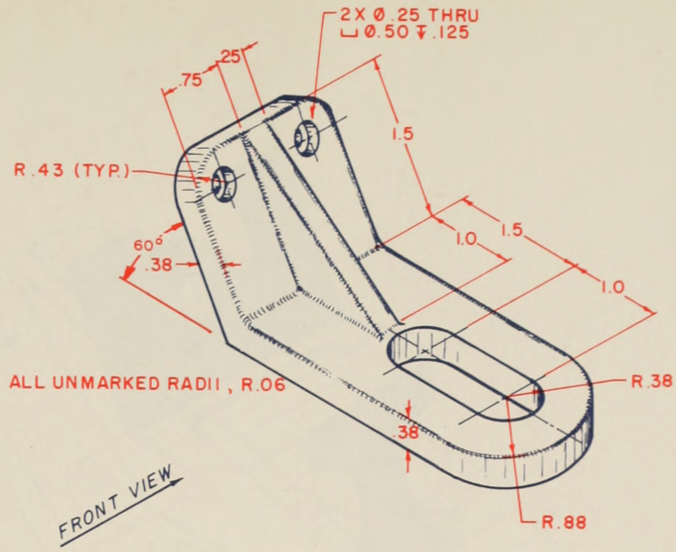
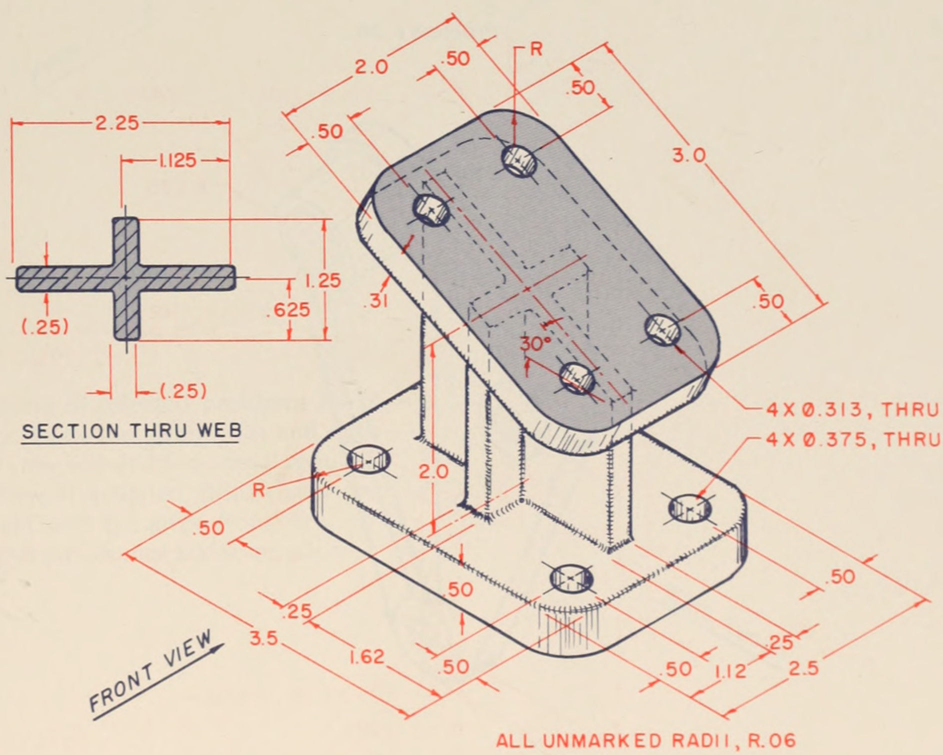
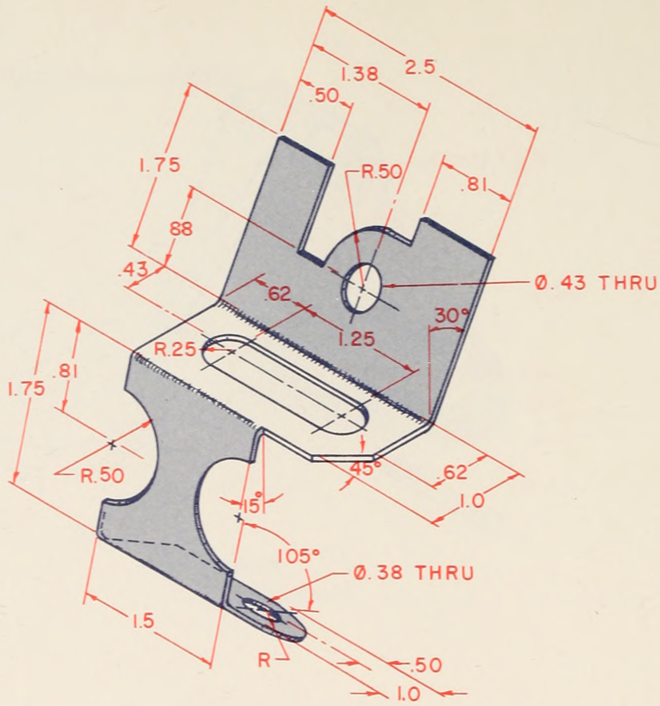
Problem 6-17



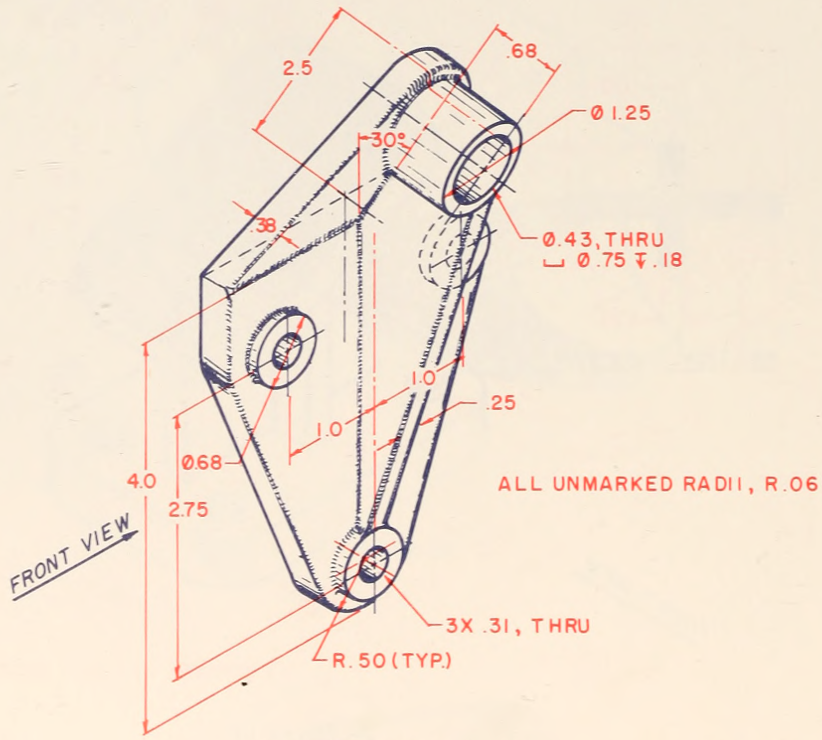
Problem 6-18



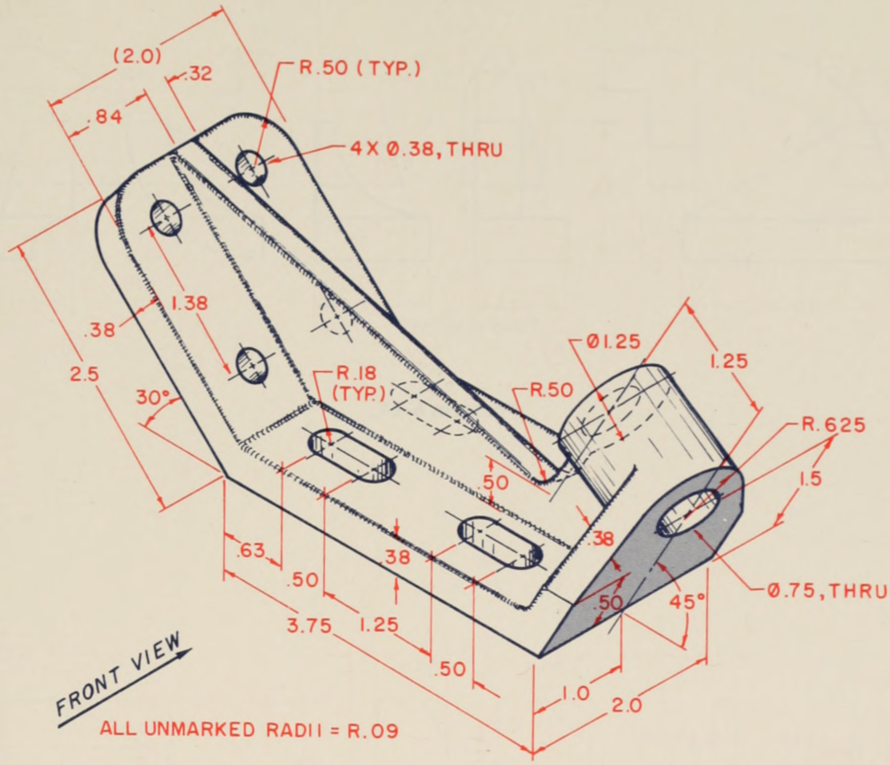
Problem 6-19



Problem 6-20



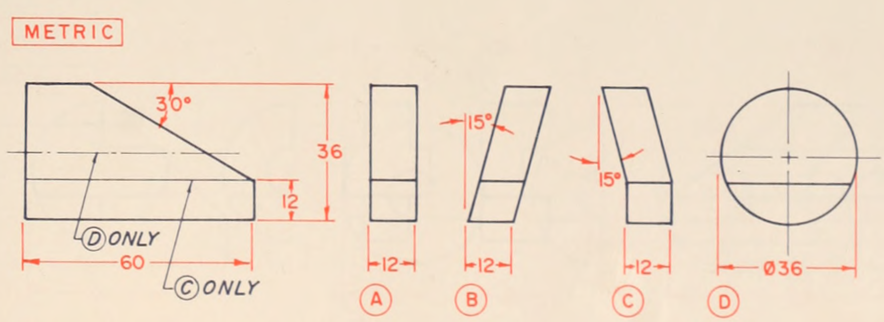
Problem 6-21



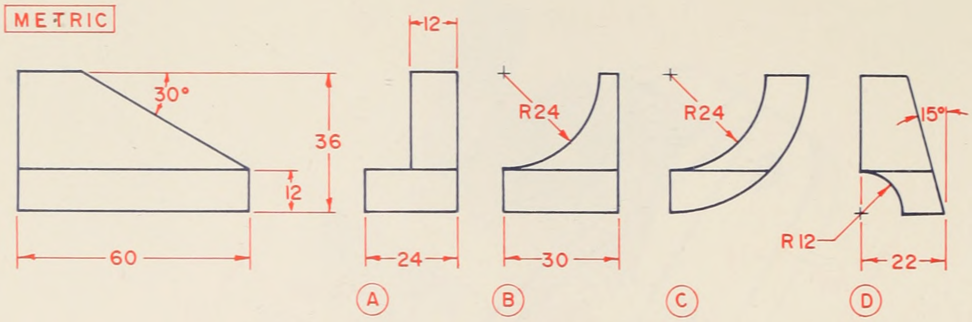
Problem 6-22

Problems 6-23 through 6-29

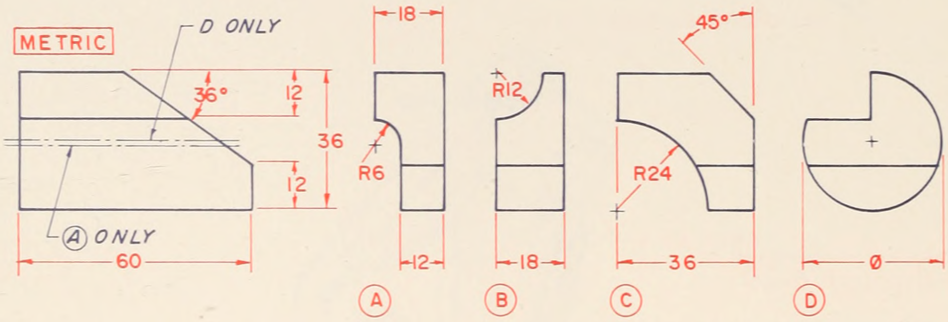
Make a finished drawing of selected problems as assigned by the instructor. Draw the given front and right-side views, add the top view with hidden lines if required, and add an auxiliary view. If assigned, design your own right-side view consistent with the given front view, and add a complete auxiliary view. Do not add dimensions.



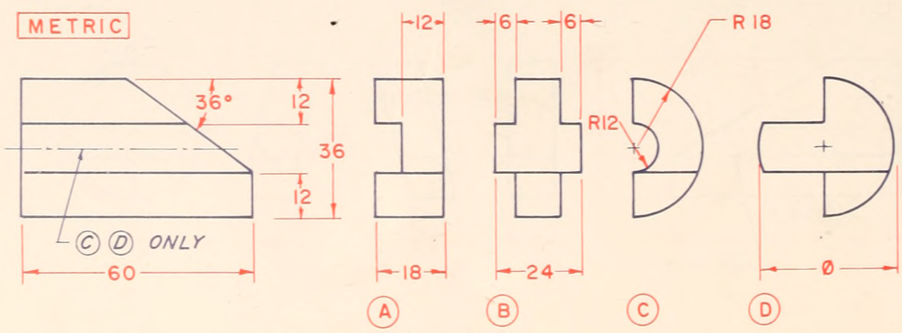
Problem 6-23



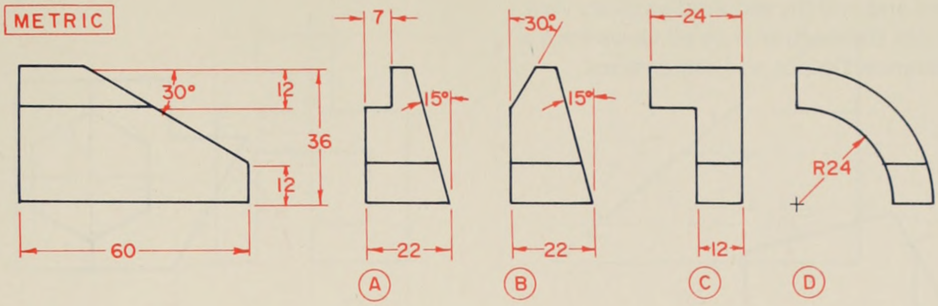
Problem 6-24



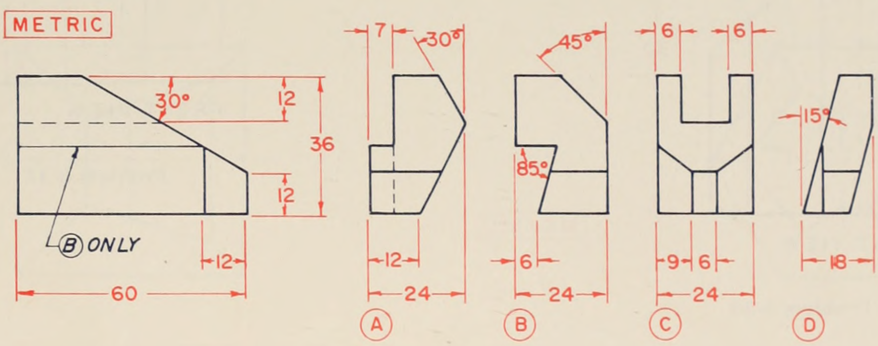
Problem 6-25



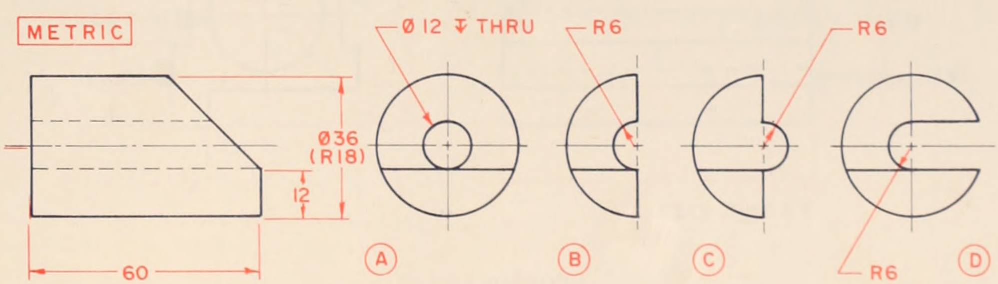
Problem 6-26



Problem 6-27



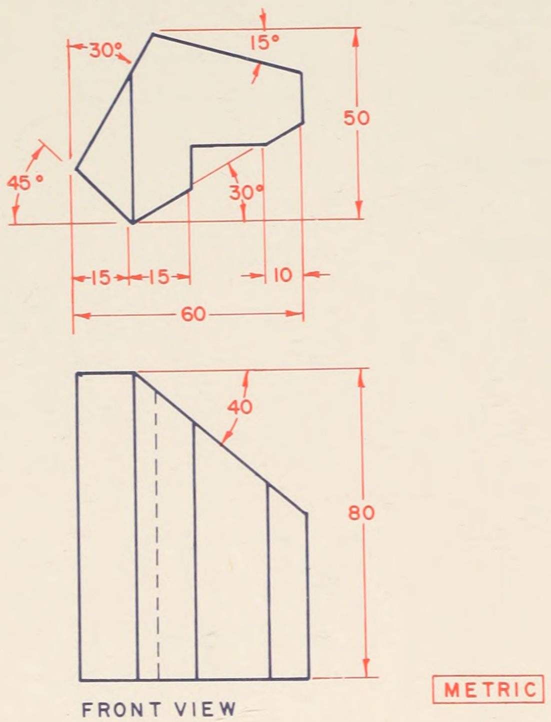
Problem 6-28



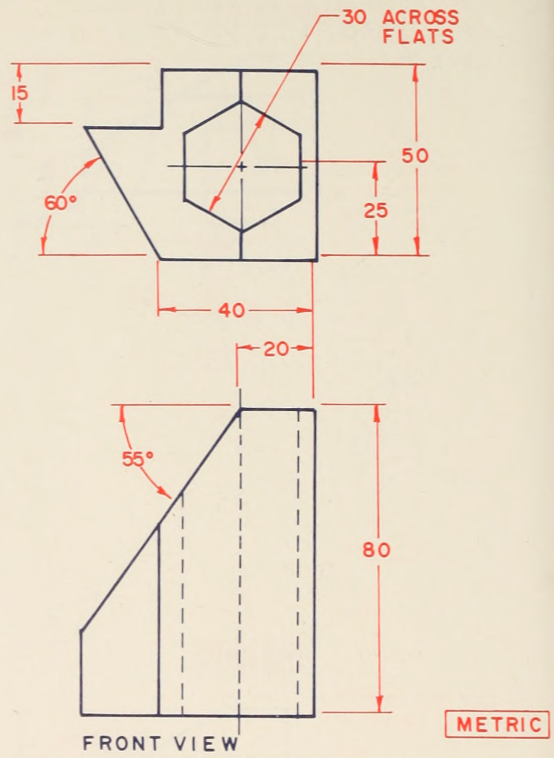
Problem 6-29

Problems 6-30 through 6-37

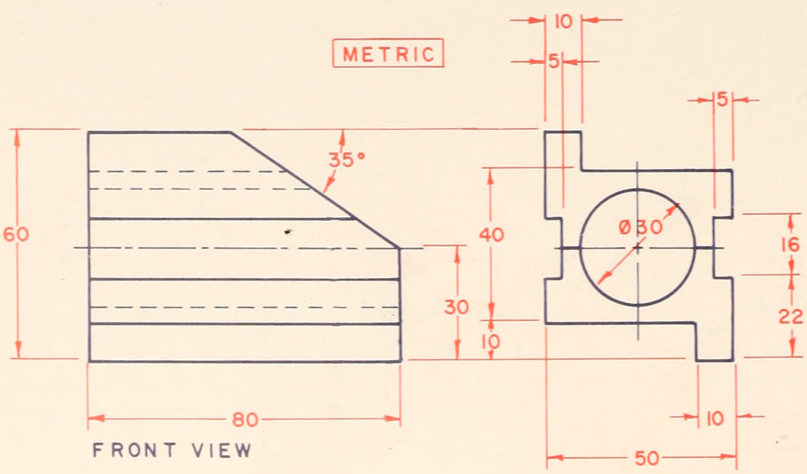
Draw the given views and add the required auxiliary view. Present the views within the work area so all views have a neat, centered appearance. Do not add dimensions.



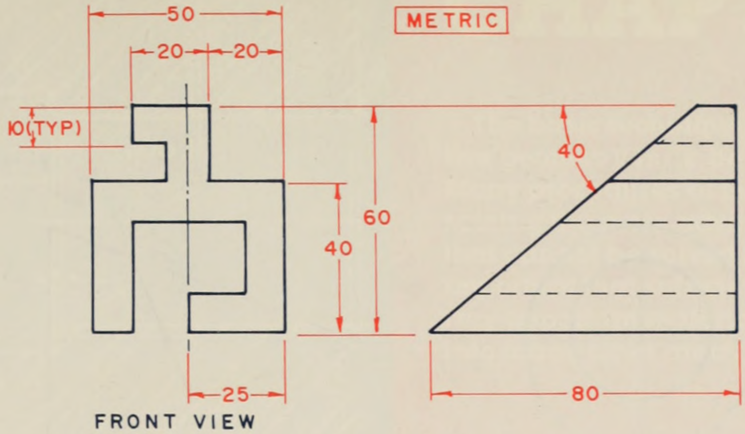
Problem 6-30



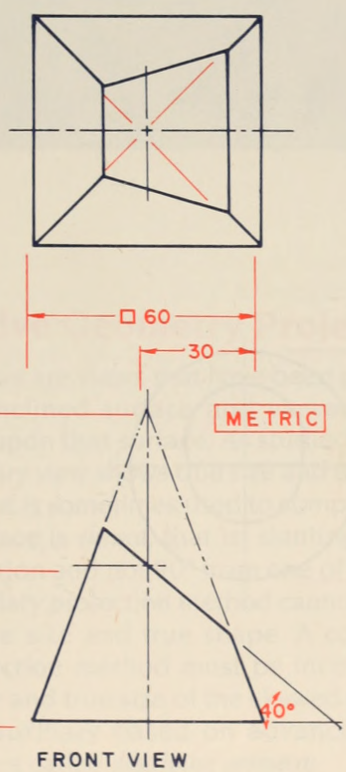
Problem 6-31



Problem 6-32



Problem 6-33



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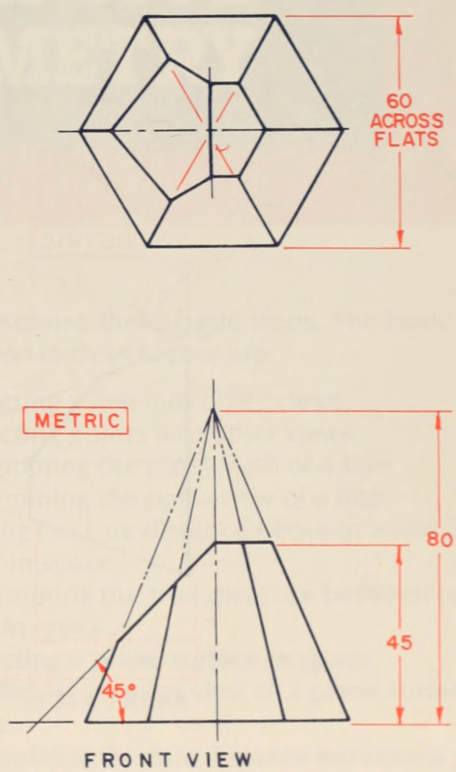

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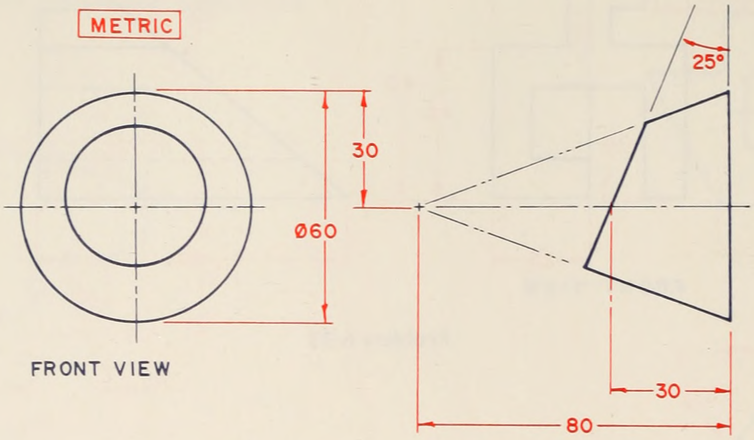

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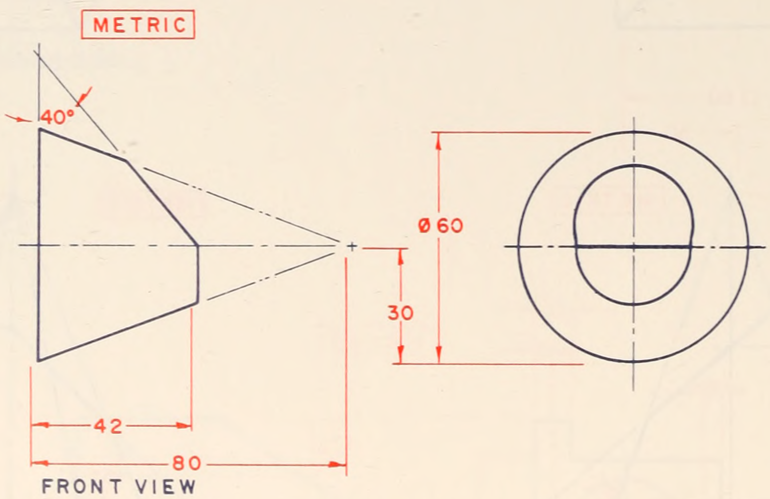

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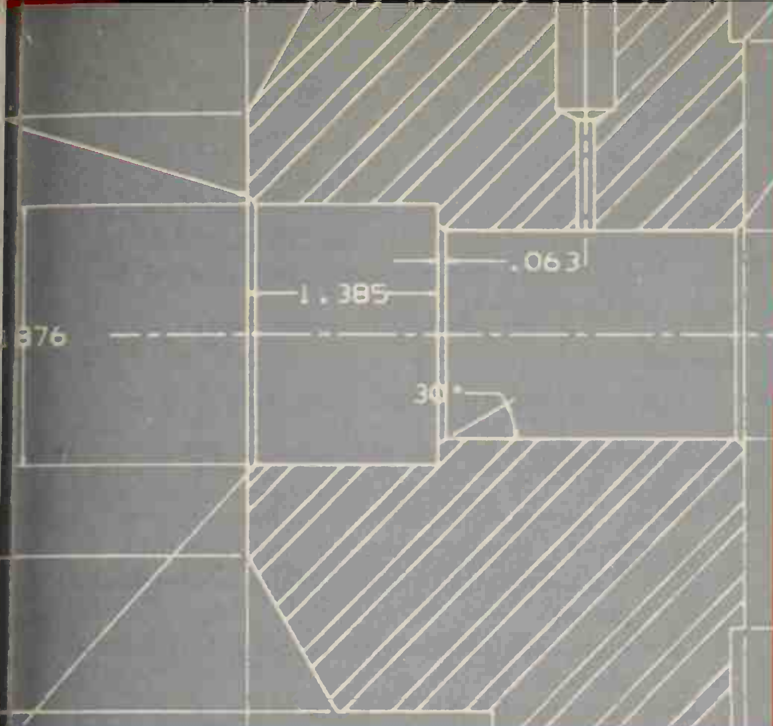


CHAPTER 7

The basic techniques associated with descriptive geometry must be thoroughly mastered. Many procedures of this chapter are used in solving the more advanced technical problems that cannot be solved by any other method. It is important that sufficient time is given to this very important material, as it is incorporated into many other areas of drafting.

DESCRIPTIVE GEOMETRY

Descriptive Geometry Projection

Auxiliary views are views that have been projected 90° from an inclined surface and viewed looking directly down upon that surface. As studied in Chapter 6, the auxiliary view shows true size and true shape of an object, and is sometimes used to complete other views. If a surface is *skewed*, that is, slanting in more than one direction and not 90° from one of the other views, the auxiliary projection method cannot be used to find the true size and true shape. A completely different projection method must be incorporated. The true shape and true size of the skewed surface is a secondary auxiliary based on advanced orthographic theories called *descriptive geometry*.

Using the descriptive geometry method of projection not only gives true size and shape, but it also can be used to find intersections, true distances of lines in space, true angles between surfaces, and exact piercing points. Descriptive geometry graphically shows the solution to problems dealing with points, lines and planes, and their relationship in space. In order to be able to apply descriptive geometry to various drafting problems, the drafter must know and understand the various basic steps involved. This chapter explains these basic steps. The basic theories covered in this chapter are:

- Projecting a line into other views
- Projecting points into other views
- Determining the true length of a line
- Determining the point view of a line
- Finding the true distance between a line and a point in space
- Determining the true distance between two lines in space
- Projecting a plane surface in space
- Developing an edge view of a plane surface in space
- Determining the true distance between a plane surface and a point in space
- Determining the true angle between plane surfaces in space

Steps Used

All problems, regardless of their complexity, use the same procedures or steps. These steps ultimately must be done in the same order each time, although some intermediate steps may be selected or are

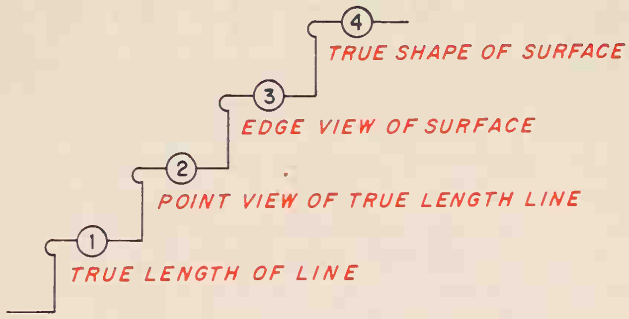


Figure 7-1 Steps used to solve descriptive geometric problems

optional. Like climbing a flight of stairs, each step must be executed, and only experience can provide the ability to perform multiple steps simultaneously. An example of the sequential steps needed in descriptive geometry problems is as follows. In order to find an edge view of a plane (flat surface), a true length line must be located in that plane (Step 1); a point view of the true length line must be projected, which yields an edge view of the plane (Step 2); see Figure 7-1. By projective means, it would be impossible to find the edge view of an oblique surface from normal views without performing Steps 1 and 2.

Notations

In order to progress through sequential steps it is important to keep track of all views and points in space. (Recall that a straight line is composed of two spatially located end points.) To do this, a system of *notations* or labeling is advisable. Each view and each point should be labeled to provide an accurate identity of each at all times. For purposes of this text, the following notations are used in this chapter.

Each *point* in space is called out in *lowercase letters*.

Example:

a, b, c, d

Each *line* in space is identified by the *two lowercase end points*.

Example:

Line a-b

Each *line* in space is assumed to end at the indicated end points, unless it is specified as an *Extended Line* (continues without end).

Example:

Line p-q and Extended Line j-k

Each *plane* in space, such as a triangle, is called out in lowercase letters.

Example:

Triangle abc

Each *plane* in space is assumed to be limited (stops at the indicated boundaries) unless otherwise defined as an *Unlimited Plane* (limitless extension beyond the indicated boundaries).

Example:

Plane defg and Unlimited Plane mno

Each *viewing plane* is called out in *uppercase letters.*

Example:

F = Frontal viewing plane (a principal plane).
T = Top (horizontal) viewing plane (a principal plane).
R = Right side (profile) viewing plane (principal plane).
L = Left side (profile) viewing plane (principal plane).
A(digit) = an auxiliary viewing plane, with the number of successive projections from a principal viewing plane.
B(digit) = same as A(digit), but using a different series of successive projections.

A combination of lowercase and uppercase letters is used to fully describe each point in space, and the view in which it is located.

Example:

aF would be point *a* location as seen in the Frontal viewing plane.
aT-bT would be line *a-b* location as seen in the Top (horizontal) viewing plane.
aR-bR-cR would be plane *a-b-c* as seen in the Right side (profile) viewing plane.

Fold Lines

A fold line is represented by a thin black line, similar to a phantom line. It indicates a 90° intersection of two viewing planes. Each fold line must be labeled using uppercase letters, Figure 7-2. In this example, the fold line is placed between the front view and the top view. This placement eliminates the usual 45° projection line, Figure 7-3. It is important to add these notations in order to keep track of exactly which viewing plane is being executed.

Figure 7-2 Fold line

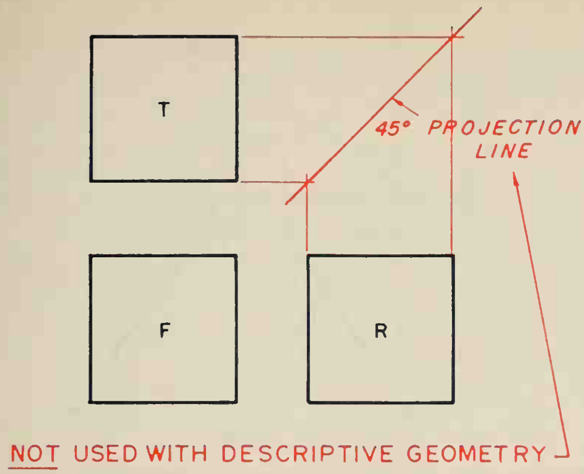


Figure 7-3 Regular multiview drawing using 45° projection line

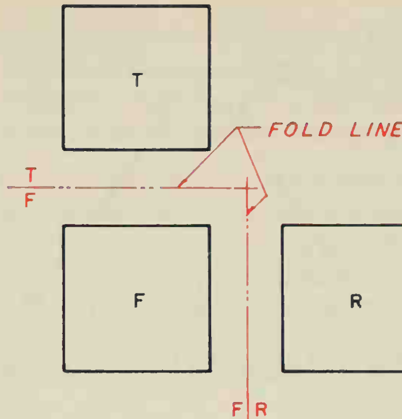


Figure 7-4 Regular multiview drawing using fold lines instead of 45° projection line

How To Project a Line into Other Views

Fold lines are placed between successive orthographic views and labeled with uppercase letters, Figure 7-4. Any appropriate spacing is permissible, but the distance from the image to the frontal viewing plane fold line *must* be equal at both the top and right-side views. The spatial positioning of a line a-b (surrounded by an imaginary transparent box) is shown in Figure 7-5. Point a is closer to the frontal viewing plane than is point b, but is farther below the top (horizontal) viewing plane.

Represented on a normal layout drawing, it would be illustrated and labeled as shown in Figure 7-6.

The customary 45° projection line is *not* used in descriptive geometry projection. All points are projected along light projection lines drawn at 90° to the fold lines. All measurements are taken *along* these light projection lines and measured *from* the fold line *to* the point in space, Figure 7-7.

An important rule to remember is to *always skip-a-view* between all measurements. In Figure 7-7, notice in the right-side view that dimension X (distance from F/R fold line to point aR) is projected into and through the front view and *up* to the top view and transferred into the top view. (Distance from F/T fold line to point aT.) The front view was skipped.

Again, referring to the right-side view of Figure 7-7, dimension Y (distance from F/R fold line to point bR) is transferred into the top view (distance from F/T fold line to point bT) and the front view was skipped. In each of the instances, the distance is measured as the perpendicular distance from the fold line to the point.

Example:

To project a top view of a line from a given front and right-side view.

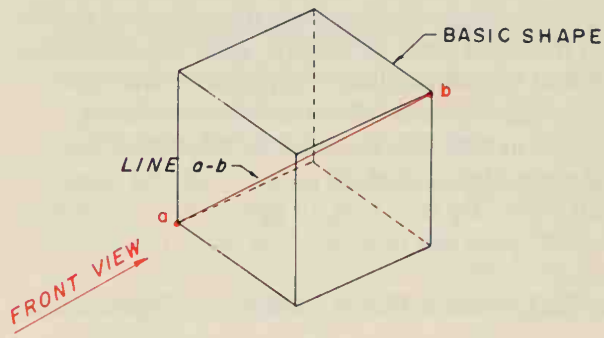


Figure 7-5 Spatial positioning of line a-b

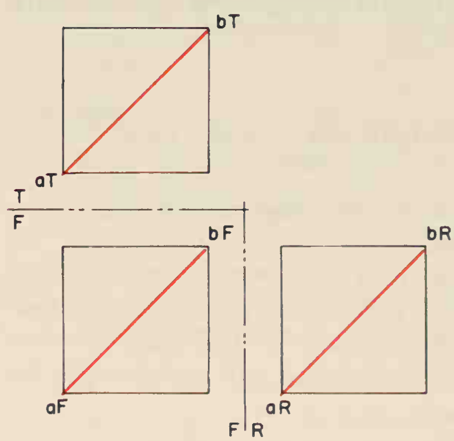


Figure 7-6 Line a-b in all three regular views

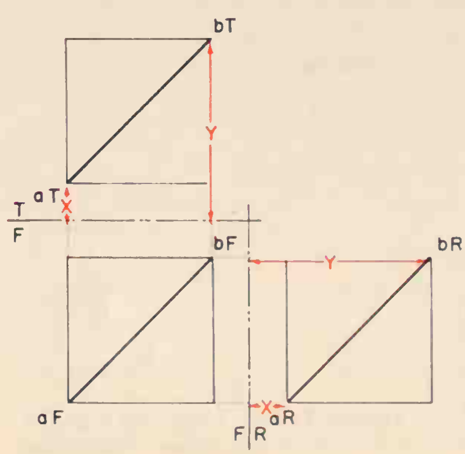


Figure 7-7 Skip-a-view when transferring distances

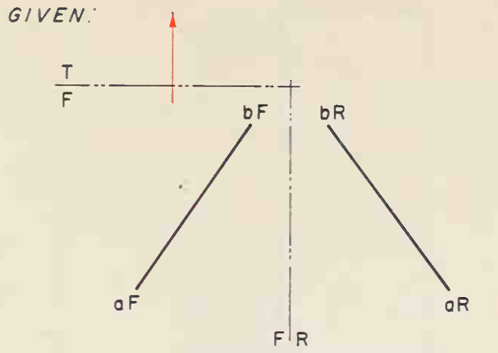


Figure 7-8 Locating line a-b in top view

Given: Line a-b in the front view and line a-b in the right-side view, Figure 7-8. Extend projection lines into the top view from the end points in the front view, aF and bF. Find the distances X and Y from the line end points in the right-side view aR and bR to the frontal viewing plane at fold line F/R and transfer them into the top view. Label all points and fold lines in all views. Be sure that all projections are made at 90° from the relevant fold lines, Figure 7-9.

How To Locate a Point in Space (Right View)

A point in space is projected and measured in exactly the same way as a line in space, except that the point is a line with a single end point, Figure 7-10A.

Example:

To project the right-side view of a point from a given top and front view.

Given: Point a in the front view and top view (Figure 7-10A).

Project point aF from the front view into the right-side view. Point aR must lie on this projection line. Find X, which is the distance from fold line F/T to aT in the top view and project it into and through the

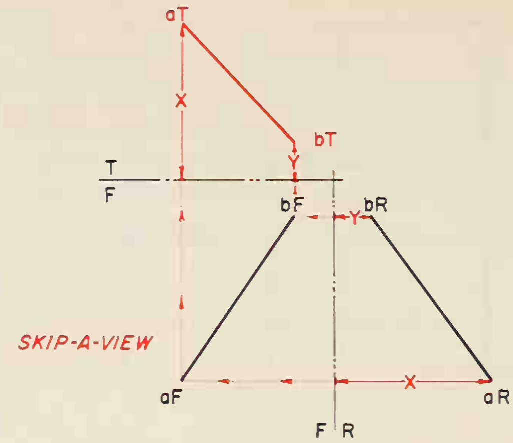


Figure 7-9 Line a-b in the top view using the fold line

front view, Figure 7-10B. Project it over into the right-side view. Transfer distance X to find point a. Be sure to always label all points and fold lines in all views.

How To Find the True Length of a Line

Any line that is parallel to a fold line will appear in its true length in the next successive view adjoining that fold line.

To find the true length of any line:

Step 1. Draw a fold line parallel to the line of which the true length is required. This can be done at any convenient distance, such as approximately one-half inch.

Step 2. Label the fold line "A" for auxiliary view.

Step 3. Extend projection lines from the end points of the line being projected into the auxiliary view. These must always be at 90° to the fold line.

Step 4. Transfer the end point distances from the fold line in the second preceding view from the one being drawn, to locate the corresponding end points in the view being drawn.

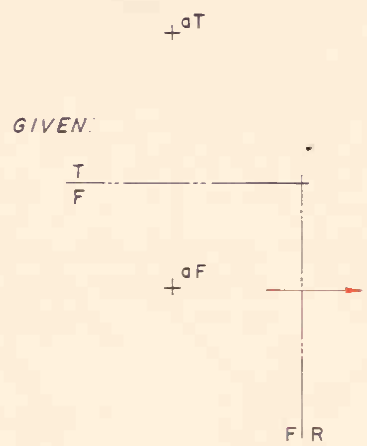


Figure 7-10A Locating a point in space (right view)

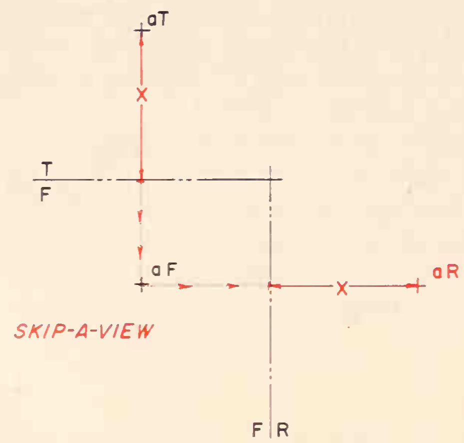


Figure 7-10B Step 1

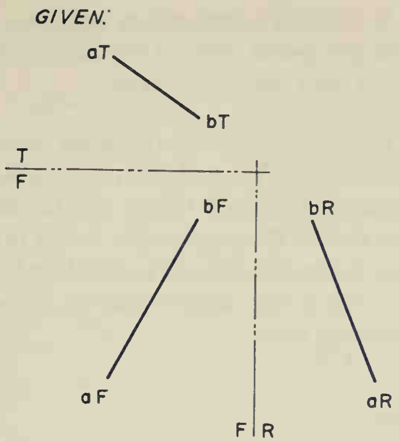


Figure 7-11A Finding the true length of a line

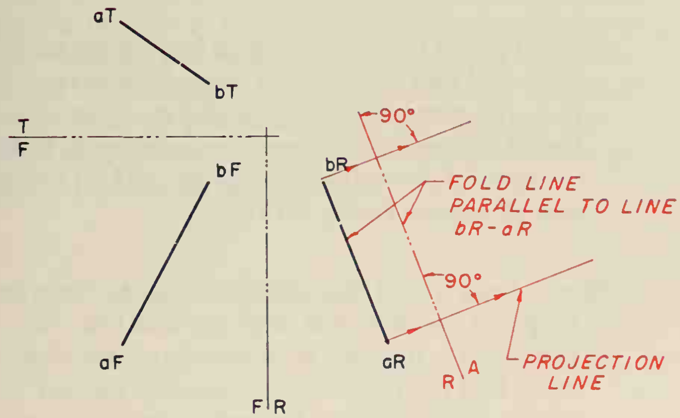


Figure 7-11B Step 1

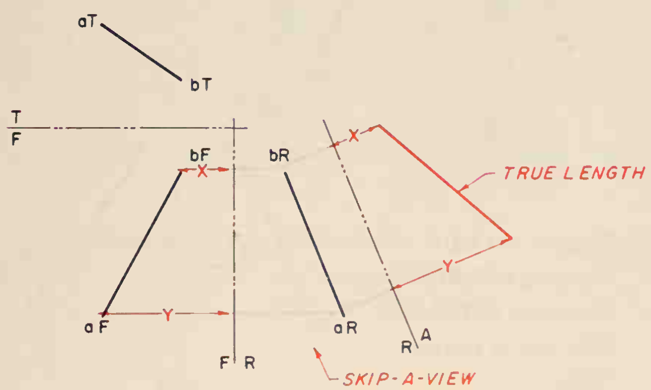


Figure 7-11C Step 2

Example:

Refer to Figure 7-11A.

Given: Line a-b in the front view, side view, and top view. The problem is to find the true length of line a-b. A true length can be projected from any of the three principal views by placing a fold line parallel to the line in any view. The right-side view is selected in this example.

Step 1. Draw a fold line parallel to line a-b, and label it as shown in Figure 7-11B. Extend light projection lines at 90° to the fold line from points a and b into the auxiliary view.

Step 2. Determine distance X and Y from the front view to the near-fold line and transfer them into the auxiliary view, as shown in Figure 7-11C. Label all points and fold lines. The result will be the actual true length of line a-b.

Use these steps to find the true length of any line.

How To Construct a Point View of a Line

To construct a point view of a line:

Step 1. Find the true length of the line.

Step 2. Draw a fold line perpendicular to the true length line at any convenient distance from either end of the true length line.

Step 3. Label the fold line A-B (B indicates a secondary auxiliary view).

Step 4. Extend a light projection line from the true length line into the secondary auxiliary view.

Step 5. Transfer the distance of the line end points into the secondary auxiliary view (B) from the corresponding points in the second preceding view.

Example:

Refer to Figure 7-12A.

Given: Line a-b in the front view, side view, and auxiliary view. The true length is located in the auxiliary viewing plane (A), which is projected from the front view. (The true length could have been projected from any of the given views.)

Step 1. At any convenient distance from either end, draw a fold line A/B perpendicular to the true length of line a-b. This will establish a viewing plane that is perpendicular to the direction of the line's path. Extend a projection line aligned with the true length line into this new

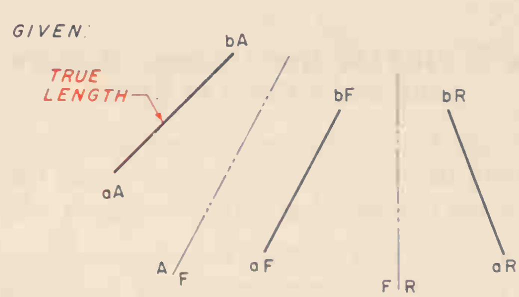


Figure 7-12A Constructing a point view of a line

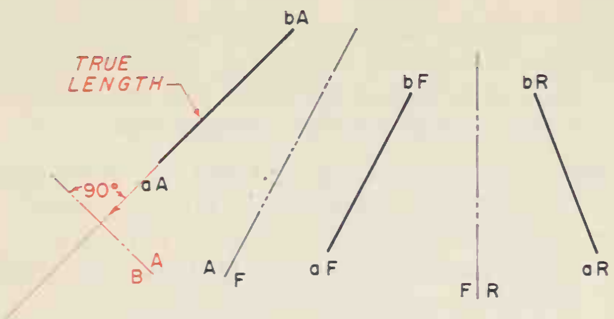


Figure 7-12B Step 1

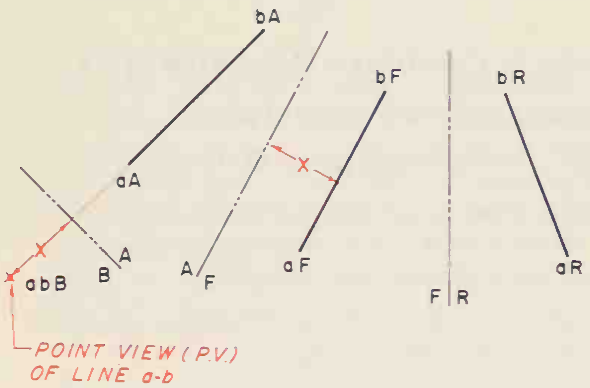


Figure 7-12C Step 2

secondary auxiliary view. The projection lines from both points a and b appear to align in this common projection line. Therefore, both points a and b must be located on this projection line in the secondary auxiliary view. In Figure 7-12B, the fold line A/B was added to the left of the true length line a-b.

Step 2. The front view is the second preceding view to the secondary auxiliary view being constructed. Therefore, distance X in the front view from the fold line T/A to line a/b is transferred to the secondary auxiliary view from the fold line A/B, Figure 7-12C. As points a and b in the front view are both at the same distance from the fold line T/A, and they both lie on the same projection line in the secondary auxiliary view, they will appear to coincide at the same location. This provides evidence that the end view of the line has been achieved.

How To Find the True Distance Between a Line and a Point in Space

The true distance between a line and a point in space will be evident in a view that shows the end point of the line and that point, simultaneously.

Step 1. Project an auxiliary view (viewing plane A) to find the true length of the line, and project the point into the same view.

Step 2. Project a secondary auxiliary view (B) to find the point view of the line, and project the point into the same view.

Step 3. The observable distance between the end view of the line and the point will be the actual distance between them. The location in the line that is nearest to the point is on the path that is perpendicular to the line from the point, but this is not discernable in the secondary auxiliary view.

Example:

Refer to Figure 7-13A.

Given: Line a-b and point c in the front view and right-side view.

Step 1. Project the true length of line a-b by placing a fold line parallel to a given view of the line, and project point c into the auxiliary view. Recall that point locations are transferred from the second preceding view. Label all fold lines and all points, Figure 7-13B.

Step 2. Draw a fold line perpendicular to the true length of line a-b, and label the fold line. Project line a-b into the secondary auxiliary view (B) to find the point view of line a-b. Project point c along into the secondary auxiliary view (B). The actual distance between the point view of line a-b/B and point cB is evident, Figure 7-13C.

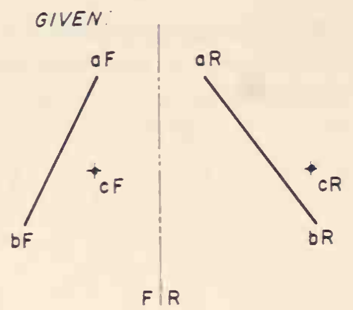


Figure 7-13A Finding the true distance between a line and a point in space

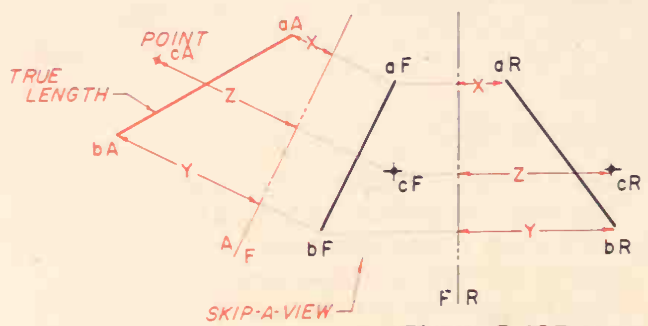


Figure 7-13B Step 1

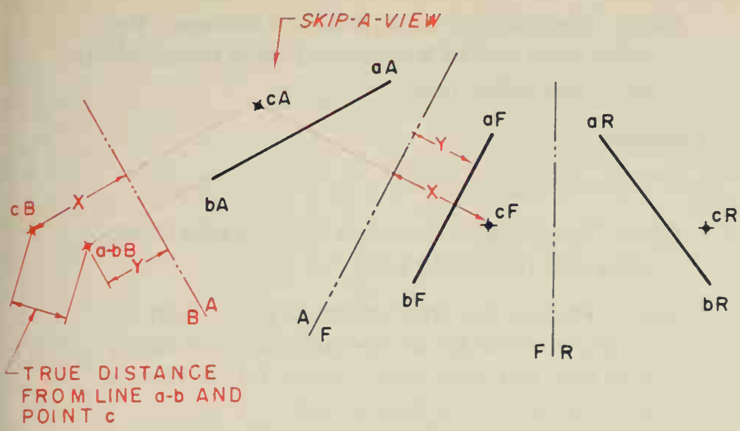


Figure 7-13C Step 2

The location in the line a-b that is nearest to point c lies on a path that is perpendicular to line ab and passes through c. Any path that is perpendicular to a line will appear perpendicular in a view where the line is true length. Therefore, the path can be drawn in the preceding view to locate point p on the line. Point p can be projected to its correct location on the original views of line a-b.

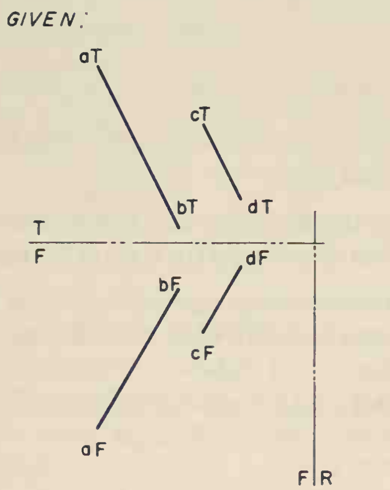


Figure 7-14A Finding the true distance between two parallel lines

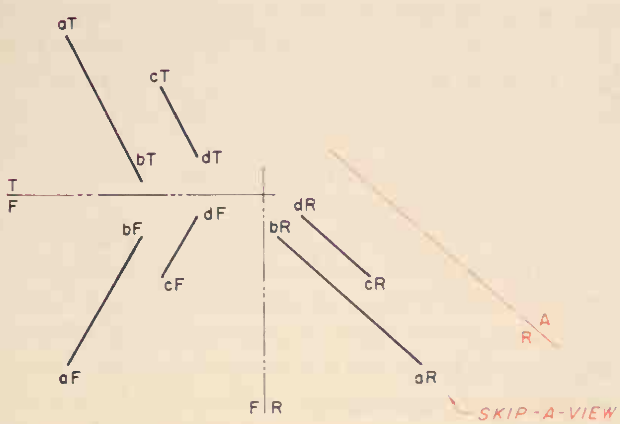


Figure 7-14B Step 1

How To Find the True Distance Between Two Parallel Lines

If two lines are actually parallel, they will appear parallel in all views. A view is needed to show the end view of both lines simultaneously, where the real distance between them will be apparent.

Step 1. Find the true length of each of the two lines. Projecting a view that will provide the true length of a line will automatically provide the true length of any other parallel line that is projected into the same view.

Step 2. Find the point view of each of the two lines. Projecting a view that will provide the end view of a line will automatically provide the end view of any other parallel line that is projected into the same view.

Step 3. The true distance between the parallel lines is the straight-line path between their end points. There is no single location within the length of the lines where this occurs, as each location in a line has a corresponding closest point location on the other line, each on the path connecting them and perpendicular to their respective lines.

Example:

Refer to Figure 7-14A.

Given: The parallel lines a-b and c-d, in a front view, right side view, and a top view.

Step 1. Find the true lengths of line a-b and line c-d in auxiliary view A. The two parallel lines will also be parallel in the auxiliary, if they are actually parallel. See Figure 7-14B.

Step 2. Draw a fold line perpendicular to the true length lines, a-b and c-d. Project the lines into the secondary auxiliary view (B) to find the point view of the two lines a-b and c-d. Measure the true distance between the point views of lines a-b/B and c-d/B. See Figure 7-14C.

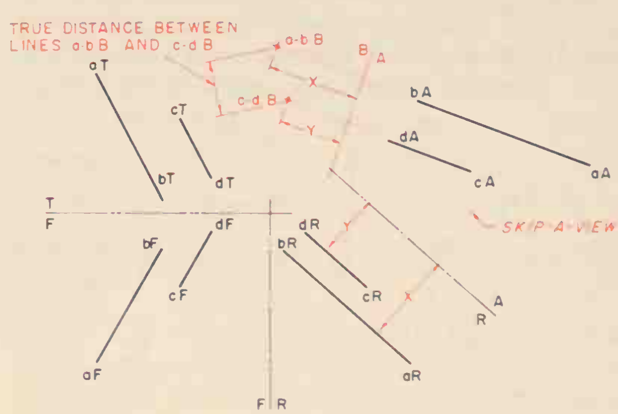


Figure 7-14C Step 2

How To Find the True Distance Between Two Nonparallel (or Skewed) Lines

If two lines are not parallel, they will appear nonparallel in at least one view. It is wise to first check two nonparallel (or skewed) lines to determine if they actually intersect, which would make the distance between them to be zero. This can be verified by projecting the apparent point of intersection of a view to the adjoining view. If the apparent points of intersection align, then the lines actually intersect.

To determine the true distance between two nonparallel lines:

Step 1. Project the true length of either one of the two lines, and project the other line into that auxiliary view (A).

Step 2. Find the point view of the true length line, and project the other line into that secondary auxiliary view (B).

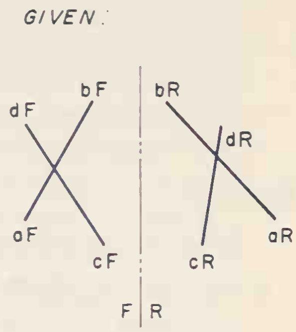


Figure 7-15A Finding the true distance between two nonparallel (or skewed) lines

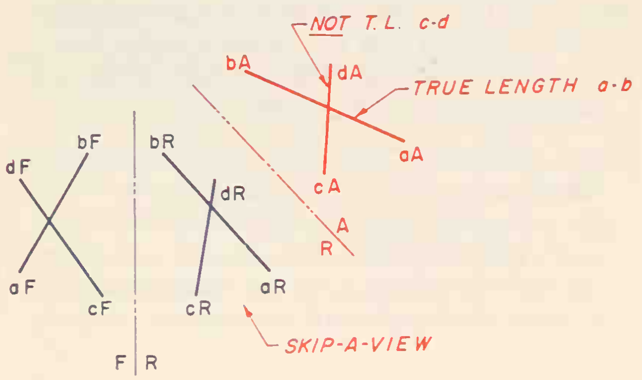


Figure 7-15B Step 1

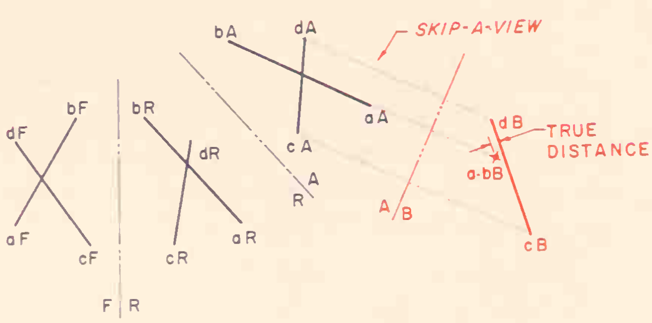


Figure 7-15C Step 2

Step 3. Measure the true distance between the point view line at a location that is perpendicular to the other line.

Example:

Refer to Figure 7-15A.

Given: Nonparallel lines a-b and c-d in a front view and right-side view.

Step 1. Project the true length of line a-b in an auxiliary view (A), and project line c-d along into that auxiliary view, Figure 7-15B. Notice that c-d is not the true length.

Step 2. Project the point view of line a-b into the secondary view (B) and project line c-d into this view. Measure the true distance between the point view of line a-b/B, perpendicular from line c-d/B, Figure 7-15C.

How To Project a Plane into Another View

A limited plane is located by points in space joined by straight lines. In order to transfer a plane, find at least three points in the plane and project each point into the next view.

Example:

Refer to Figure 7-16A.

Given: Triangular plane abc shown in the top view and front view.

Step 1. In the top view, find the distance from the fold line to points aT, bT, and cT, Figure 7-16B.

Step 2. Project these same points from the front view into the right-side view, and transfer the corresponding distances from the top view points to the top view fold line into the right-side view, Figure 7-16C. Construct straight lines between points a, b, and c. This transfers the plane surface.

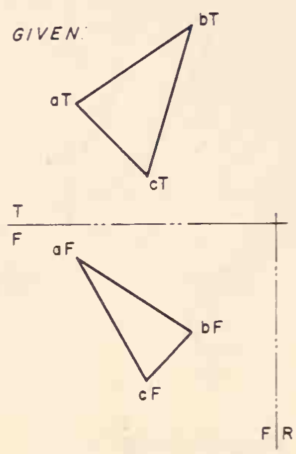


Figure 7-16A Projecting a plane into another view

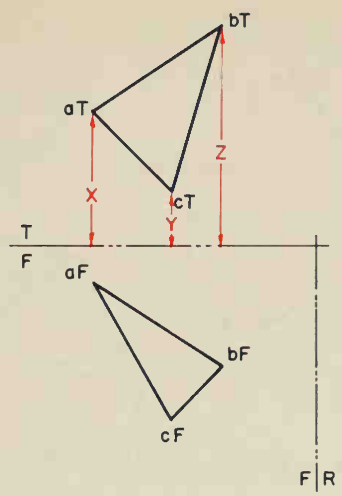


Figure 7-16B Step 1

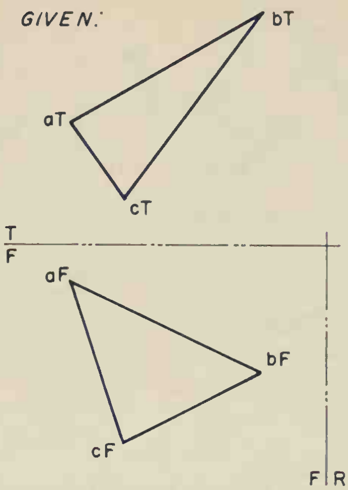


Figure 7-17A Constructing an edge view of a plane surface

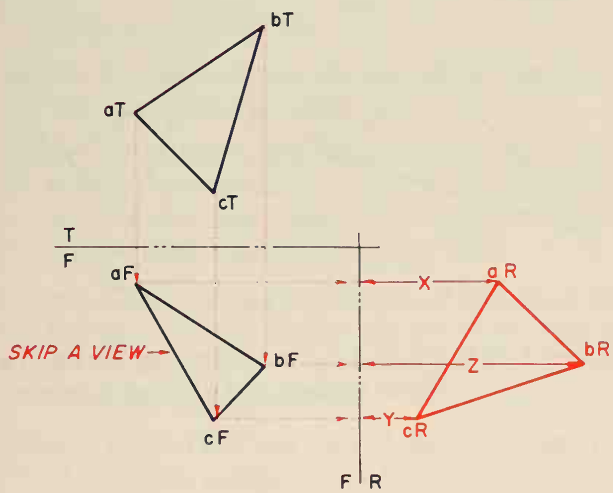


Figure 7-16C Step 2

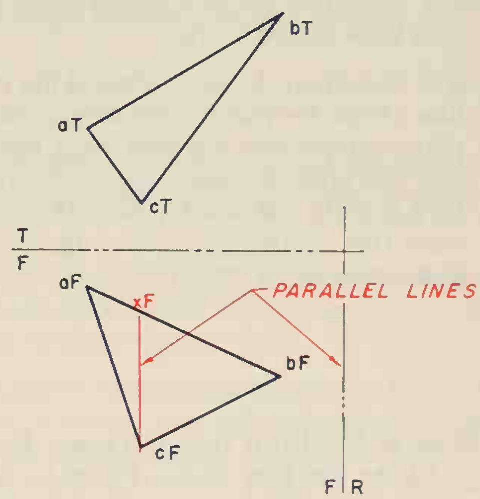


Figure 7-17B Step 1

How To *Construct an Edge View of a Plane Surface*

If the end view of a line that is in a plane is shown, then the edge view of that plane is shown also. Recall that to find the end view of a line, a true length must be found first. When the boundaries of a plane are provided, projecting a view to find the true length of a selected boundary is a simple procedure. It is necessary only to locate a fold line parallel to the boundary to ensure its true length in the next projected view.

A shorter method of securing a true length line in a plane is also used, if a true length line is not present already. A line may be added on the plane in any view, arranged to be parallel to an adjoining fold line, and to have its terminations at the plane boundaries. Projecting the added-line terminations to the corresponding boundaries in the adjoining view relocates the added line in that view. Moreover, it will be a true length line, as it was made to be parallel to the fold line in the preceding view.

Whichever method is used to find a true length line in the plane, all point locations within the plane should be projected to the view where the true length line exists, if not there already. A fold line perpendicular to the true length line will provide a direction for projecting the edge view of the plane. Projecting all the points in the plane will provide evidence of this, as they will all align into a single, straight path.

Example:

Refer to Figure 7-17A.

Given: Plane surface abc in the top view and front view.

Step 1. Construct a line parallel to fold line F/R and through one or more points if possible. In this example, the line passes through point c. Label this newly constructed line cF/xF. Figure 7-17B.

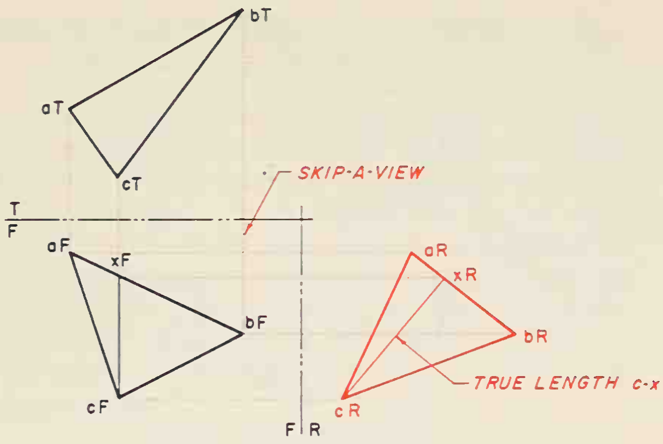


Figure 7-17C Step 2

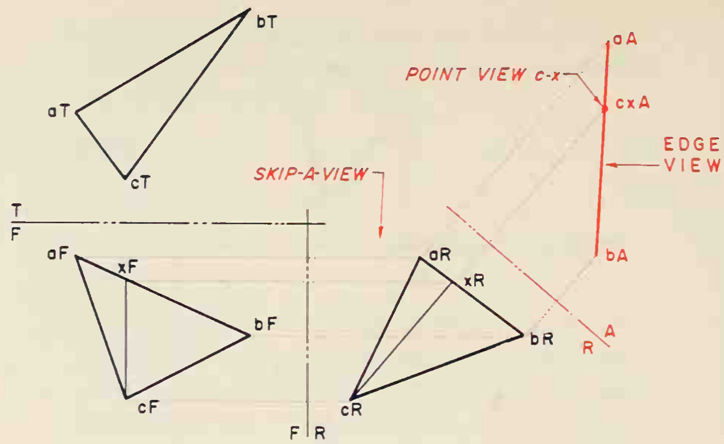


Figure 7-17D Step 3

Step 2. Construct the true length of line cF/xF in the next view. Figure 7-17C.

Step 3. Construct the point view of the true length line c-R/xR. Project the remaining points of the plane surface into this view. Also, label all points and fold lines. If done correctly, the result should be a straight line which passes through the point view. This straight line is the edge view of the plane. Figure 7-17D.

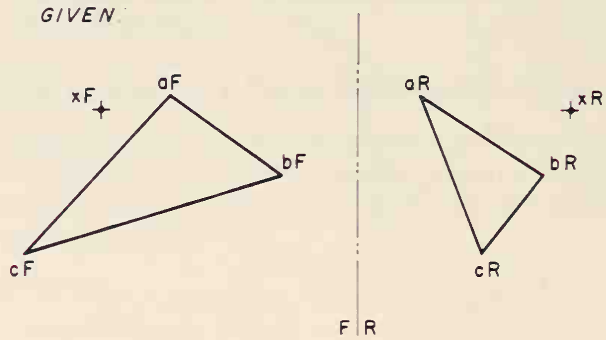


Figure 7-18A Finding the true distance between a plane surface and a point in space

How To Find the True Distance Between a Plane Surface and a Point in Space

Finding the true distance between a given point and a plane in space requires a view that shows the edge view of the plane and the point in the same view. The distance from the point to the plane is the path that is perpendicular to the plane, and passing through the point.

Step 1. Add a line on the plane parallel to a fold line, if a true length line is not already available in the plane.

Step 2. Project the added line to an adjoining view, where it will be seen in true length..

Step 3. Project a point view of the added true length line.

Step 4 .Project the points of the plane into this view. The result should be a straight line which passes through the added line end view, which is the edge view. Project the point in space into this view. Measure the perpendicular distance from the plane's edge view to the point in space. This is the actual true distance between the plane surface and the point in space.

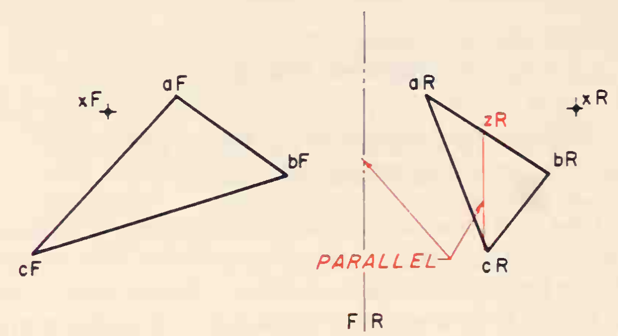


Figure 7-18B Step 1

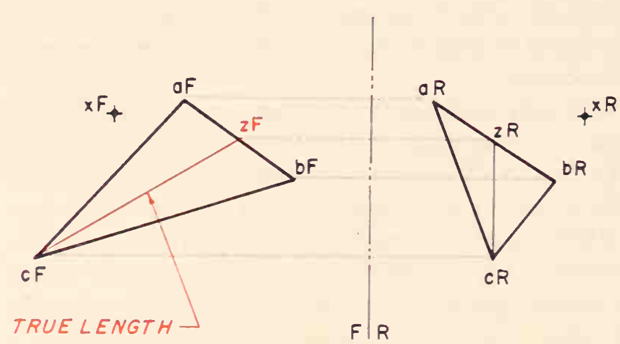


Figure 7-18C Step 2

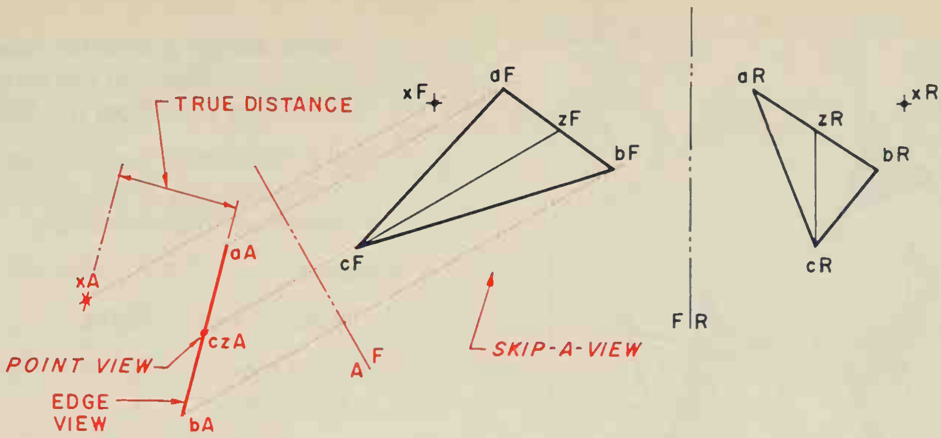


Figure 7-18D Step 3

Example:

Refer to Figure 7-18A.

Given: Triangular plane abc and point X in the front view and right-side view.

Step 1. Construct a line parallel to the fold line F/R and through one or more points. Point c is a convenient line termination. Label this newly constructed line cR/zR, Figure 7-18B.

Step 2. Construct the true length of line cR/zR in the front view, and label the line cF/zF, Figure 7-18C. Bring point X into this view, also. Label all points and fold lines.

Step 3. Project the end view of the true length line cF/zF in the auxiliary view, Figure 7-18D. Project the points of the plane surface into this view, and also point X, projecting 90° from the fold line. Label all points and fold lines. Measure the perpendicular distance from the edge view to the point in space. This is the true distance between the plane surface and the point X in space.

How To Find the True Angle Between Two Planes (Dihedral Angle)

The edge of intersection between two planes is a line that is common to both planes. The end view of that line will provide the edge view of both planes simultaneously, and the angle between them will be evident.

To find the true angle between two surfaces:

Step 1. Construct the true length of the intersection between the two surfaces, and project all other points of both planes into that auxiliary view.

Step 2. Project the end view of the true length edge of intersection line and project the points of both planes into this secondary auxiliary view. Label all points and fold lines. Measure the true angle between the two surfaces.

Example:

Refer to Figure 7-19A.

Given: Plane abc and plane abd that intersect one edge, a-b, in the front view, side view, and top view.

Step 1. Project the true length of the edge of intersection a-b, and project all other points into this auxiliary view (A), Figure 7-19B.

Step 2. Project the point view of the true length of the edge of intersection a-b and project all other points into this secondary auxiliary view (B), Figure 7-19C. Measure the true angle between two surfaces.

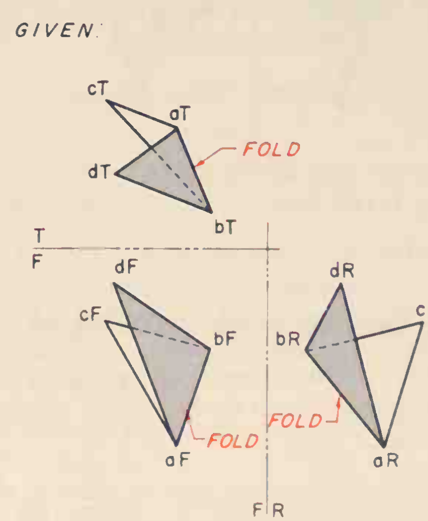


Figure 7-19A Finding the angle between two surfaces

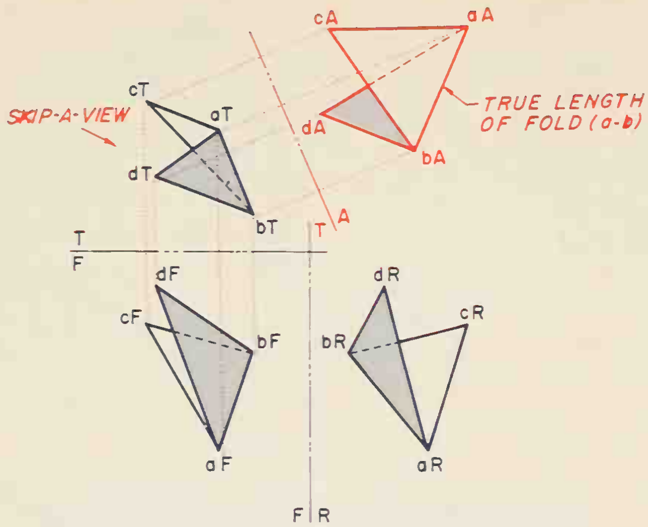


Figure 7-19B Step I

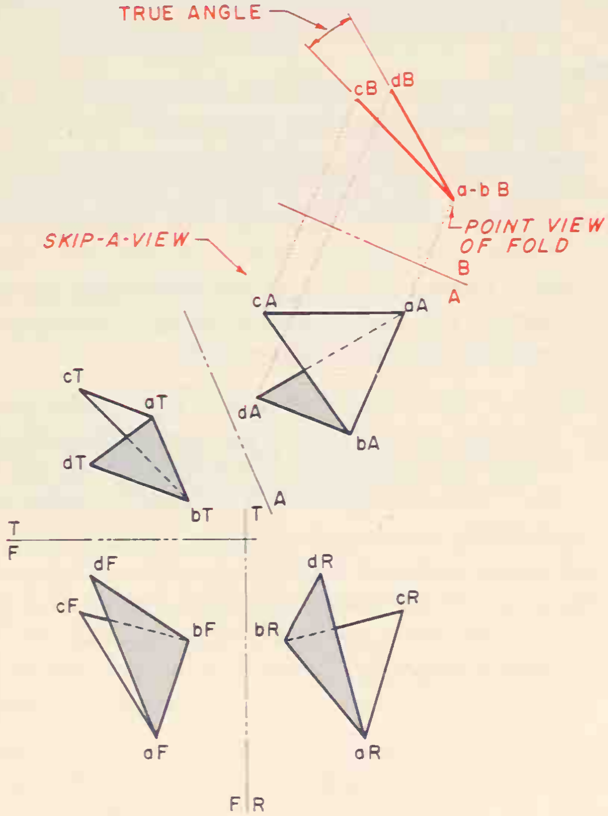


Figure 7-19C Step 2

How To Determine the Visibility of Lines

To determine which line of an apparent intersection of two lines is closer to the viewer, the following steps are used.

Step 1. From the exact crossover point of the lines, project to an adjoining view.

Step 2. In the adjoining view, determine which of the lines is closest to the fold line between the views, on the projection line from the first view (or the first line that the projection line encounters on its path from the first view).

Step 3. Whichever line is closest to the fold line at that point only is the line that is in front of the other line in the first view.

Example:

Refer to Figure 7-20A.

Given: Lines a-b and c-d in the front view and top view.

Step 1. At the exact crossover of lines a-b and c-d in the top view, project down through the fold line to the corresponding lines in the front view. At this exact point along the lines, line c-d is closer to the fold line and line a-b is farther away from the fold line; thus, in the top view, line c-d is in front of line a-b, Figure 7-20B.

Step 2. See 7-20C. At the exact crossover of lines a-b and c-d in the front view, project up through the fold line to the corresponding lines in the top view. At this exact point along the lines, line a-b is closer to the fold line and line

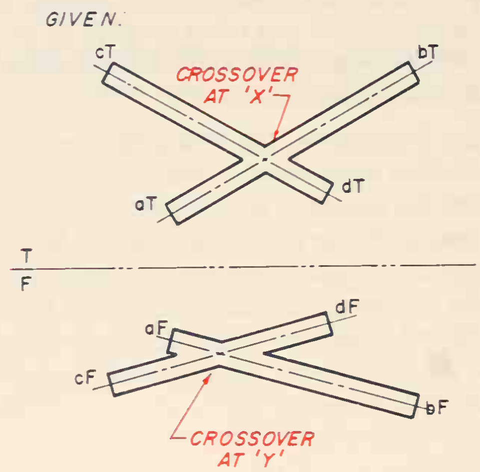


Figure 7-20A Determining the visibility of lines

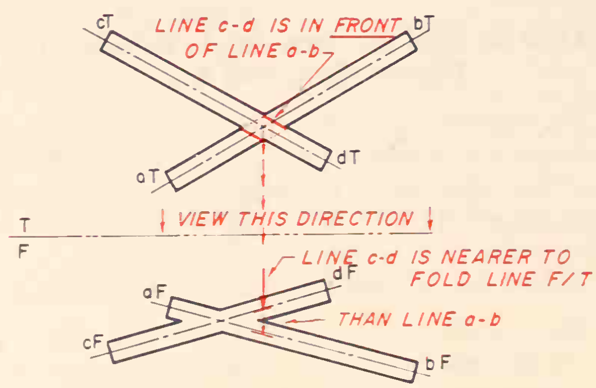


Figure 7-20B Step 1

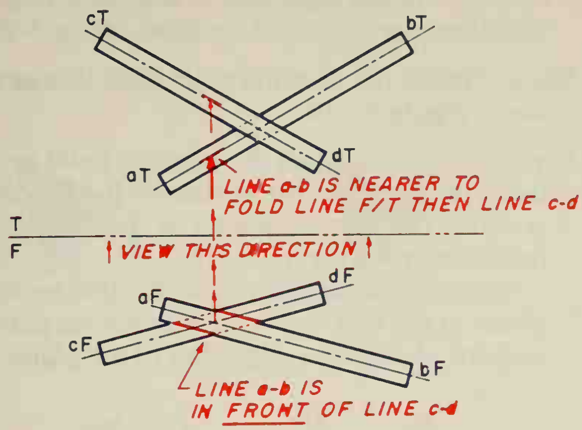


Figure 7-20C Step 2

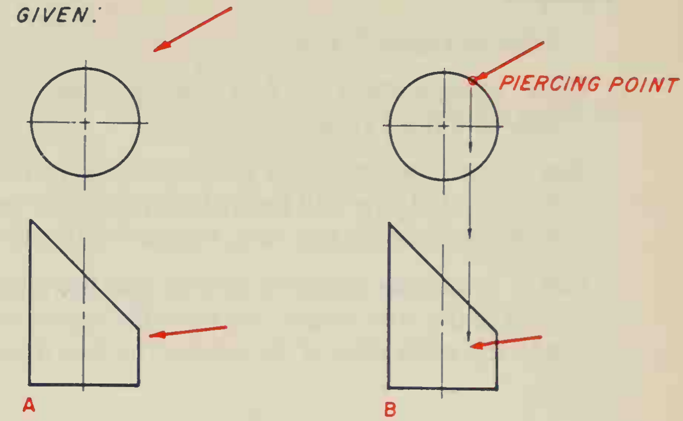


Figure 7-21 Determining the piercing point by inspection

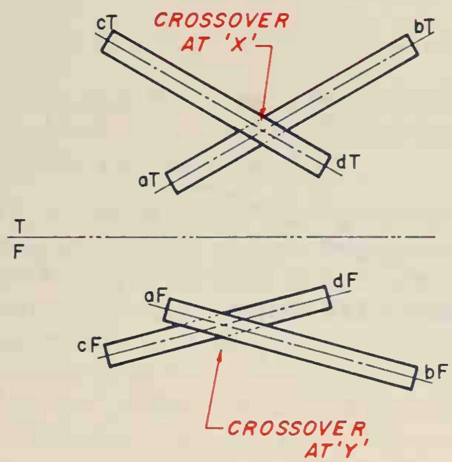


Figure 7-20D Step 3

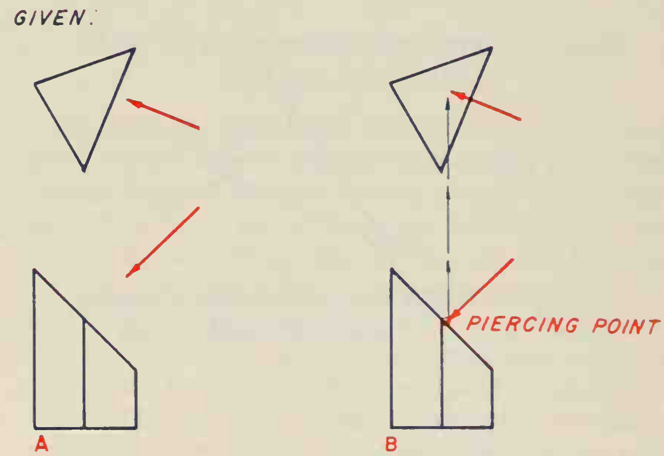


Figure 7-22 Determining the piercing point by inspection

c-d is farther away from the fold line; thus, in the front view, line a-b is in front of line c-d.

Step 3. The end result is drawn (in Figure 7-20D) to illustrate this crossover.

How To Determine the Piercing Point by Inspection

The *piercing point* is the exact location of the intersection of a surface and a line. The exact piercing point is determined from the view where the surface appears as an edge view. In example 7-21, Part A, the top view illustrates the edge view of the surface. The piercing point is established in the top view and projected down into the front view, Figure 7-21, Part B. In example 7-22, Part A, the front view illustrates the edge view of the surface. The piercing point is established in the front view and projected up into the top view, Figure 7-22, Part B.

How To Determine the Piercing Point by Construction

To determine the exact piercing point by construction:

Step 1. Construct a true length of a line on the plane surface.

Step 2. Project a point view of the true length line, and an edge view of the plane surface. The edge view of the plane lies in the path of the line in this view, indicating the piercing point location.

Step 3. Transfer the piercing point back into the other views.

Step 4. Determine the visibility of lines to find which part of the line is visible from the viewing direction. Use the fold line to determine visibility, if necessary.

Example:

Refer to Figure 7-23A.

Given: Plane surface abc and line x-y, in the top view and front view.

Step 1. In the front view of plane abc, construct a line parallel to a fold line (bF-dF) and find its true length in the top view, Figure 7-23B.

Step 2. Project an auxiliary view to find the point view of the true length line from the top view, and the edge view of the plane. The line intersection with the edge view of the plane indicates the piercing point location, Figure 7-23C.

Step 3. Project the piercing point back into other views, Figure 7-23D.

Step 4. In each view that the piercing point is being projected to, the portion of the line that is visible can be determined by checking its preceding view, Figure 7-23E.

Notice in the auxiliary view that line x-y is closer to the fold line from the piercing point to point yA than the edge view of the plane

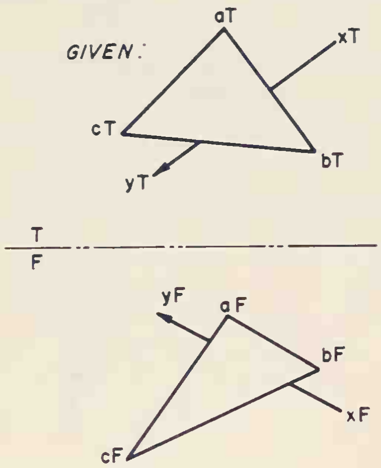


Figure 7-23A Determining the piercing point by construction

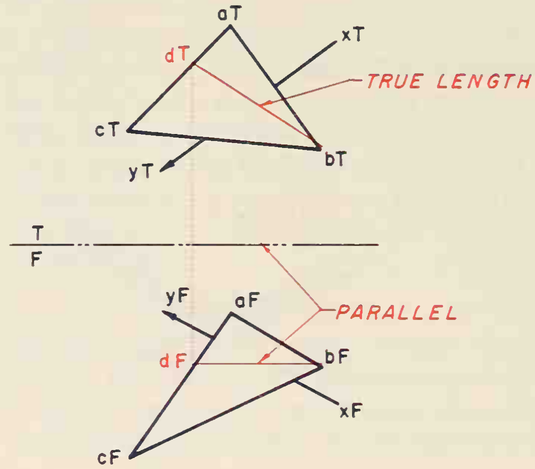


Figure 7-23B Step 1

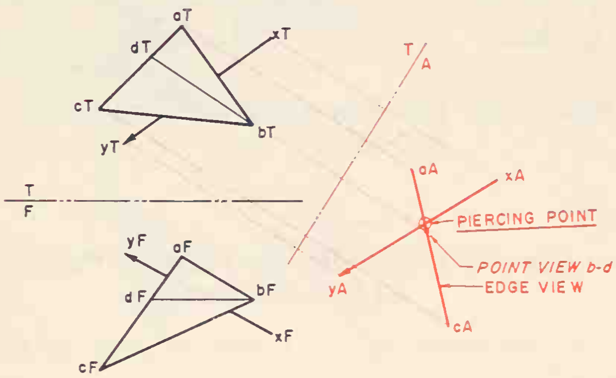


Figure 7-23C Step 2

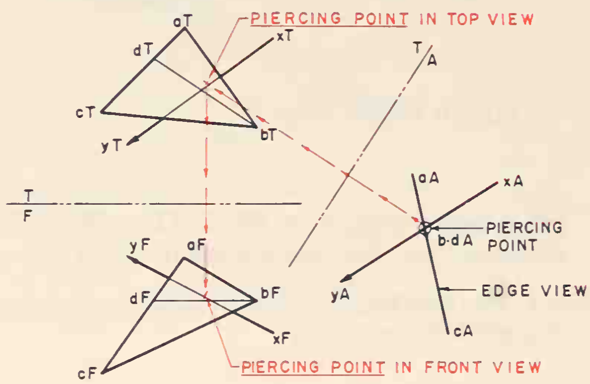


Figure 7-23D Step 3

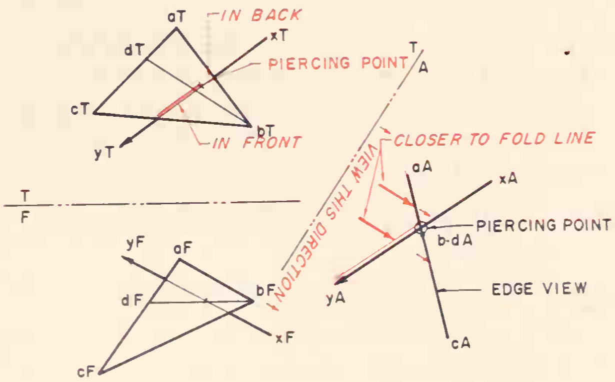


Figure 7-23E Step 4

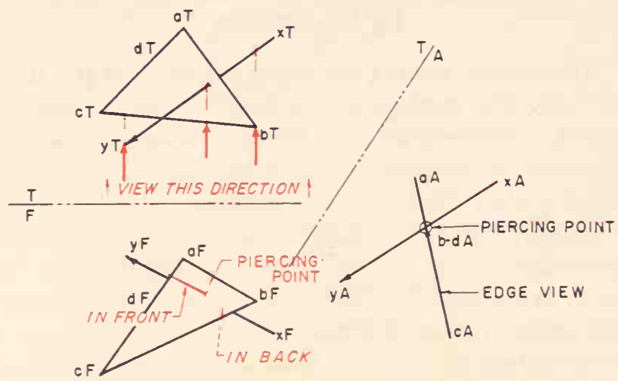


Figure 7-23F Step 5

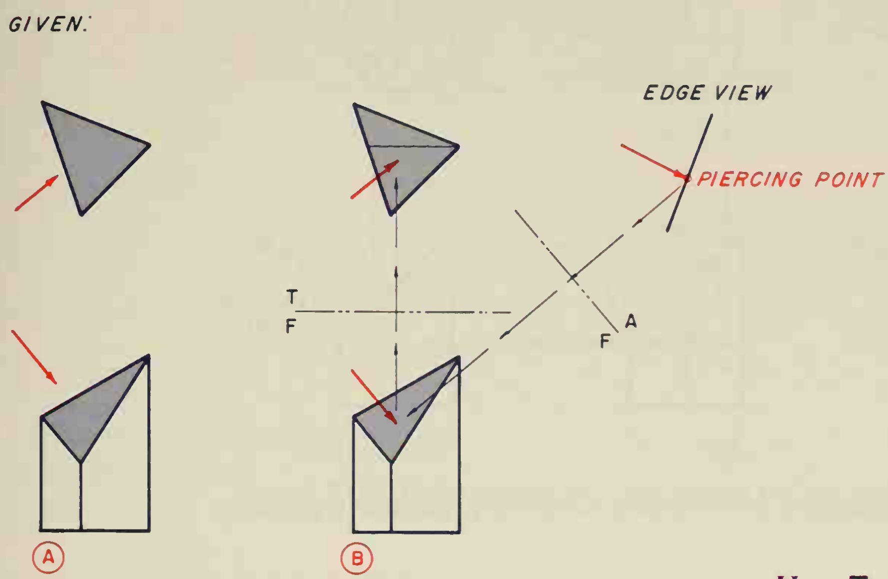


Figure 7-24
Determining the piercing point by construction

surface from the piercing point to point cA. Therefore, in the top view, line x-y is seen only from the piercing point to yT.

Step 5. By viewing back into the top view, determine the visibility of lines of the plane surface and line x-y in the front view, Figure 7-23F. Notice in the top view that line x-y is closer to the fold line from the piercing point to point yT than the edge view of the plane surface cT/bT; therefore, in the front view, line x-y is seen only from the piercing point to yF.

When the edge view does not appear in the regular views, it must be constructed using the preceding steps, Figure 7-24, Part A. Once the edge view is constructed, the piercing point can easily be seen. The piercing point is now projected down into the front view and up into the top view, Figure 7-24, Part B.

How To Determine the Piercing Point by Line Projection

An alternate method of determining the piercing point simply locates the path of a cutting plane that passes through the line, leaving a "scar" on the surface of the given plane. Since the line lies in the cutting plane, an intersection of the line and the scar on the given plane locates the piercing point. The end points of the scar are found by aligning the cutting plane with the given line in one view, where it crosses the boundary of the given plane in two places. Projecting the cutting plane intersection to the corresponding boundaries of the given plane in the next view, locates the scar end points in that view, and provides a view of the scar that the given line can cross at the piercing point.

Example:

See Figure 7-25, Part A.

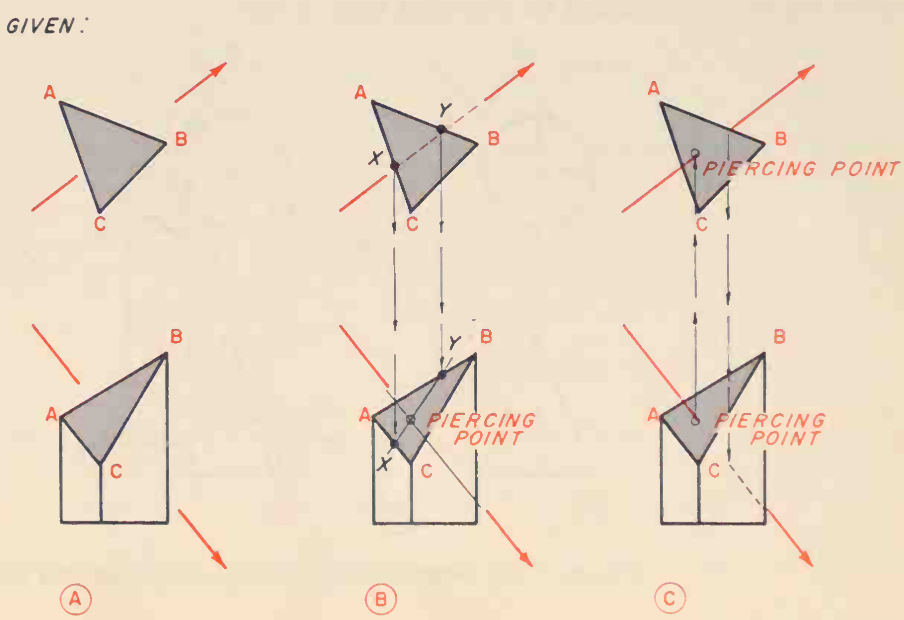


Figure 7-25
Determining piercing points by line projection (skewed surface)

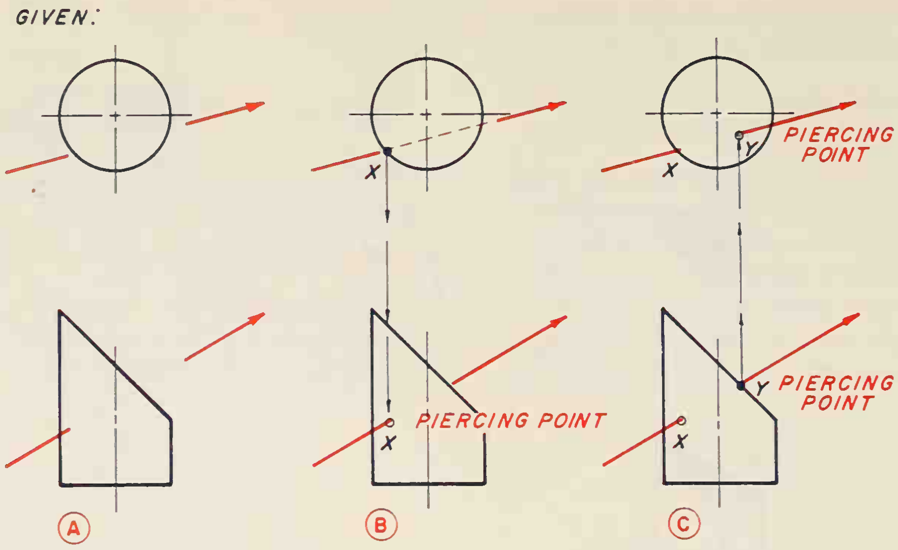


Figure 7-26 Determining piercing points by line projection (cylinder)

Given: Skewed surface abc, and a line.

Step 1. In the top view, lightly draw the piercing line and determine points X and Y where they cross the boundary of plane abc. The piercing point is located somewhere between these points.

Step 2. Project points X and Y down into the front view to the corresponding edges of the plane abc, Figure 7-25, Part B. Where line X-Y crosses the given line is the exact piercing point.

Step 3. Project the piercing point to the top view, Figure 7-25, Part C. Visibility of the piercing line is determined by inspection.

Figure 7-26, Part A, illustrates a cylinder pierced by a line. Lightly draw the piercing line in the top view and find point X. Project point X down into the front view, Figure 7-26, Part B, to find piercing point X. Because the piercing line exits the skewed surface, piercing point Y is found on the edge view of the front view, Figure 7-26, Part C. Project piercing point Y up into the top view. Visibility of the piercing line is determined by inspection.

If the object is a cone, line segments must be located and drawn from the base of the cone up to the vertex of the cone.

Given: A cone with a piercing line, Figure 7-27, Part A.

Lightly draw the piercing line in the top view and find points X and Y, Figure 7-27, Part B. Project points X and Y down to the base of the cone. Project light line segments from points X and Y on the base up to the vertex of the cone. Where these lines cross the piercing line is the location of the two piercing points. Visibility of the piercing line is determined by inspection, Figure 7-27, Part C.

If the object is spherical, an imaginary flat surface on the sphere must be established along the piercing line.

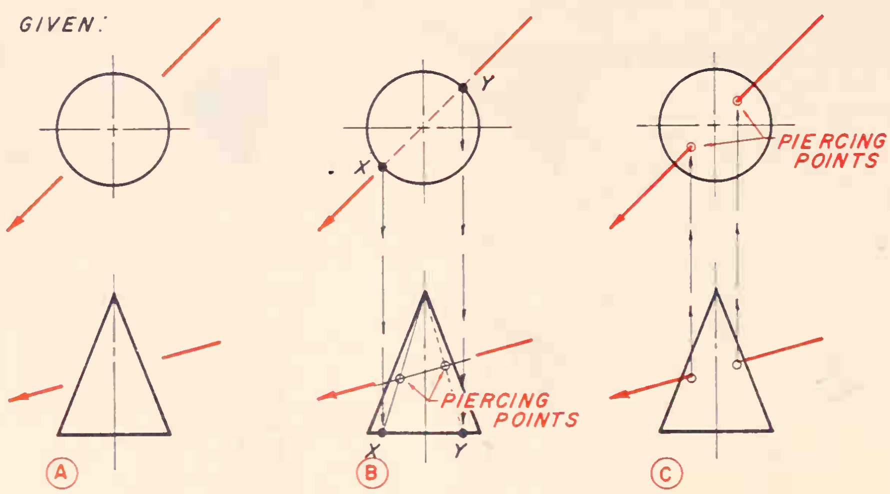


Figure 7-27 Determining piercing points by line projection (cone)

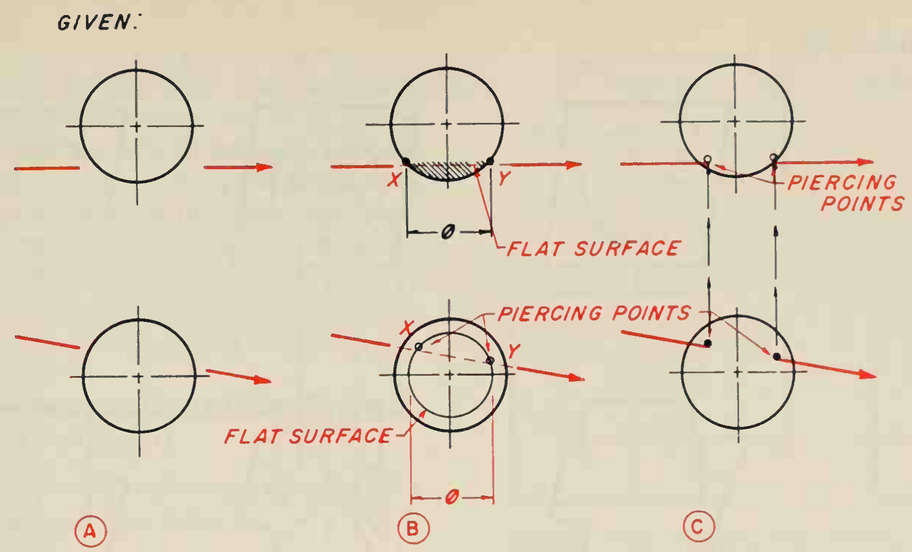


Figure 7-28 Determining piercing points by line projection (sphere)

Given: A sphere with a piercing line, Figure 7-28, Part A.

Lightly draw the piercing line in the top view. Where the piercing line intersects with the sphere is the location of the imaginary flat surface, Figure 7-28, Part B. This also establishes the diameter of the flat surface. Transfer the imaginary flat surface to the front view. Where the piercing line intersects the imaginary flat surface is the exact piercing point locations. Once the piercing point locations are found they are projected up into the top view, Figure 7-28, Part C. Visibility of the piercing line is determined by inspection.

How To Find the Intersection of Two Planes by Line Projection

The intersection of two planes can be determined by generating an edge view of one of the planes. Another method, somewhat simpler, is the line-projection method.

Given: Two plane surfaces, Figure 7-29, Part A.

In the top view, locate points X and Y on edge ab of one of the planes. Project points X and Y down into the front view as illustrated in Figure 7-29, Part B, and draw a light line from X-Y in the front view. The piercing point is where line X-Y crosses the edge ab. Project points from edge ac of the same plane. Project these points down into the front view. Draw a line connecting these points; where they cross edge ac is the exact piercing point. Complete the views as illustrated in Figure 7-29, Part C.

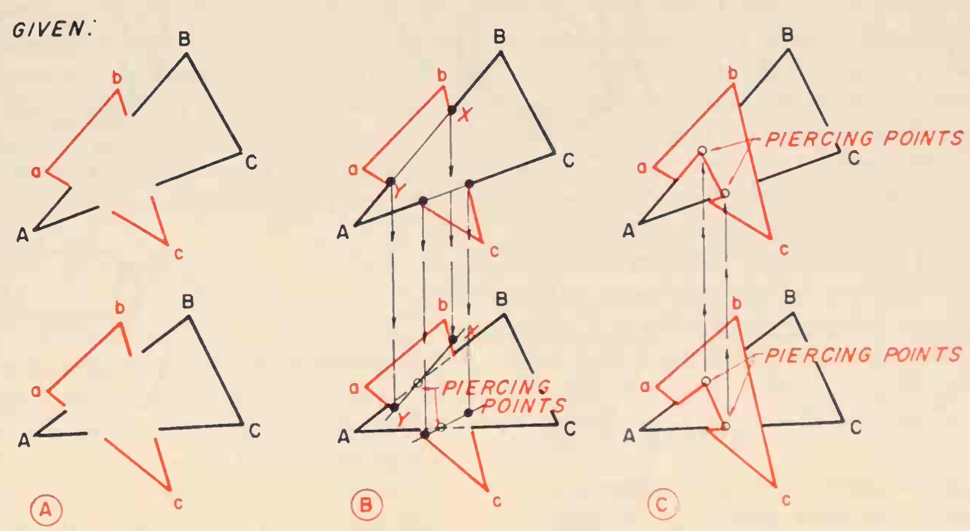
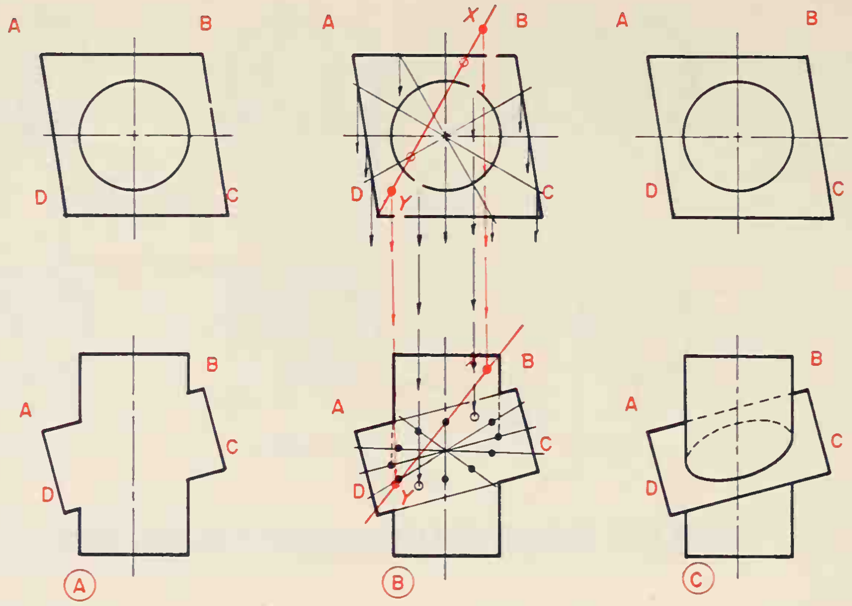


Figure 7-29 Determining the intersection of two planes

Figure 7-30 Determining the intersection of a cylinder and a plane surface



How To Find the Intersection of a Cylinder and a Plane Surface by Line Projection

The intersection of a cylinder and a plane surface can also be determined by generating an edge view of the plane surface. Another method is the line-projection method.

Given: A cylinder and a plane surface, Figure 7-30, Part A.

Divide the circle into equal parts; in this example, 12 equal parts. Extend these lines out to the edges of the plane surface, Figure 7-30, Part B. The example illustrated uses points 1 o'clock and 7 o'clock to find points X and Y on the edge of the plane surface. Project points X and Y down into the front view. Draw a line from X-Y in the front view. Points 1 o'clock and 7 o'clock are located somewhere on this line. To find their exact locations, project points 1 and 7 from the top view to the line in the front view. Continue around the various points to locate each of the 12 points. Complete the drawing as shown in Figure 7-30, Part C.

How To Find the Intersection of a Sphere and a Plane Surface

Given: A sphere and a plane, Figure 7-31, Part A.

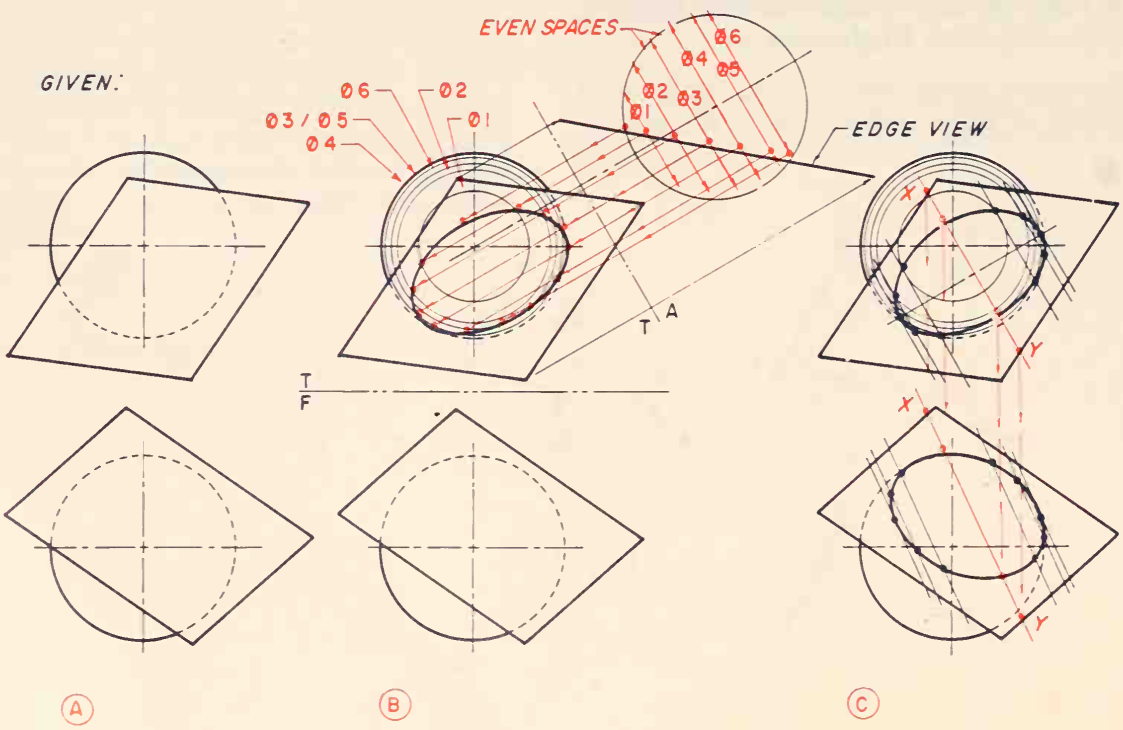


Figure 7-31 Determining the intersection of a sphere and a plane surface

Construct an edge view of the plane, Figure 7-31, Part B. Divide the sphere into even spaces as illustrated. Think of each evenly spaced line as an imaginary sliced-off portion of the sphere. Draw each imaginary slice in the top view and where the projection from the corresponding point on the edge view cross is the piercing point. Complete the top view as illustrated. Once these points have been found in the top view, the line-projection method is used to transfer them to the front view, Figure 7-31, Part C.

How To Find the Intersection of Two Prisms (Method 1)

Given: The top, front, and right-side views of two intersecting prisms, Figure 7-32.

Label the various points as illustrated. Project each point to the 45° projection and into the next view and where they intersect is the location of each point, as illustrated. The only point in question is point X; using the three views, it can be easily found.

How To Find the Intersection of Two Prisms (Method 2)

Using only two views, point X creates a problem to locate point X in the front view. Refer to Figure 7-33. In the top view extend line C'-X to where it crosses line segment A-A'. Project point Y down into the front view to line A-A'. Draw a line from C' to Y to locate point X in the front view.

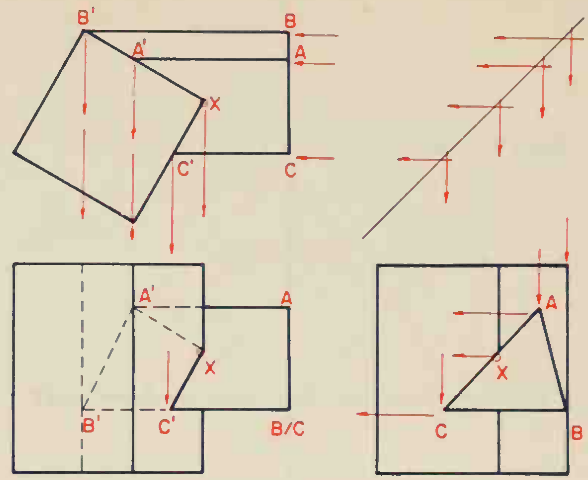


Figure 7-32 Finding the intersection of two prisms (method 1)

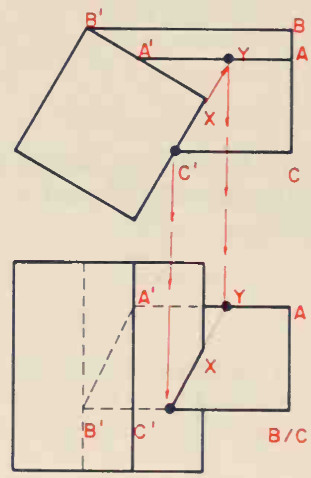


Figure 7-33 Finding the intersection of two prisms (method 2)

Bearings, Slope, and Grade

In some fields of drafting the exact position of a line in space is described by its *bearing* and *slope* or by its *bearing* and *grade*.

Bearing of a Line

The *bearing* or *heading* of a line is the direction of that line as it is drawn in the *top view* of a drawing on a map. Using a map of a given area on the earth's surface, a view looking directly down would be an example of how a bearing of a line is used.

There are two methods used to call off a bearing. It is called off by either its *north/south* deviation or by its *azimuth bearing*.

North/South Deviation

A bearing of a line is measured in degrees with respect to the north or the south. It is customary to consider the north as being located from the *top* of the page and the south as being located from the *bottom* of the page, unless otherwise noted. See Figure 7-34. Bearings are called off in angles *less* than 90° and are always given *from* the north or south, heading *toward* either the east or west. See Figure 7-35. In this example a line, 1-2, is projected 45° *from* the north and *toward* the west. It has a bearing of, and is called off as, N 45° W. A line, 1-2, is projected 30° *from* the south *toward* the east. See Figure 7-36. It has a bearing of, and is called off as, S 30° E. It is important to know *where* the point of origin or the beginning of the line is, and in which direction the line is heading. Refer to Figure 7-37. Line 2-2' could be called off as either N 45° W or as S 45° E, depending on its point of origin. If the line is projected from point 1 to point 2, the bearing would be N 45° W; if from 1' to point 2', the bearing would be S 45° E.

Azimuth Bearing

In using the azimuth bearing method, the *total* angle is used, going *clockwise* from the north. A given line, 1-2, is drawn at 45° from the north and heading

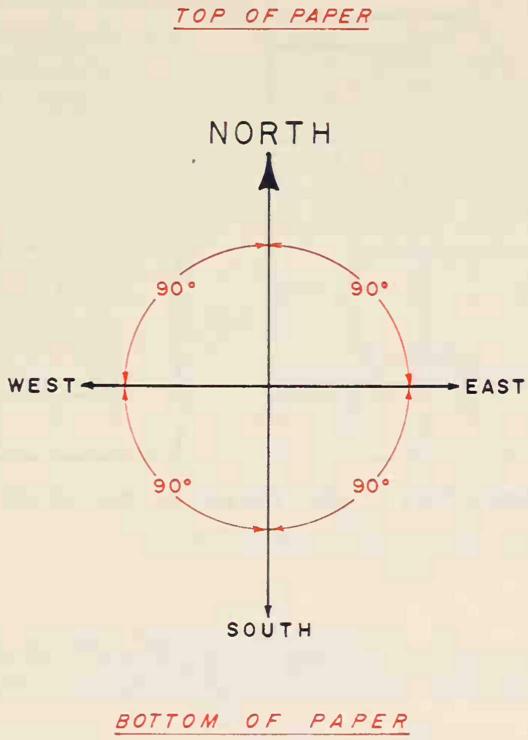


Figure 7-34 North, south, east, west headings: north is usually located at the top of the page

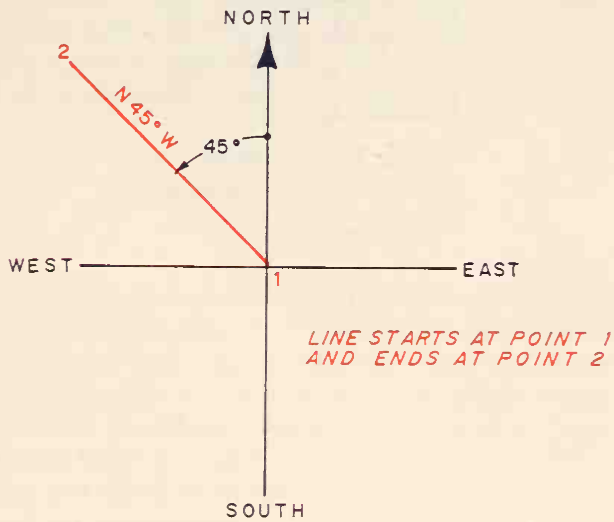


Figure 7-35 A line with a heading of N 45° W: headings are always drawn in the top view

toward the west, Figure 7-38. Using the azimuth method and measuring *clockwise* from the north, it has a bearing of 315°, (90° plus 90° plus 90° plus 45°). It is usually understood that the north bearing is the starting point, thus the "N" is usually omitted in verbally describing the bearing: on the drawing, how-

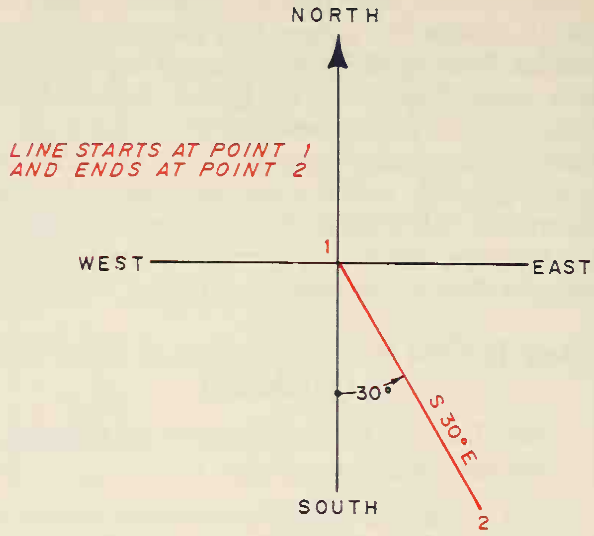


Figure 7-36 A line with a heading of S 30° E

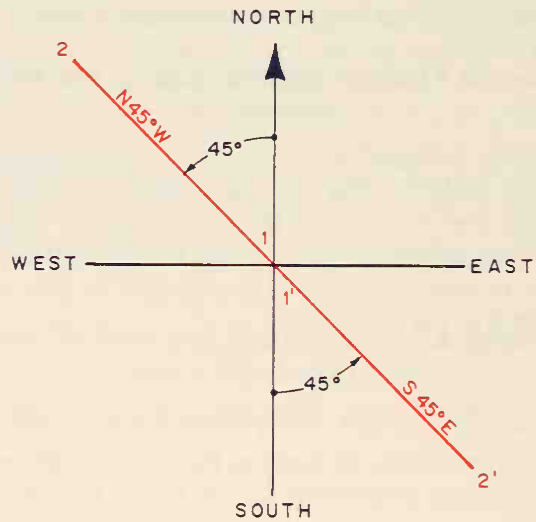


Figure 7-37 This line could be either N 45° W or S 45° W, depending upon the starting point and the direction in which it is projected

ever, it is best to use the "N" or "North" so as to avoid any confusion. Note that *bearing* is sometimes noted as *heading*.

Slope Angle

Using the slope angle is a way to describe the inclination of a line. The slope of a line is the angle, in degrees, that the line makes with a horizontal (level) plane, Figure 7-39. The line is heading *from* point 1 *toward* point 2, and it is rising; therefore, it is a *plus* (+) slope angle.

Note that the *true slope* of a line can only be seen in the view that has a horizon (level) line and in which it is drawn as a *true length*, Figure 7-40. In this example, the true length can be found from the front view

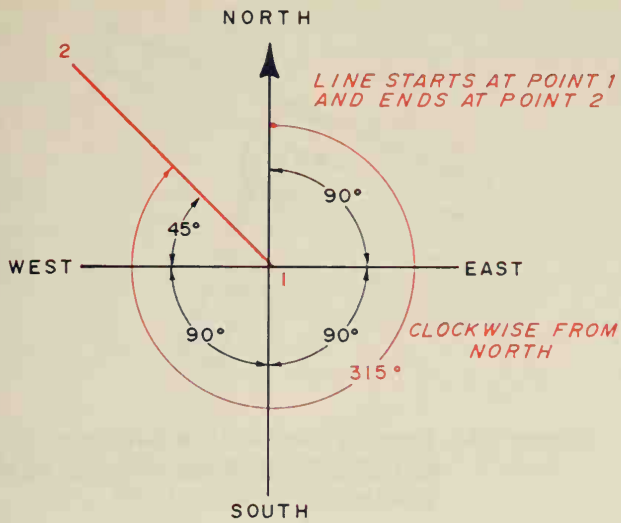


Figure 7-38 Azimuth bearing is indicated from the north clockwise to the line

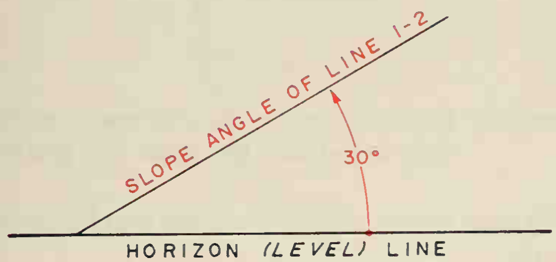


Figure 7-39 Slope angle is the angle in degrees from the horizon

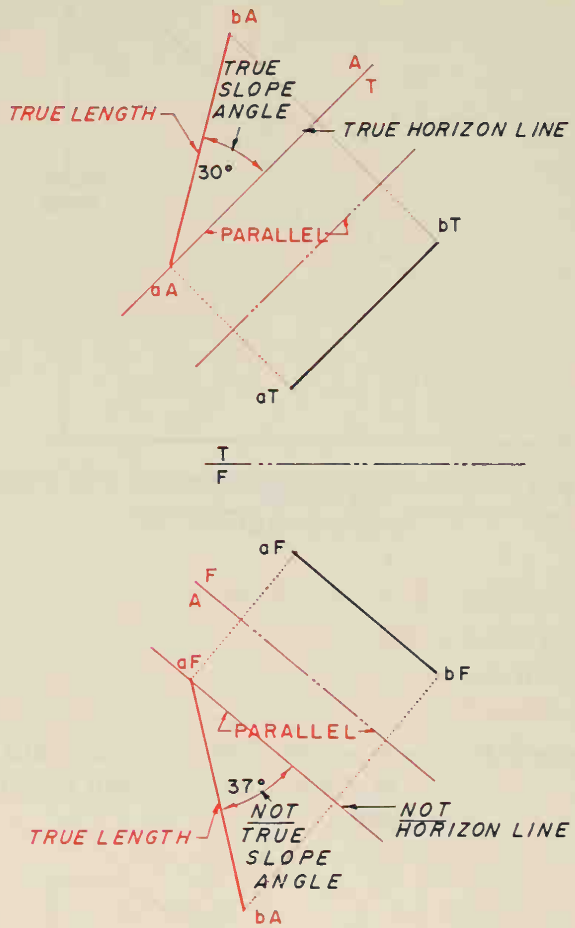


Figure 7-40 True slope angle of a line can only be seen in a view that has a horizon line. It is noted in degrees.

and/or from the top view. However, projecting from the front view will *not* give a horizon (level) line—it is only found by projecting from the top view.

Grade Percent

Another way to describe the inclination of a line in relation to the horizon is by the ratio of the vertical rise (R) to the horizontal (H). It is expressed in percent and calculated by the simple formula:

$$\text{Percent of Grade} = \frac{\text{Units of vertical rise (R)}}{\text{Units of horizon (H)}} \times 100$$

Figure 7-41 illustrates a simple 45° angle line with 100 horizontal units and 100 vertical units. 100 divided by 100 times 100 equals a 100% grade. If the angle were 30°, the grade would be 57%, Figure 7-42. The most common method of measuring the horizontal and vertical units is with an engineer's scale using multiples of ten. Percent of grade is another way to express the slope of a line, but, as in laying out grade percents, *the view that has both the true horizon and true length must be used*. Refer back to figure 7-40.

Other Ways to Call Off the Slope of a Line

Various fields of drafting use slightly different methods to call off the specified inclination of lines. Each method is similar to that of calling off percent of slope and/or percent of grade in that each expresses the relationship of the line to the horizontal (level) plane. Three common methods are *pitch*, *bevel*, and *batter*.

Pitch. Pitch is usually used in the architectural field of drafting and is used to call off the *slope* of a roof. It is expressed as the ratio of vertical rise to 12 inches or 12 feet of horizontal span, Figure 7-43. In each horizontal 12 inches the roof *rises* 6 inches.

Bevel. In structural engineering, where steel members are used in the construction of the building, the slope of a member is called off by the bevel of the beam, Figure 7-44. It is very similar to that of the pitch used in architectural drafting.

Batter. In the field of civil engineering the slope of the grade (earth) is used and is referred to as *batter*. It is called off as illustrated by Figure 7-45. This means

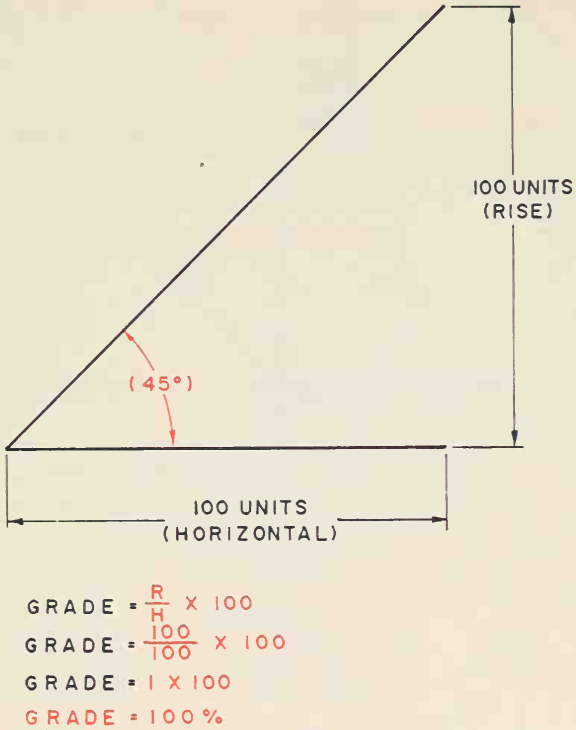


Figure 7-41 Grade percent is the inclination of a line in relation to the horizon, noted in percent

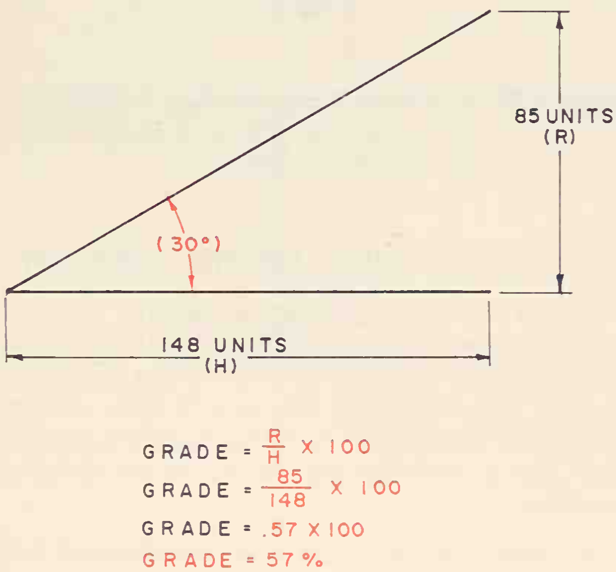


Figure 7-42 Example of a line with a grade of 57%

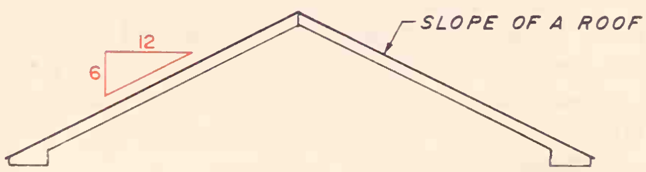


Figure 7-43 Pitch is the slope of a roof and is a ratio of vertical rise for every 12 inches or 12 feet of horizontal span

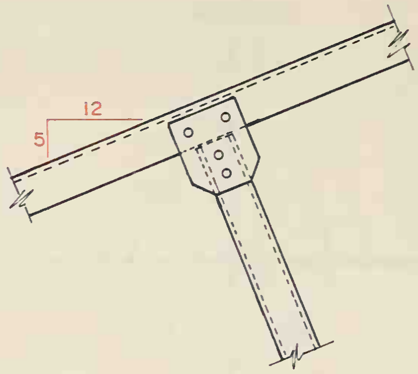


Figure 7-44 Bevel is used in structural engineering to indicate the slope of a structural member

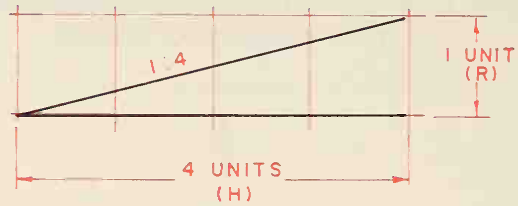


Figure 7-45 Batter is used in the civil engineering field to indicate the slope of a grade

that for each unit of rise (R), there are four horizontal (H) units.

Angles Between Bearings or Headings

If you know the bearings of two lines, the angle between the lines can be determined, Figure 7-46. Given are lines 1-2 and 1-3, as illustrated. Both these lines fall within one 90° quadrant; therefore, to find the angle between the lines, subtract one bearing from the other, Figure 7-47. Fifteen degrees is subtracted from eighty degrees, and the true angle between the bearings is sixty-five degrees.

If the bearings fall within two or more quadrants, the actual angles in each quadrant must be added or subtracted, as illustrated in Figures 7-48, 7-49, 7-50, and 7-51.

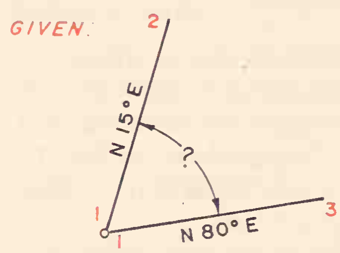


Figure 7-46 Angle between two headings in one quadrant (90°)

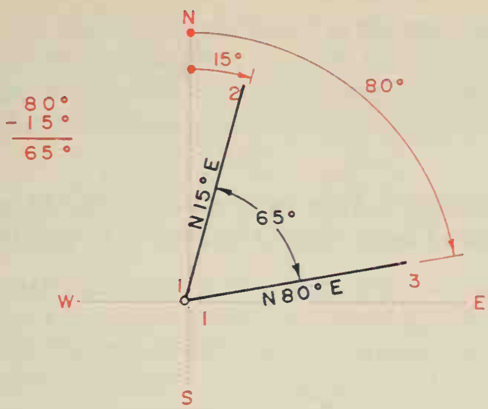


Figure 7-47 How to calculate the angle between headings in one quadrant

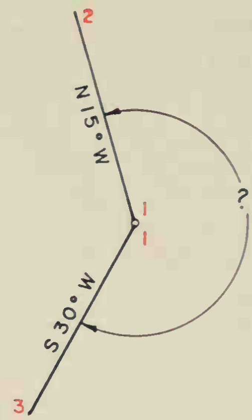


Figure 7-50 Angle between two headings in four quadrants

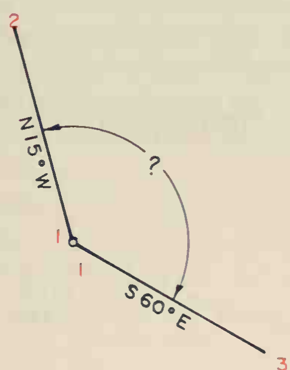


Figure 7-48 Angle between two headings in three quadrants

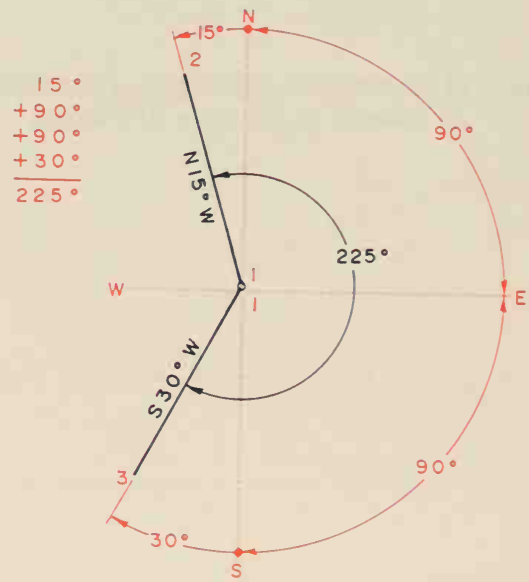


Figure 7-51 How to calculate the angle between headings in four quadrants

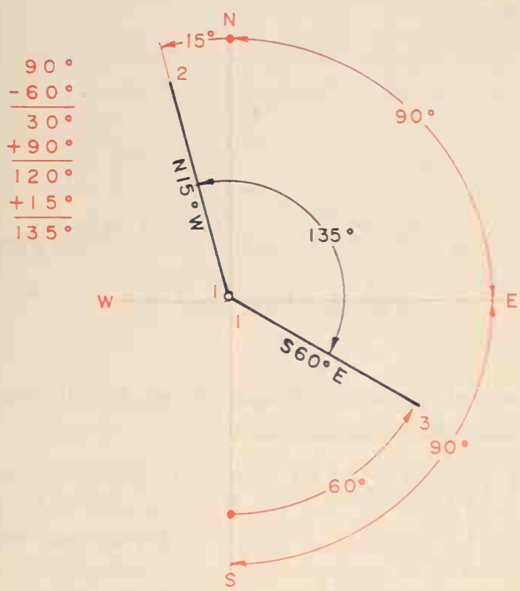


Figure 7-49 How to calculate the angle between headings in three quadrants

How to Construct a Line with a Specified Bearing, Slope Angle, and Length

The bearing is always drawn in the top view, and the true length can be drawn *if* the line is to be *exactly* horizontal. Any line with an incline up (+) or down (−) from the horizon *must* be laid out using the following steps:

Given: The starting point aT and aF of a line with a bearing of N 60° E, with a slope angle of +15°, and 230.0 feet long, Figure 7-52.

Because the line is *not* horizontal and has a slope angle of plus (+) 15°, the true length must be constructed *before* the heading length can be drawn in the top view.

Step 1. In the top view, draw a line starting from aT, at 60° from the north and toward the east.

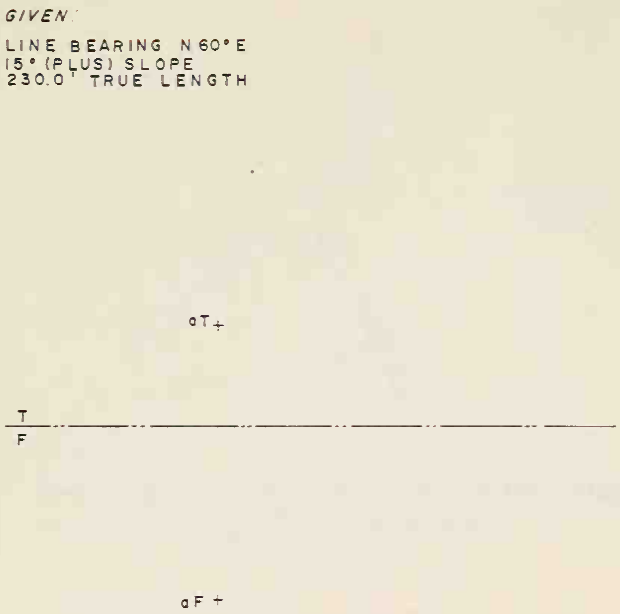


Figure 7-52 Constructing a line with a specified bearing, slope angle, and length

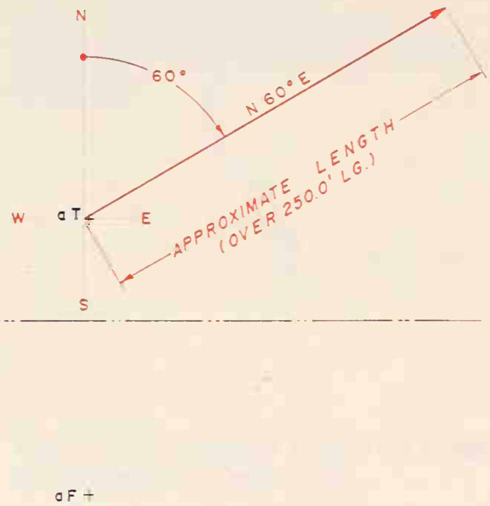


Figure 7-52A Step 1

Figure 7-52A. Temporarily draw the line actually *longer* than the 230.0 feet required.

Step 2. Find the true length of the line by adding a fold line, T/A, *parallel* to the bearing line aT. Project point a into the auxiliary view to find aA, Figure 7-52B, and refer to dimension X. Don't forget to skip-a-view.

From point aA in the auxiliary view, draw a light horizon line *parallel* to the fold line T/A. From point aA, construct a 15° angle *toward* the fold line as shown.

Note: Draw the line *toward* the fold line for a rise (+) and *away* from the fold line for a drop (−) in elevation. Along *this* line measure the true length, 230.0 feet, to establish point bA. Project bA back into the top view to find point bT. Remember, this line is *not* the true length in the top view.

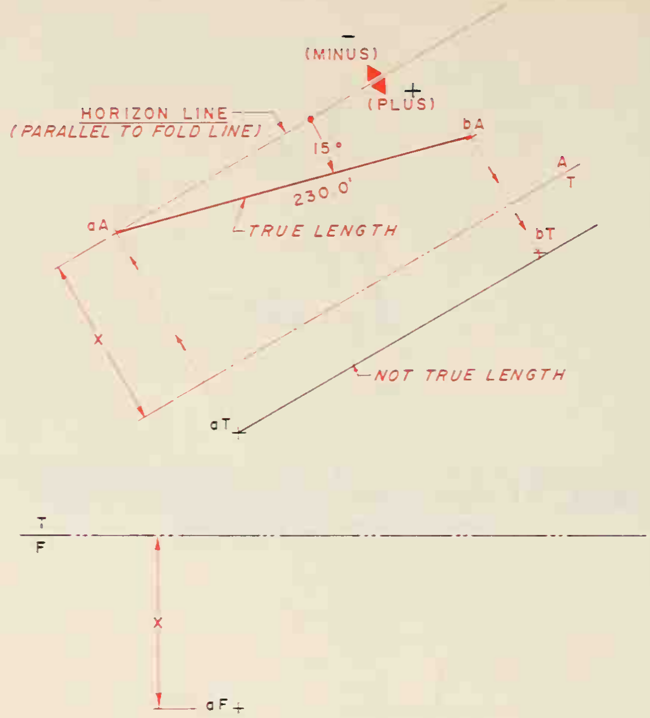


Figure 7-52B Step 2

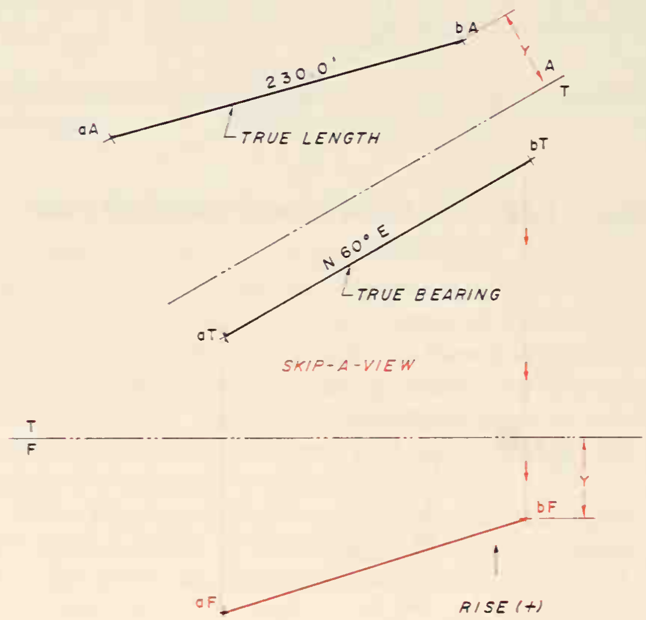


Figure 7-52C Step 3

Step 3. Project point bT down into the front view to find point bF. Use the Y dimension to find point bF, but do not forget to skip-a-view, Figure 7-52C. Construct line aF/bF. Note that the line *rises* from a to b in the front view, which indicates a plus (+) rise.

The true bearing is found in the top view and the true length is found in the auxiliary view. Remember, true length must be found before the other views can be completed.

How to Construct a Line with a Specified Bearing, Percent of Grade, and Length

Approximately the same steps are used in constructing a line with a specified bearing, percent of grade, and length as was used in constructing a line with a specified bearing, slope angle, and length. The bearing is always drawn in the top view, and the true length of the line can be drawn *if* the line is to be *exactly* horizontal. Any line with an incline up (+) or down (−) from the horizon *must* be laid out using the following steps:

Given: The starting point aT and aF of a line with a bearing of N 45° W, with a grade of (−) 40%, and 190.0 feet long, Figure 7-53. Because the line is *not* horizontal and has a grade of minus (−) 40%, the true length must be constructed *before* the bearing length can be drawn in the top view.

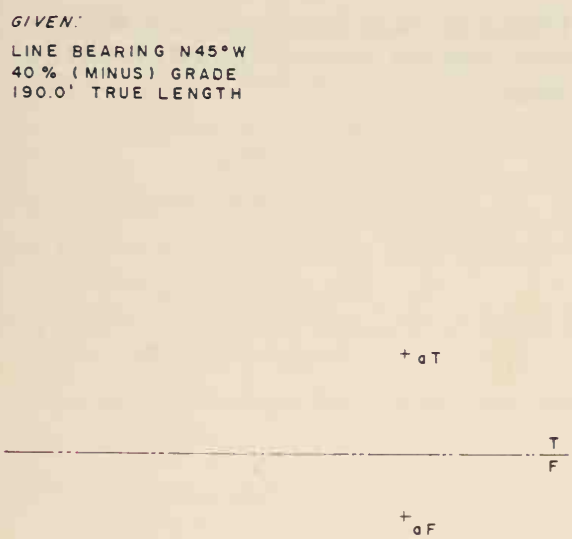


Figure 7-53 Constructing a line with a specified bearing, percent of grade, and length

Step 1. In the top view, draw a line starting from aT, at 45° from the north and toward the west, Figure 7-53A. Temporarily draw the line actually *longer* than the 190.0 feet required.

Step 2. Find the true length of the line by adding a fold line, T/A, *parallel* to the bearing line aT. Project point a into the auxiliary view to find aA, Figure 7-53B, and refer to dimension X. Don't forget to skip-a-view.

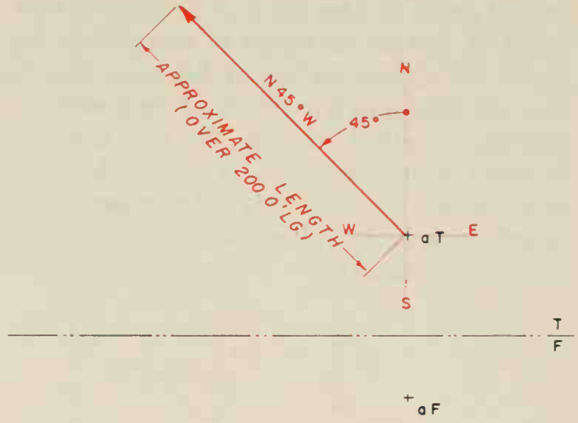


Figure 7-53A Step 1

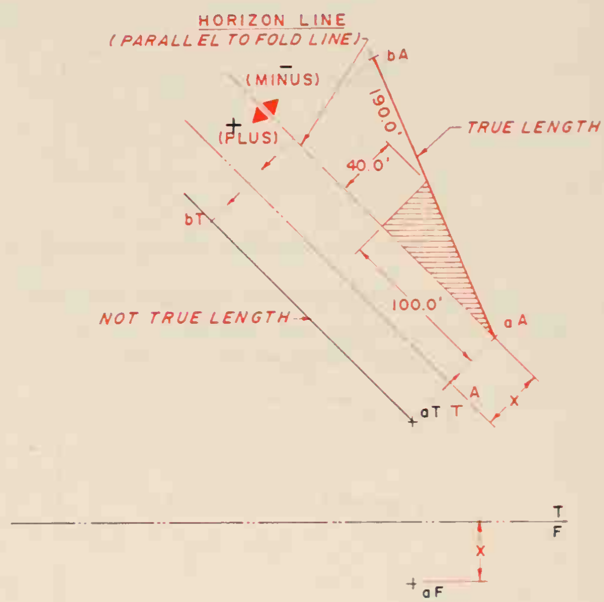


Figure 7-53B Step 2

From point aA in the auxiliary view, draw a light horizon line *parallel* to the fold line T/A. From point aA, and *along* the horizon line, measure 100 units. From this point, turn 90° *away* from the fold line and measure 40 units, and put a point. Construct a line from aA to this new point and *extend* it out to the 190.0 feet true length to find point bA.

Note: Construct the triangle *toward* the fold line for a rise (+) and *away* from the fold line for a drop (−) in elevation. Project bA back into the top view to find point bT. Remember, this line is *not* the true length in the top view.

Step 3. Project point bT down into the front view to find point bF. Use the Y dimension to find point bF, but do not forget to skip-a-view, Figure 7-53C. Construct line aF/bF. Note that the line *falls* from a to b in the front view, which indicates a minus (−) drop. The true bearing is found in the top view and the true length is found in the auxiliary view. Remember, true length must be found before the other views can be completed.

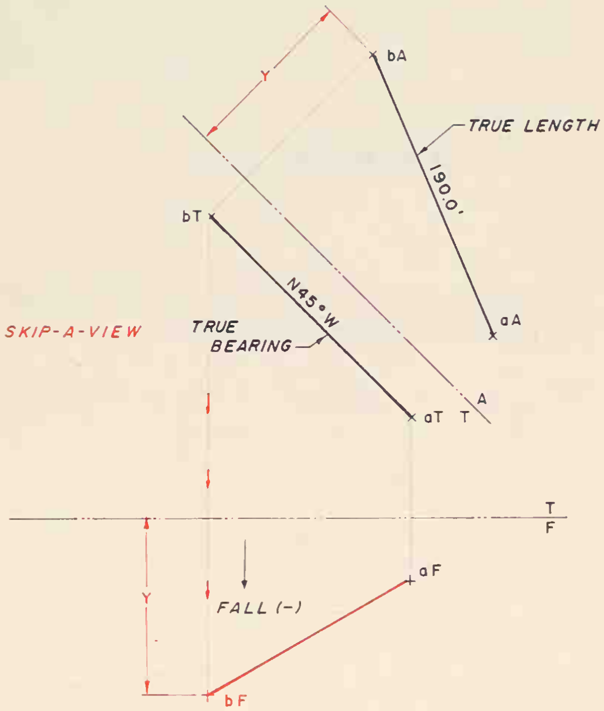


Figure 7-53C Step 3

Review

1. Why is descriptive geometry used by a drafter?
2. Explain the basic steps involved in laying out the true shape of a plane.
3. What are notations and why are they so important?
4. What is a point view of a line?
5. Explain the basic steps involved in laying out the true distance between two parallel lines in space.
6. Explain the basic steps involved in laying out the true distance between two nonparallel lines.
7. What is an edge view?
8. How is a point called-out in a given view?
9. What is an important rule to remember in projecting from one view to another?
10. Explain the basic steps involved to find the true length of any line.
11. What is a fold line and what does it represent?
12. Explain the basic steps involved to find the point view of a line as projected from its true length?

Chapter Seven Problems

The following problems are intended to give the beginning drafter practice in using the various principles of descriptive geometry. Problems 1 through 13 deal with each of the various principles used to solve actual design problems. Problems 14 through 32 apply these principles to develop required views of various objects.

The steps to follow in laying out problems 1 through 13 and 23 through 32 are:

1. On an 8½ x 11 sheet of paper with a sharp 4-H lead, locate all lines, points, and fold lines per the given dimensions.
2. Complete the problem per the given instructions. Project in the direction of the large arrow.

The steps to follow in laying out problems 14 through 27 are:

Step 1. Study the problem carefully.

Step 2. Using the given front view, make a sketch of all required views.

Step 3. Center the required views within the work area with a 1-inch (25-mm) space.

Step 4. Use light projection lines. Do *not* erase them.

Step 5. Lightly complete all views.

Step 6. Check to see that all views are centered within the work area.

Step 7. Check that there is a 1-inch (25-mm) space between all views.

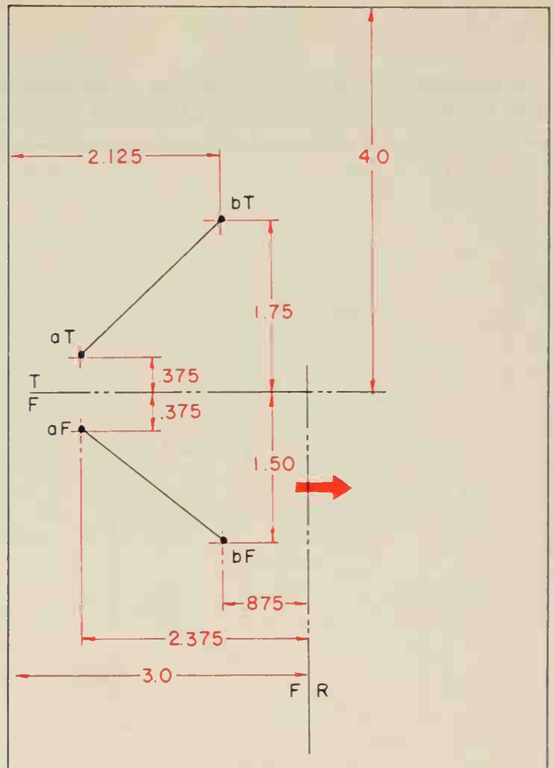
Step 8. Carefully check all dimensions in all views.

Step 9. Darken in all views using correct line thickness.

Step 10. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problem 7-1

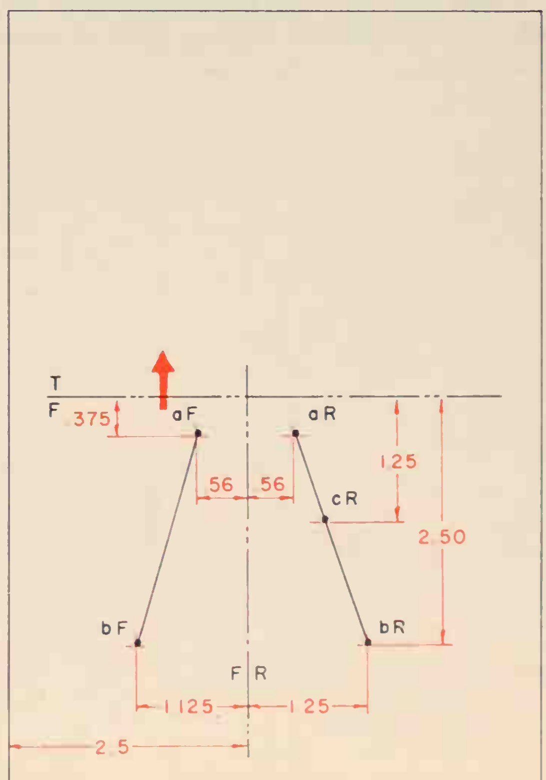
Locate line a-b and fold lines per given dimensions. Locate line a-b in the right-side view. Label all points in all views.



Problem 7-1

Problem 7-2

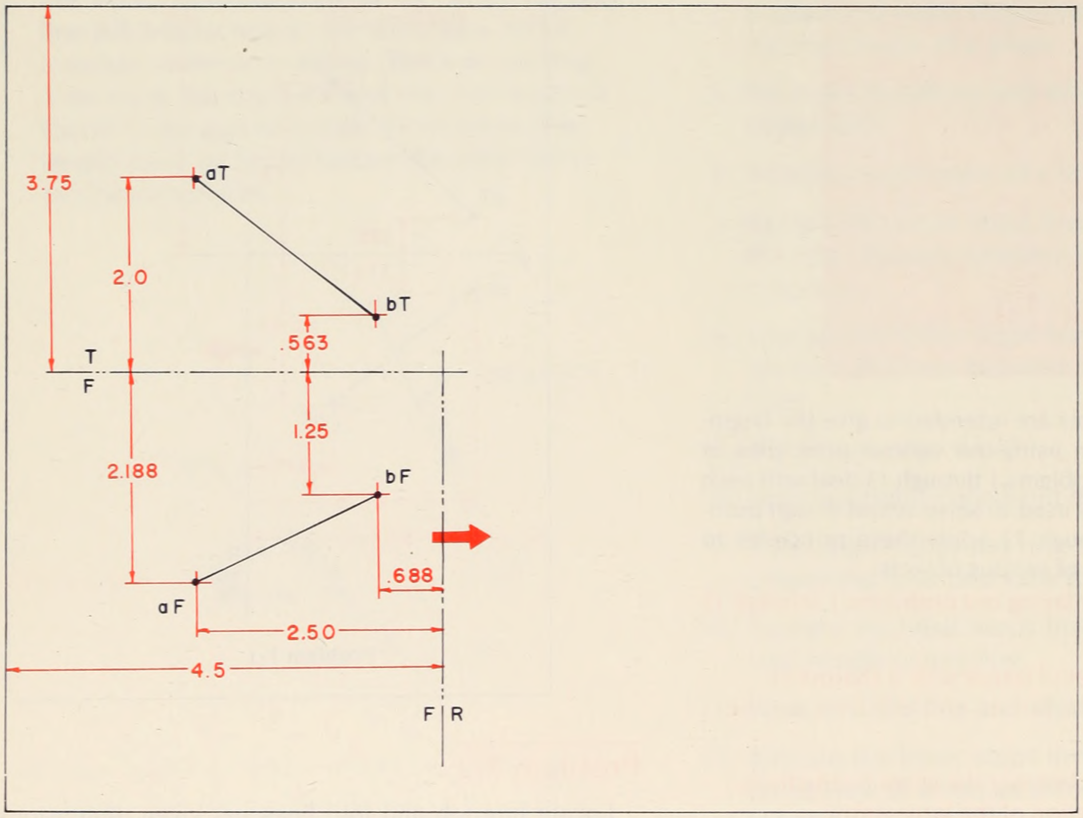
Locate line a-b and fold lines per given dimensions. Locate line a-b in the top view. Locate point c on line a-b in all views. Label all points in all views.



Problem 7-2

Problem 7-3

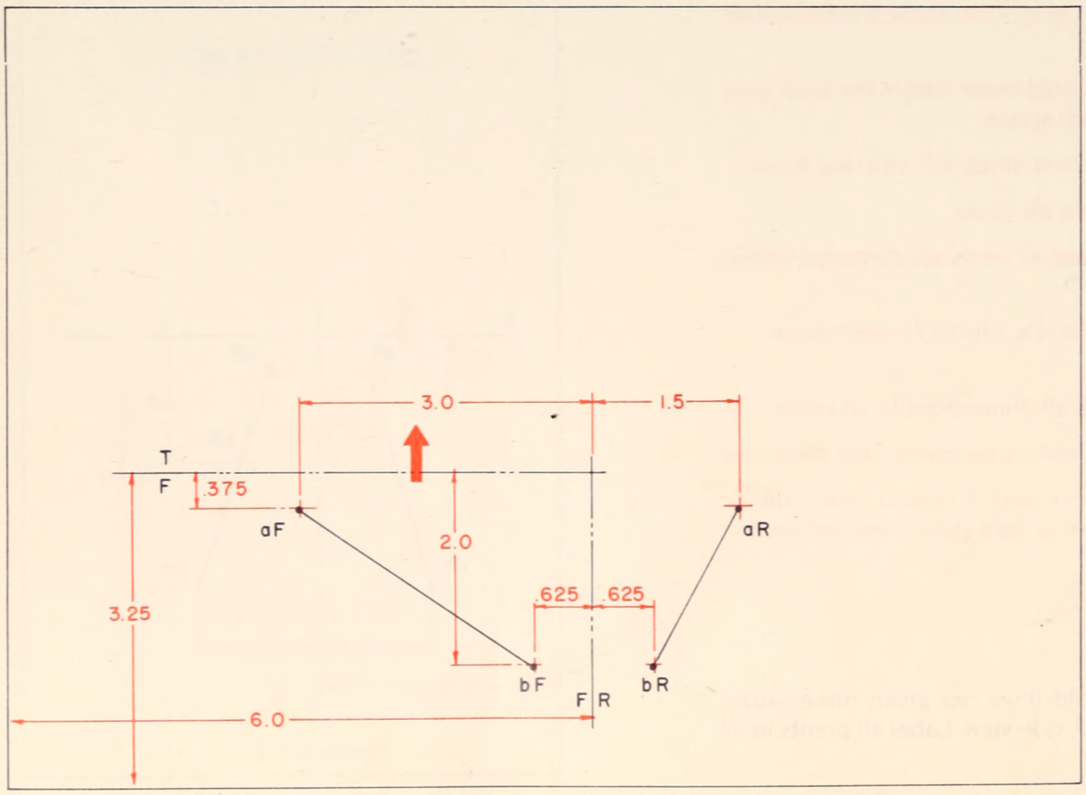
Locate line a-b and fold lines per given dimensions. Locate line a-b in the right view. Find the true length of line a-b, projecting from the right side. Label all points in all views.



Problem 7-3

Problem 7-4

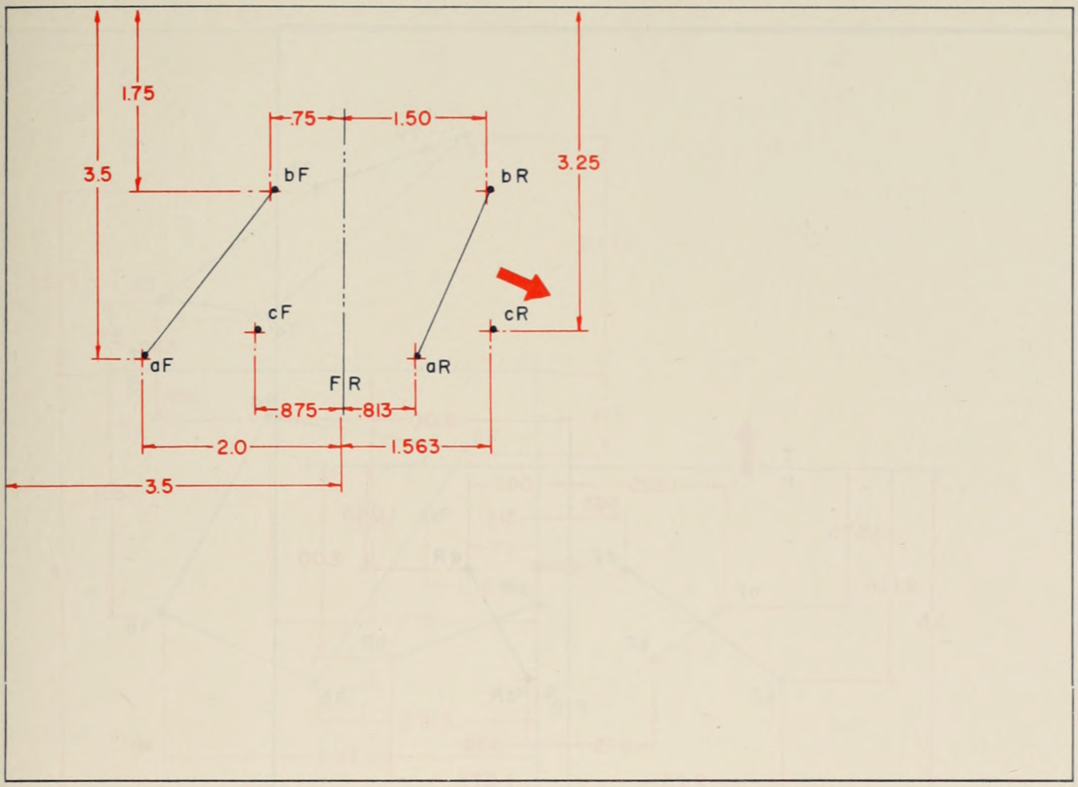
Locate the line a-b and fold lines per given dimensions. Locate line a-b in the top view. Find the point view of line a-b, projecting from the top view. Label all points in all views.



Problem 7-4

Problem 7-5

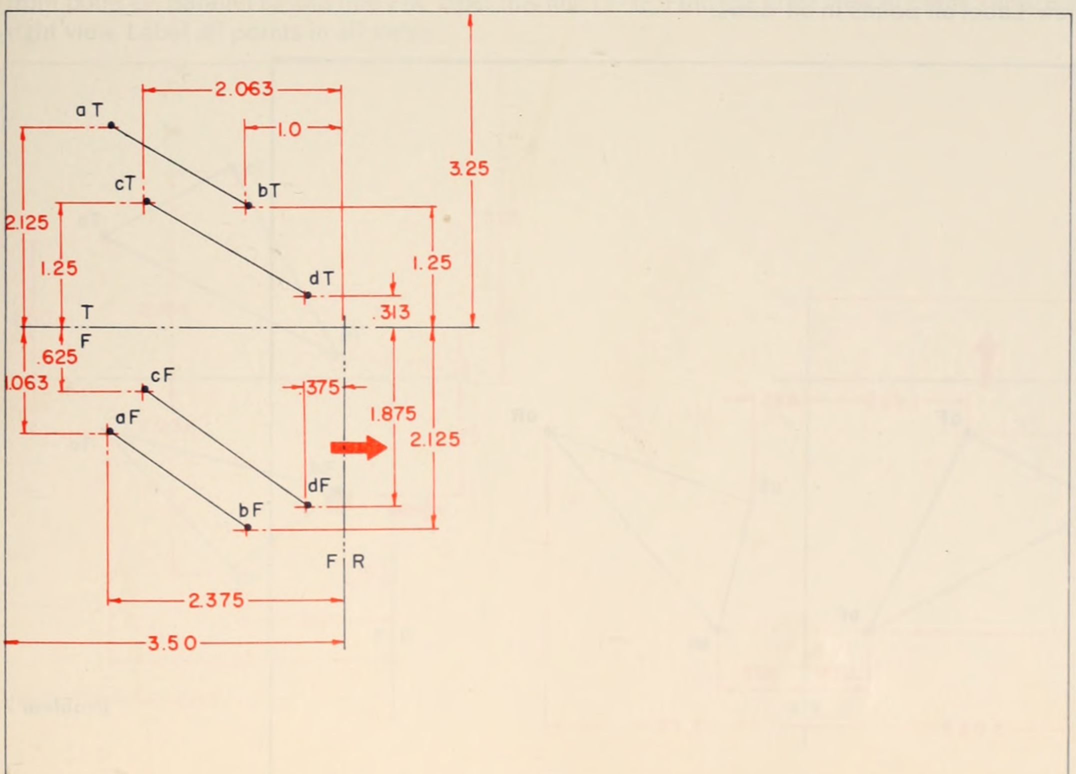
Locate line a-b, point c, and fold lines per given dimensions. Find the true distance from line a-b to point c. Project from the right view. Label all points in all views.



Problem 7-5

Problem 7-6

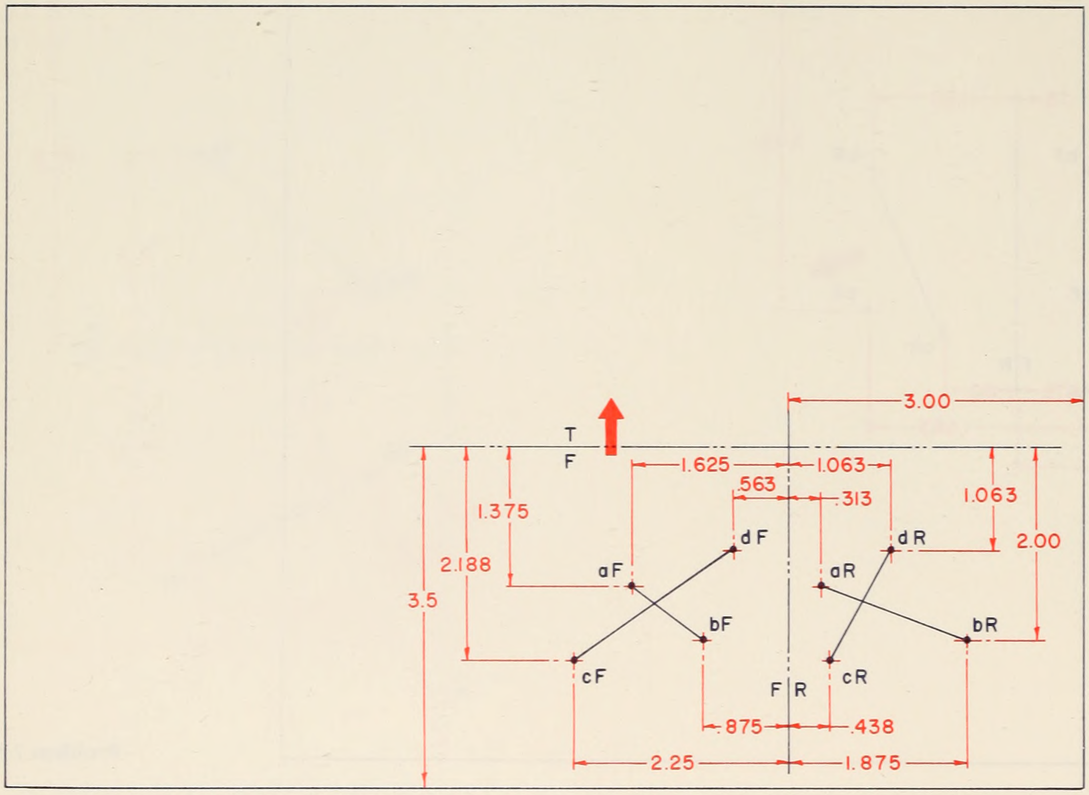
Locate parallel lines a-b and c-d, and fold lines per given dimensions. Find the true distance between lines a-b and c-d. Project from the front view. Label all points in all views.



Problem 7-6

Problem 7-7

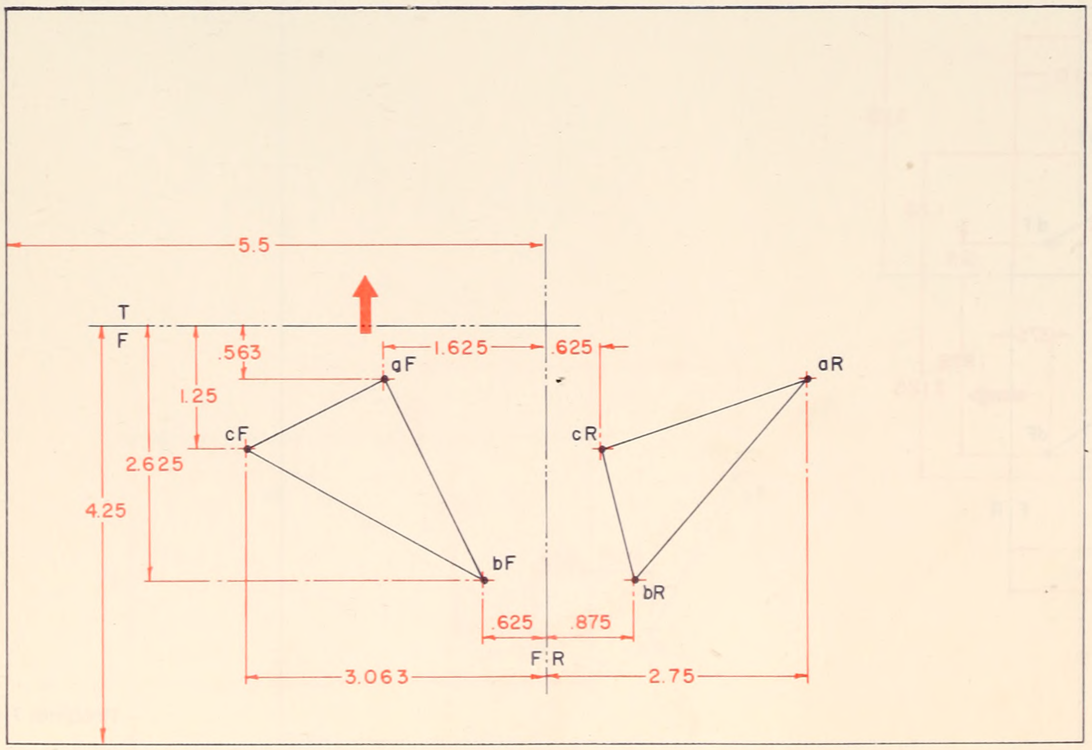
Locate lines a-b and c-d, and fold lines per given dimensions. Find the true distance between lines a-b and c-d. Project from the top view. Label all points in all views.



Problem 7-7

Problem 7-8

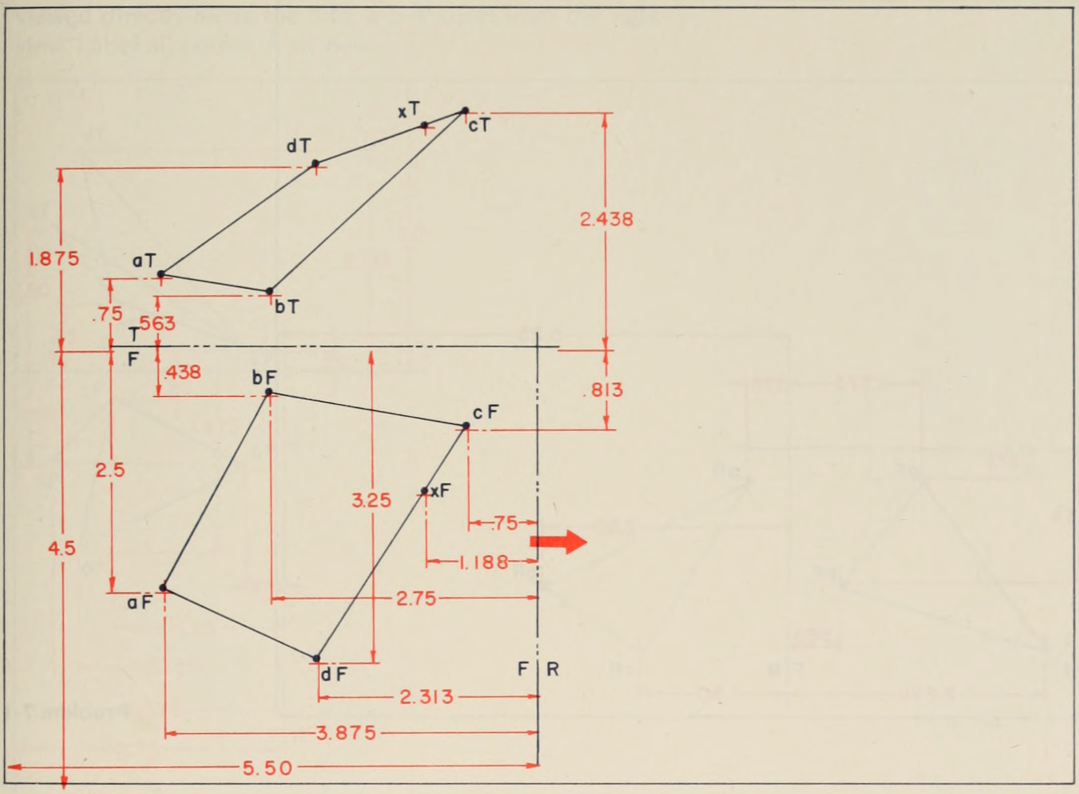
Locate points a, b, and c, and fold lines per given dimensions. Connect points a, b, and c to form a plane. Project plane abc into the top view. Label all points in all views.



Problem 7-8

Problem 7-9

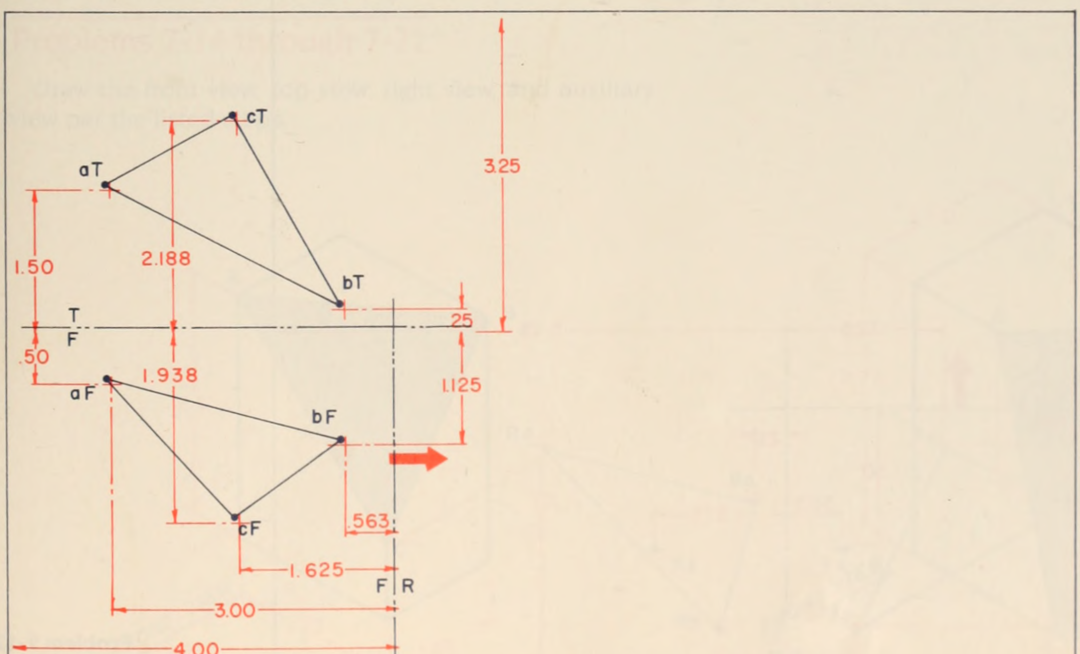
Locate points a, b, c, and d, point x, and fold lines per given dimensions. Connect points a, b, c, and d to form a plane. Project plane abcd into the right view; locate point x in all views. Label all points in all views.



Problem 7-9

Problem 7-10

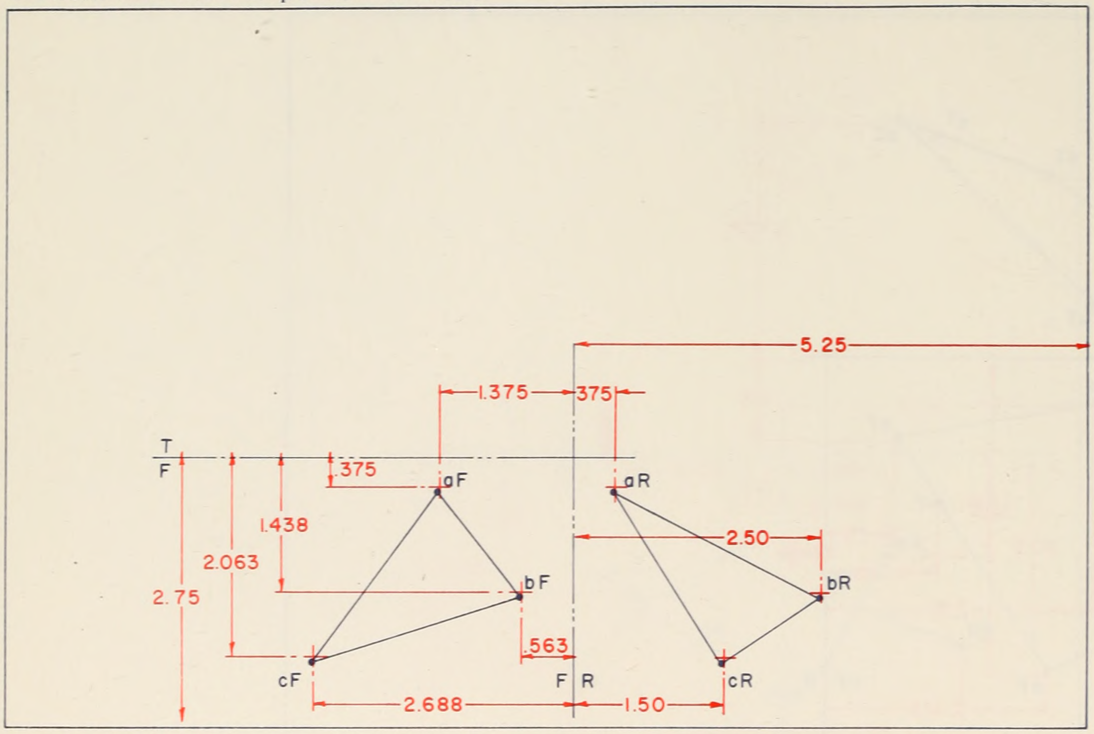
Locate points a, b, c, and fold lines per given dimensions. Connect points a, b, and c to form a plane. Draw a line from point cF, parallel to fold line F-R; label this line cF-xF. Find the edge view of plane surface abc. Project from the right view. Label all points in all views.



Problem 7-10

Problem 7-11

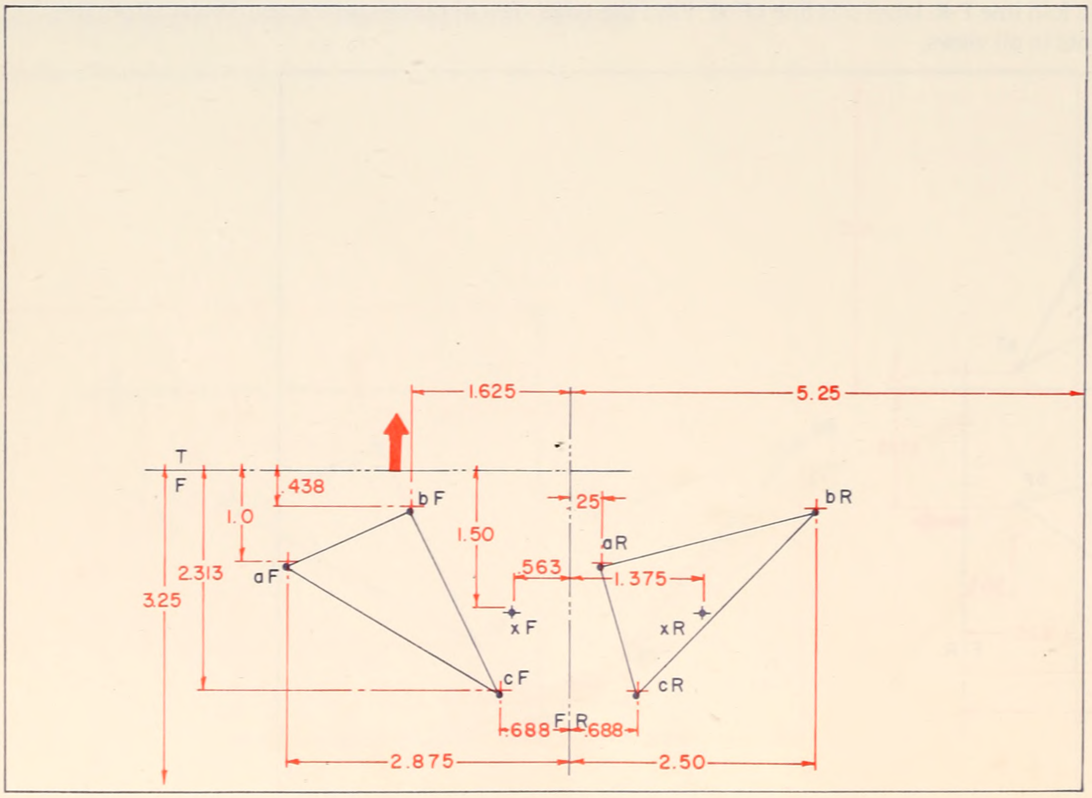
Locate points a, b, and c, and fold lines per given dimensions. Connect points a, b, and c to form a plane. Draw a line from point bF, parallel to fold line F-T; label this line bF-xF. Find the edge view of the plane abc and project from the front view. Label all points in all views.



Problem 7-11

Problem 7-12

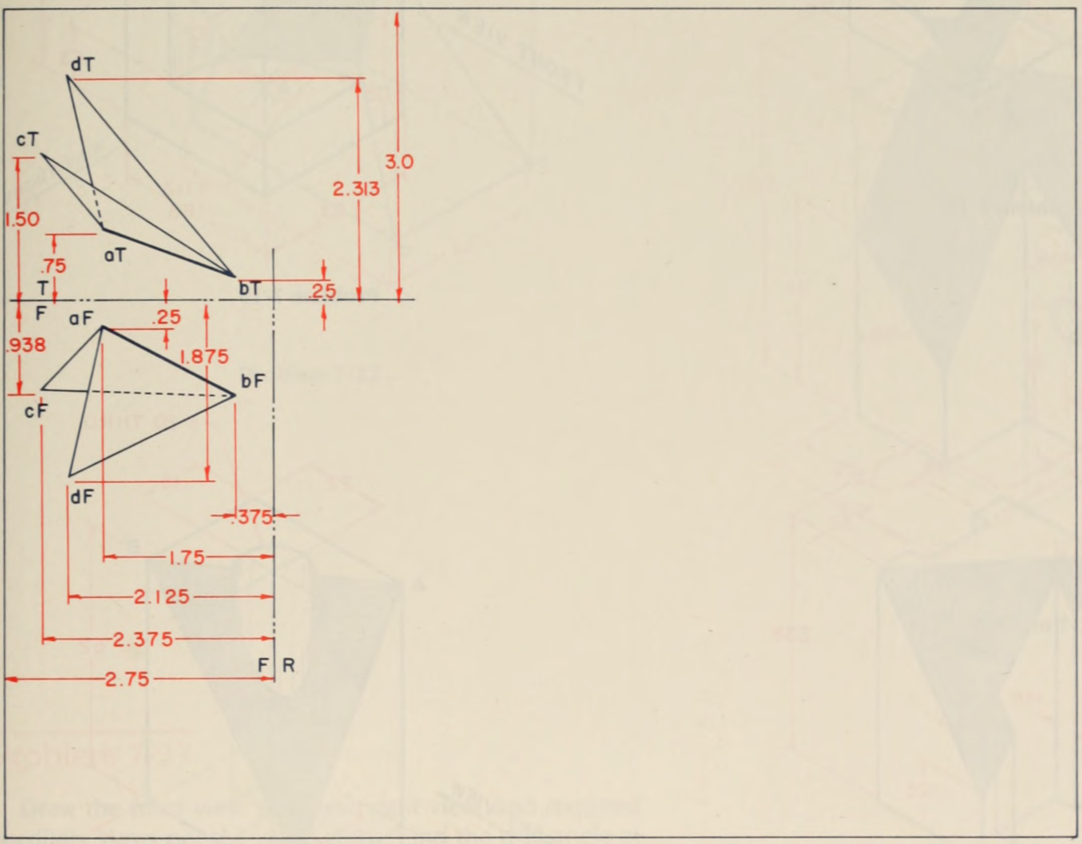
Locate points a, b, and c, point x, and fold lines per given dimensions. Connect points a, b, and c to form a plane. Find the true distance between plane surface abc, and point x. Project from the front view. Label all points in all views.



Problem 7-12

Problem 7-13

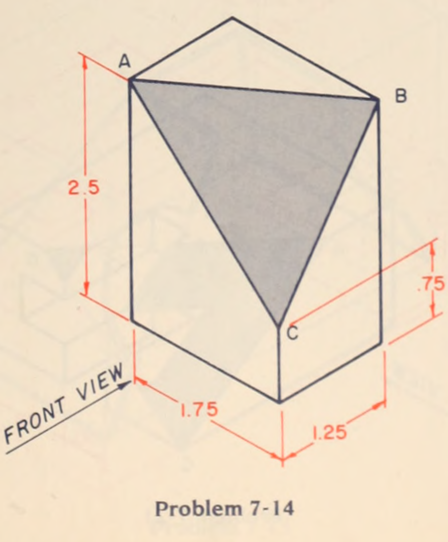
Locate points a, b, c, and d, and fold lines per given dimensions. Connect points a, b, c, and d to form a folded object. Find the true angle between the plane surfaces as viewed directly along the fold, a-b. Project from the right view. Label all points in all views.



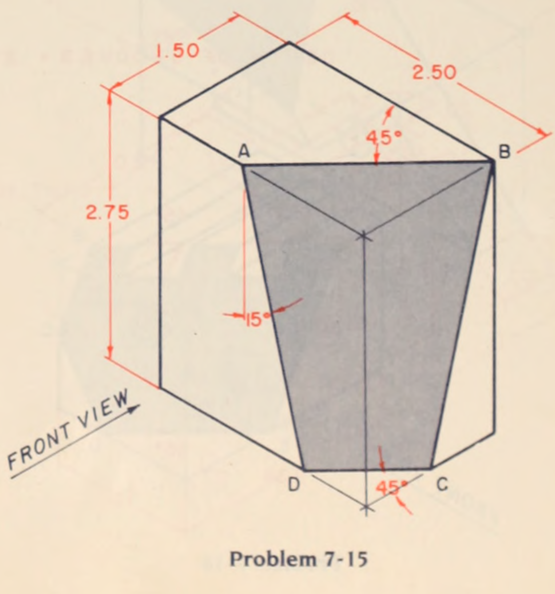
Problem 7-13

Problems 7-14 through 7-22

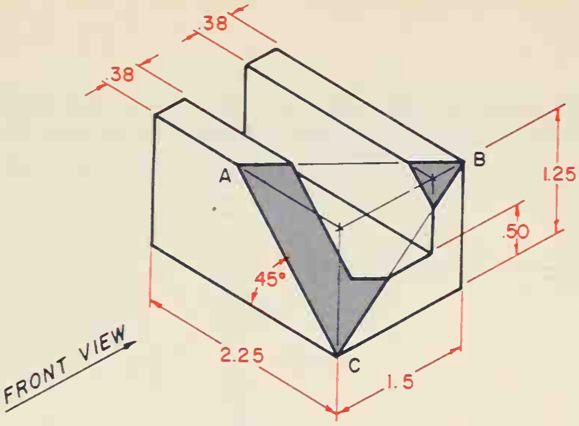
Draw the front view, top view, right view, and auxiliary view per the listed steps.



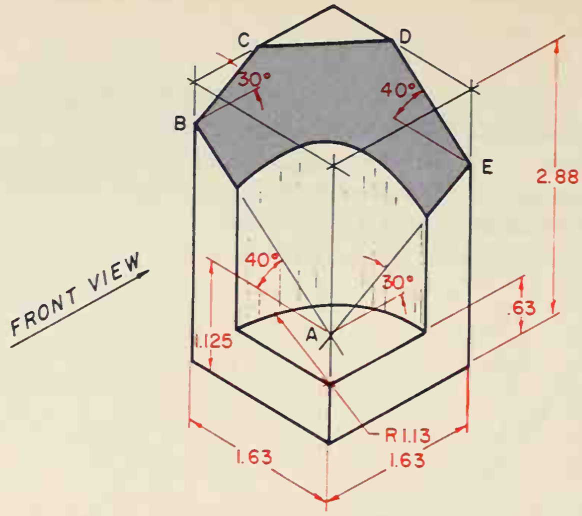
Problem 7-14



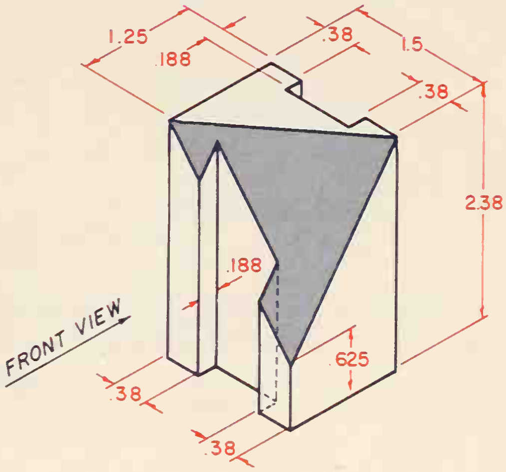
Problem 7-15



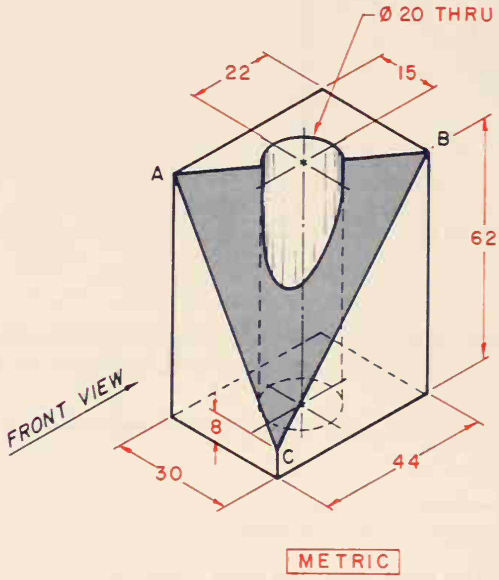
Problem 7-16



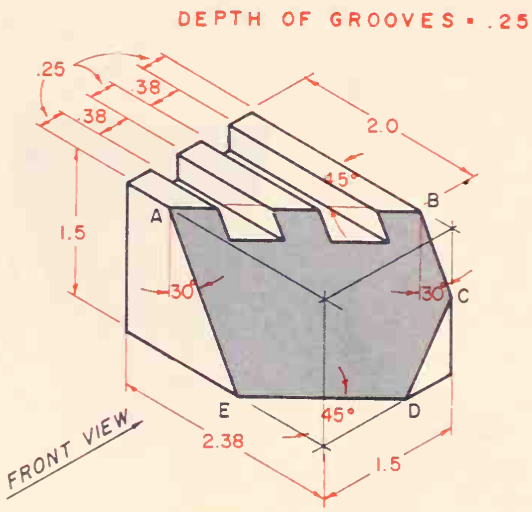
Problem 7-19



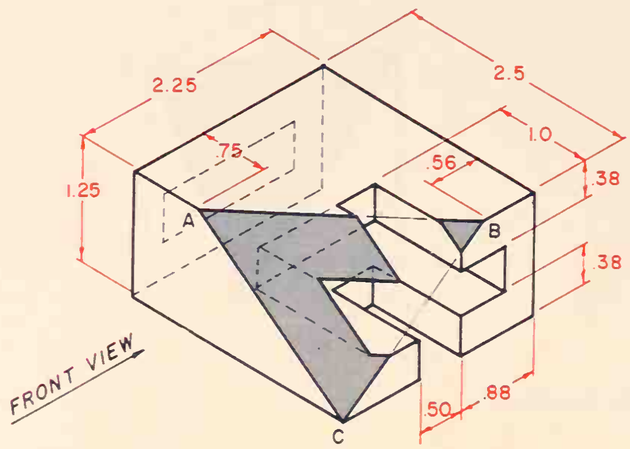
Problem 7-17



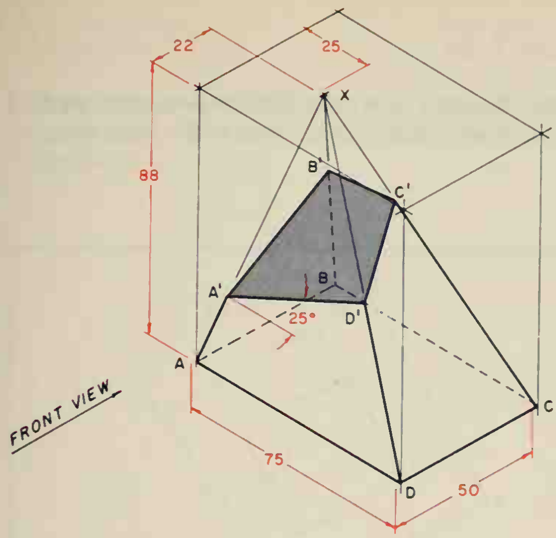
Problem 7-20



Problem 7-18



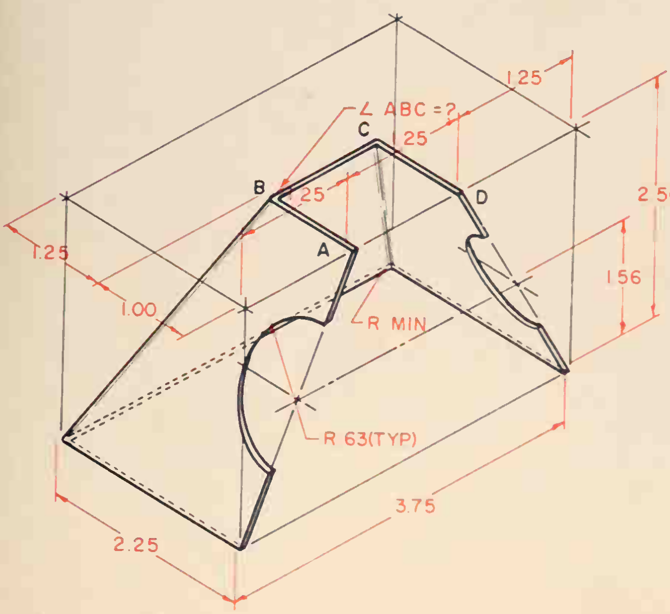
Problem 7-21



Problem 7-22

Problem 7-23

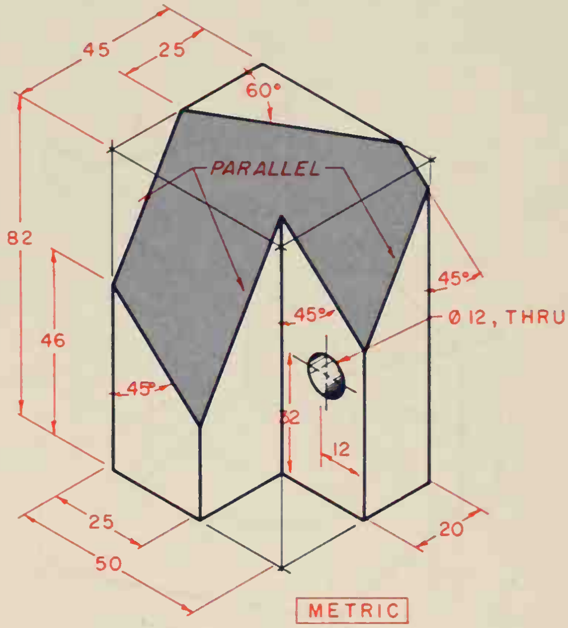
Draw the front view, top view, right view, and required auxiliary views per the listed steps. Find the true angle at abc, as viewed along the fold.



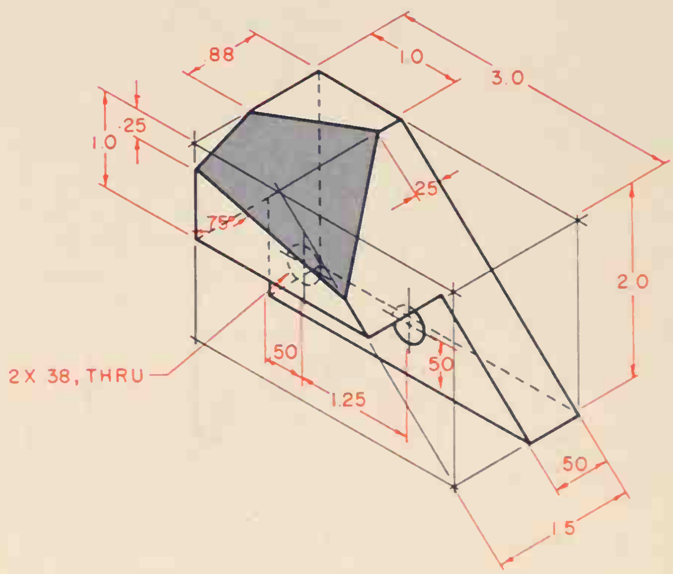
Problem 7-23

Problems 7-24 and 7-25

Draw the front view, top view, right view, and auxiliary view per the listed steps.



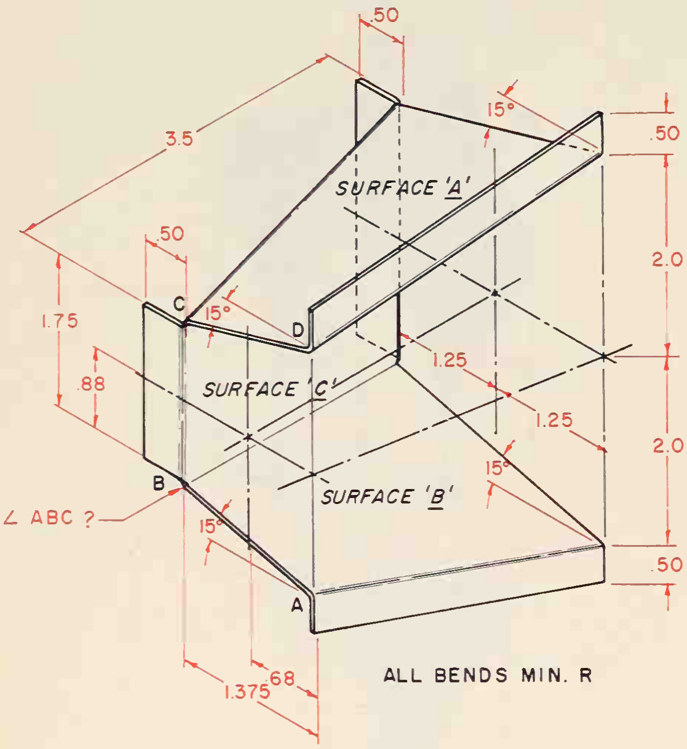
Problem 7-24



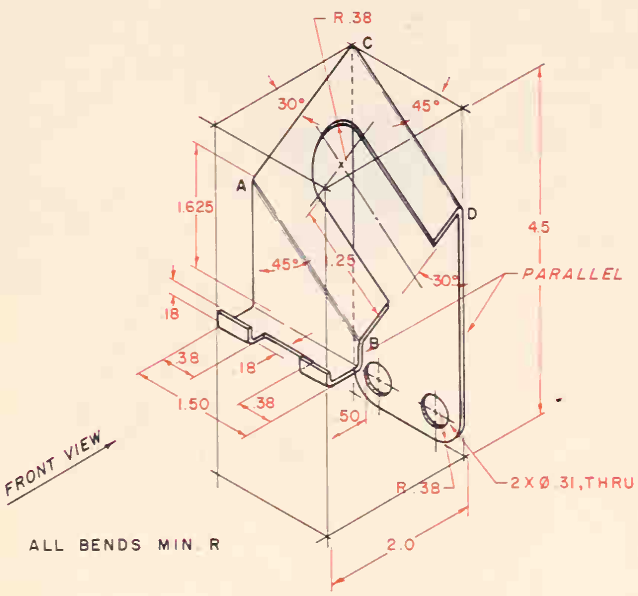
Problem 7-25

Problems 7-26 and 7-27

Draw the front view, top view, right view, and required auxiliary views per the listed steps. Find the true angle between the various surfaces as viewed along the fold.



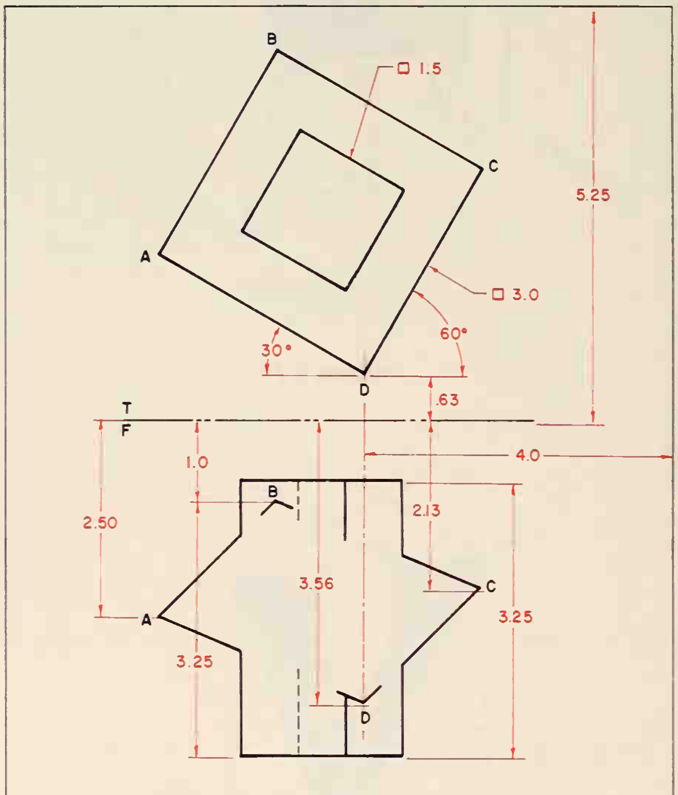
Problem 7-26



Problem 7-27

Problem 7-28

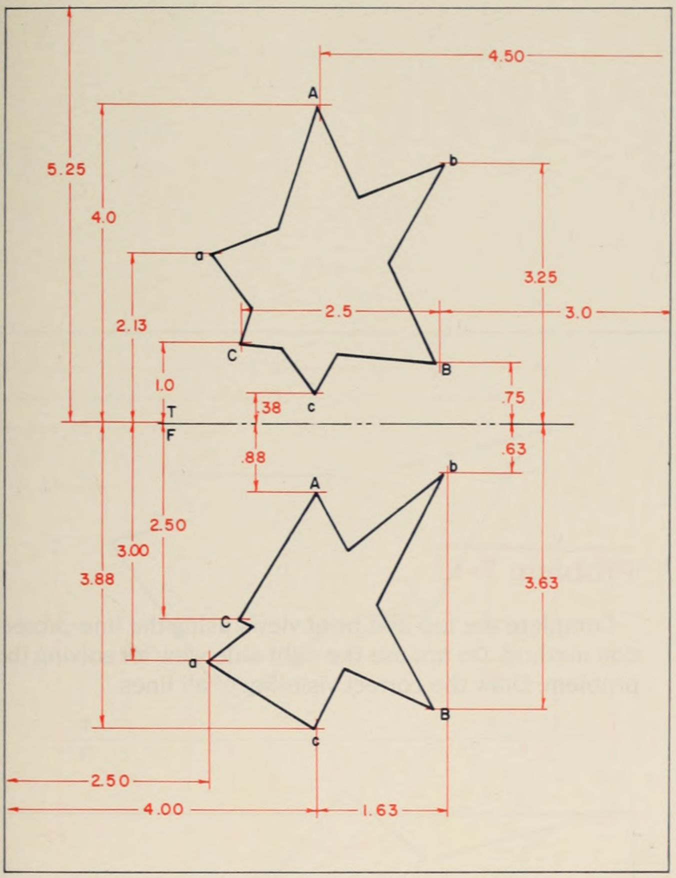
Complete the front view using the line-projection method. Draw the correct visibility of all lines in the front view.



Problem 7-28

Problem 7-29

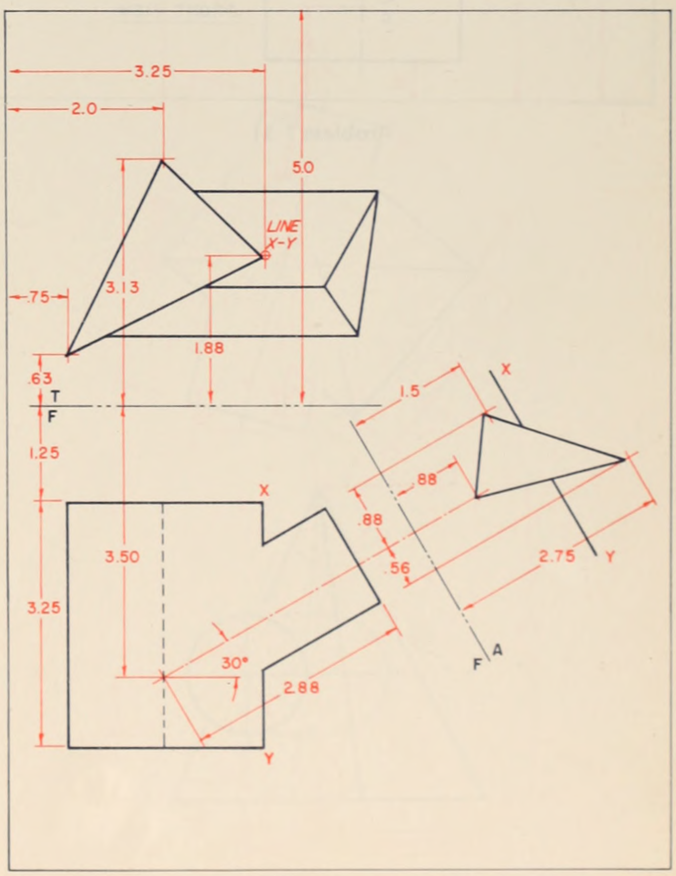
Complete the top and front views using the line-projection method. Draw the correct visibility of all lines by inspection.



Problem 7-29

Problem 7-30

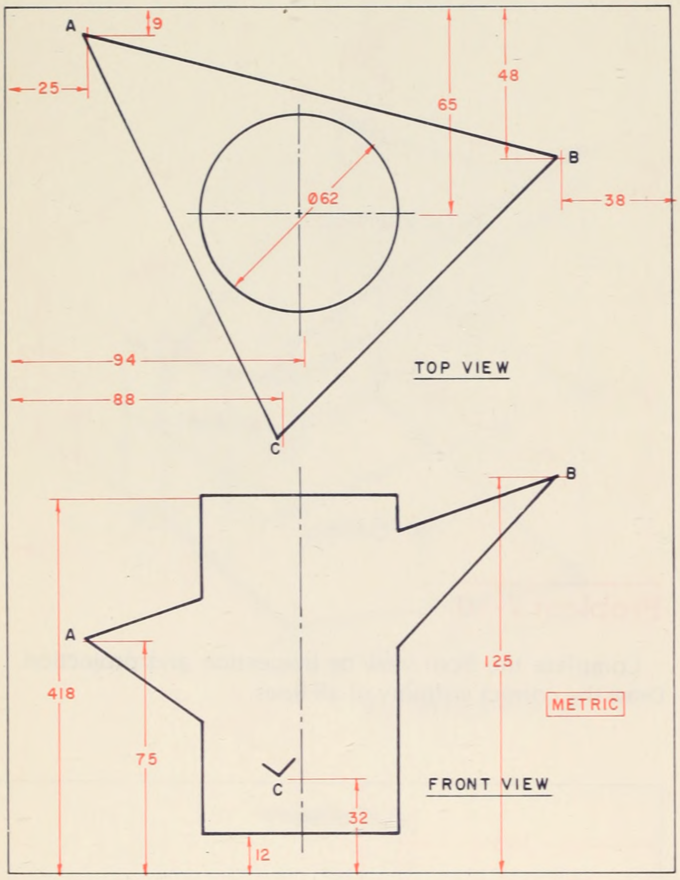
Complete the front view by inspection and projection. Draw the correct visibility of all lines.



Problem 7-30

Problem 7-31

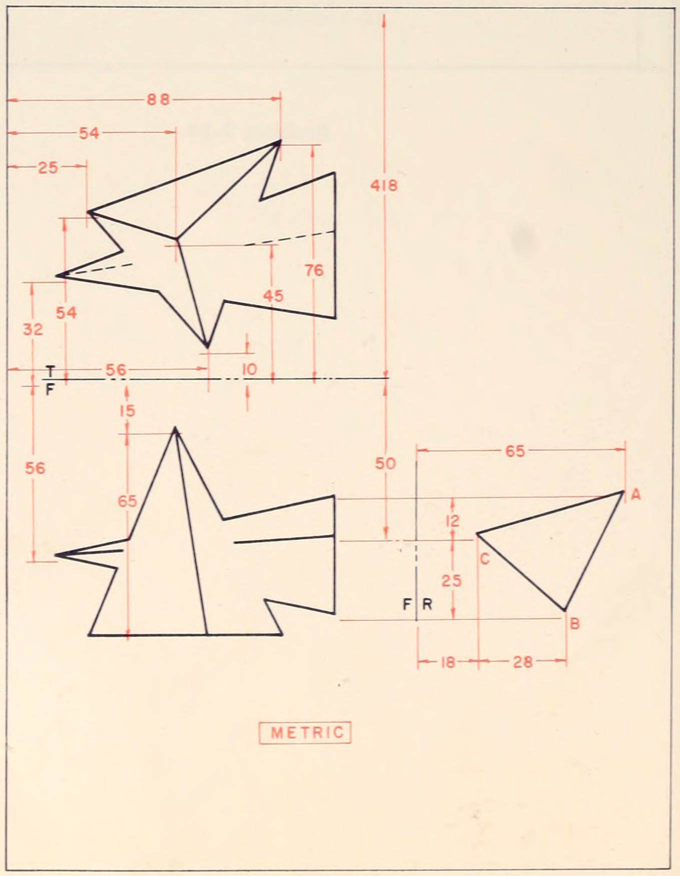
Complete the front view using the line-projection method. Draw the correct visibility of all lines.



Problem 7-31

Problem 7-32

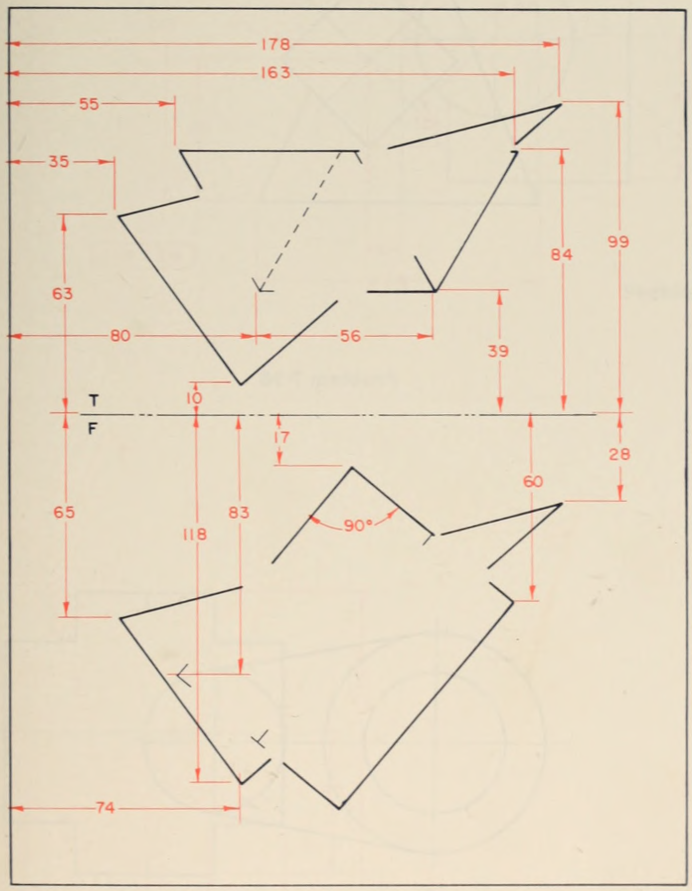
Complete the top and front views using the line-projection method. Do not use the right-side view for solving the problem. Draw the correct visibility of all lines.



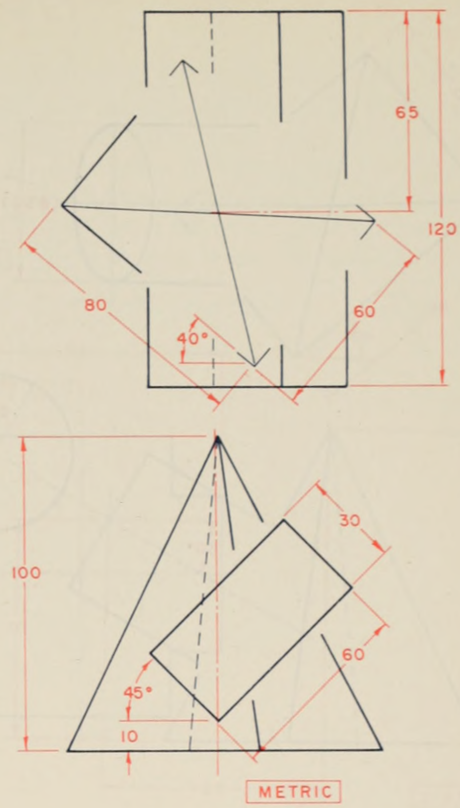
Problem 7-32

Problems 7-33 through 7-42

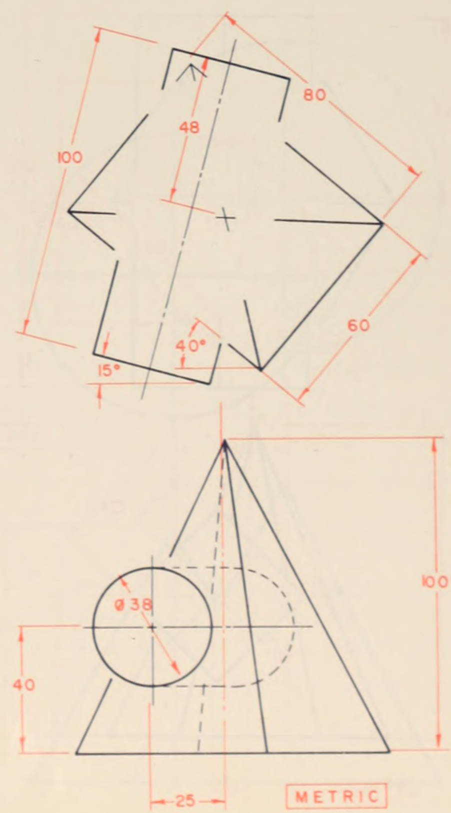
Lightly lay out and draw the two views and the fold line on an A size sheet of vellum using the given dimensions. Complete all views using correct line thickness—add all hidden lines.



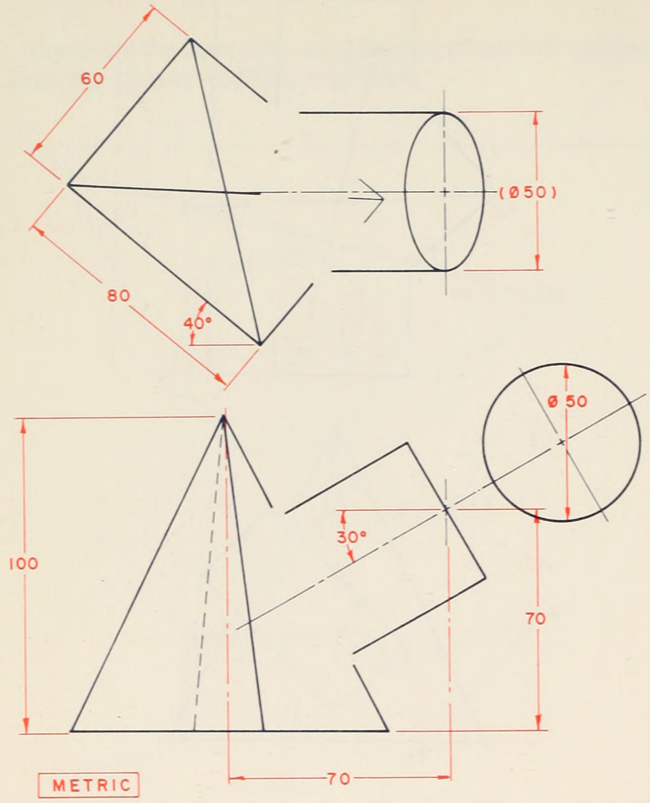
Problem 7-33



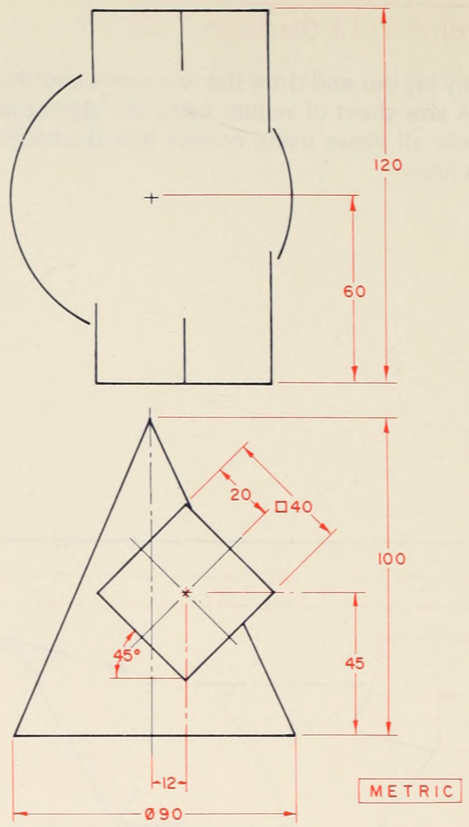
Problem 7-34



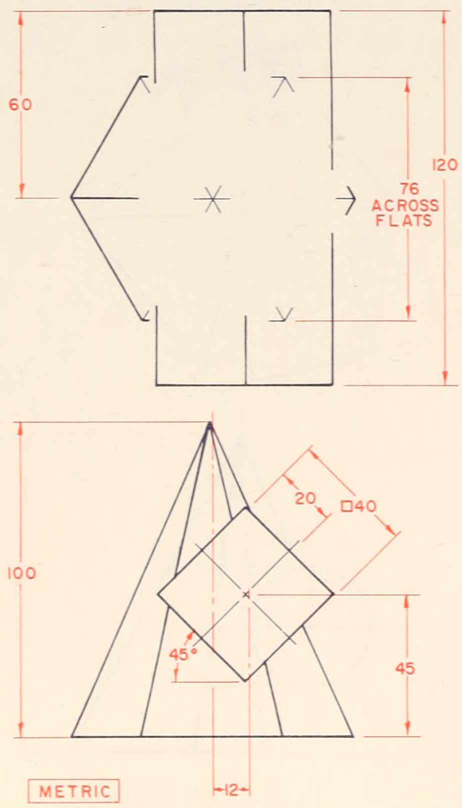
Problem 7-35



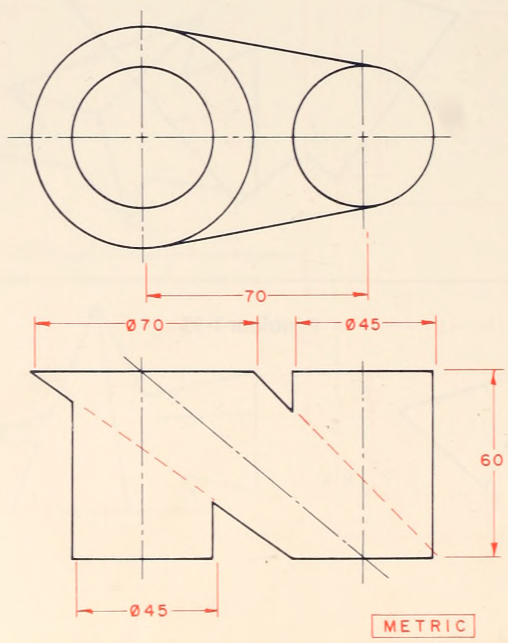
Problem 7-36



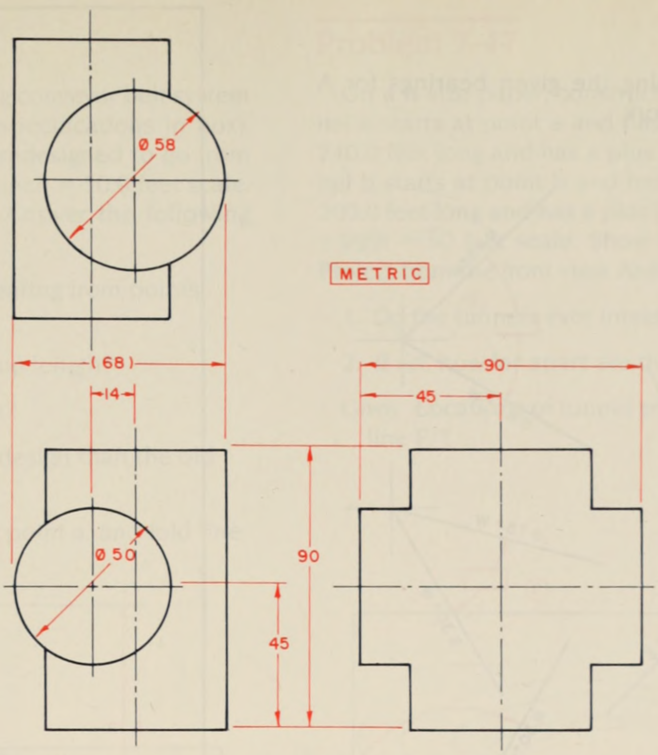
Problem 7-38



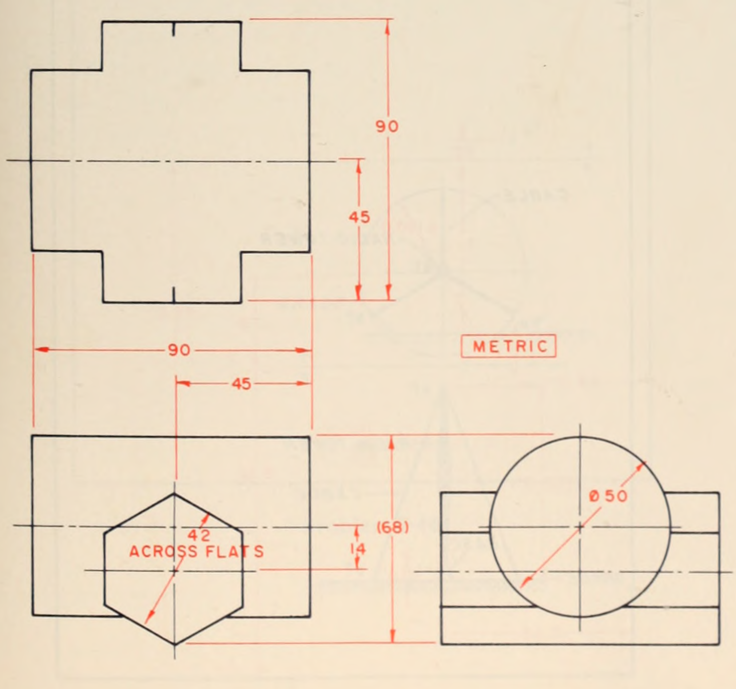
Problem 7-37



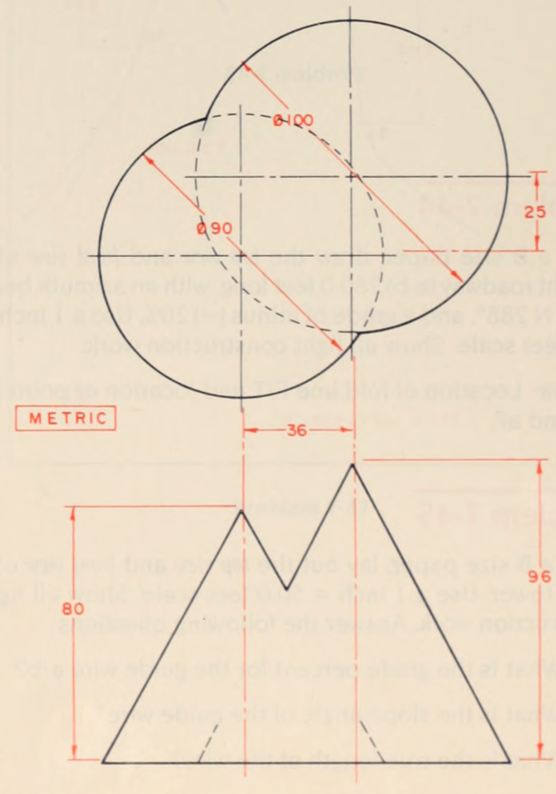
Problem 7-39



Problem 7-40



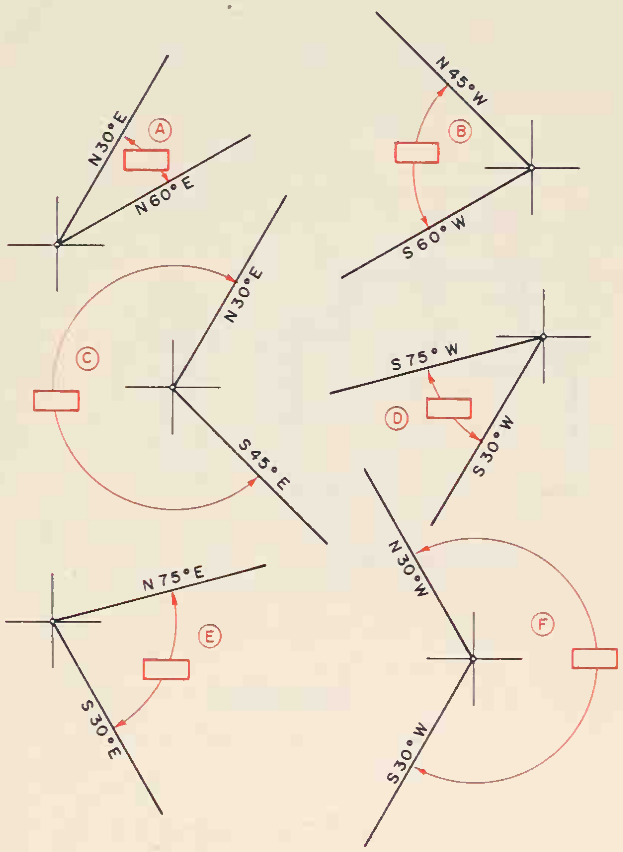
Problem 7-41



Problem 7-42

Problem 7-43

Calculate the angles using the given bearings for A through F. Show all math work.



Problem 7-43

Problem 7-44

On a B size paper, draw the *top view* and *front view* of a straight roadway (a-b) 280.0 feet long, with an azimuth bearing of N 288°, and a grade of minus (−) 20%. Use a 1 inch = 50.0 feet scale. Show all light construction work.

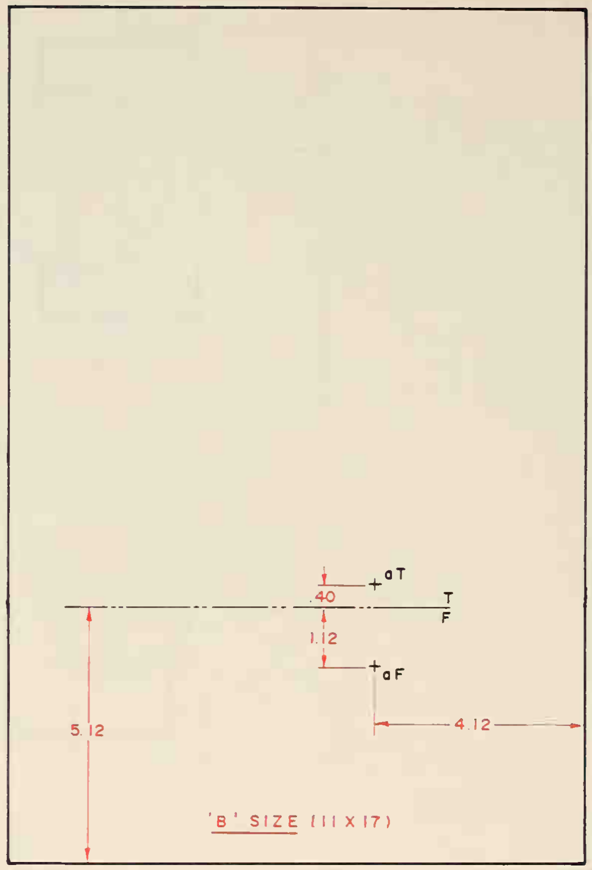
Given: Location of fold line F/T and location of point aT and aF.

Problem 7-45

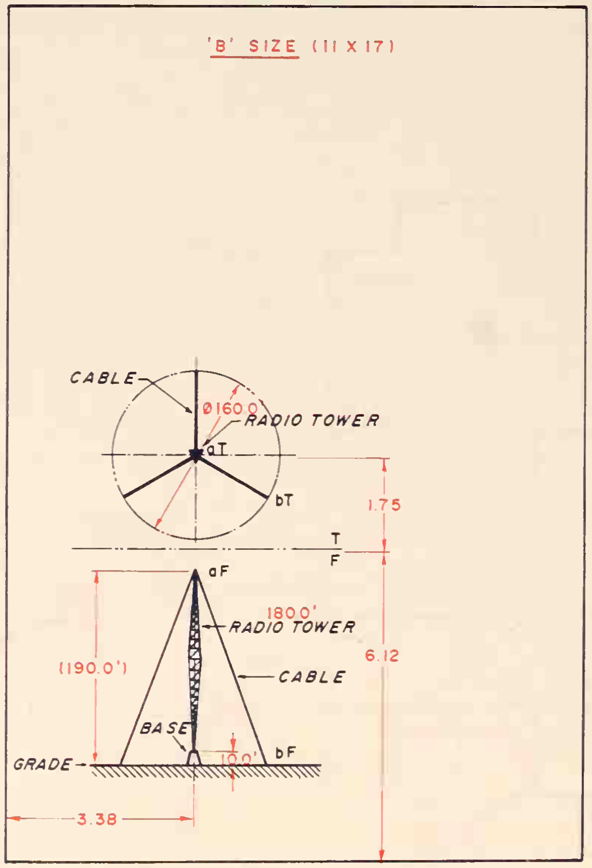
On a B size paper, lay out the *top view* and *front view* of a radio tower. Use a 1 inch = 50.0 feet scale. Show all light construction work. Answer the following questions:

1. What is the grade percent for the guide wire a/b?
2. What is the slope angle of the guide wire?
3. What is the true length of the wire?

Given: Location of the radio tower, guide wires, and fold line F/T.



Problem 7-44



Problem 7-45

Problem 7-46

On a B size paper, draw an existing conveyor belt system with the given specifications (see specifications in box). The conveyor belt system is to be redesigned to go from point a directly to point d. Use a 1 inch = 50.0 feet scale. Show all light construction work. Answer the following questions:

1. What is the new redesigned bearing from points a to d?
2. What is the new redesigned true length?
3. What is the new grade percent?
4. How much shorter is the new design than the old design?

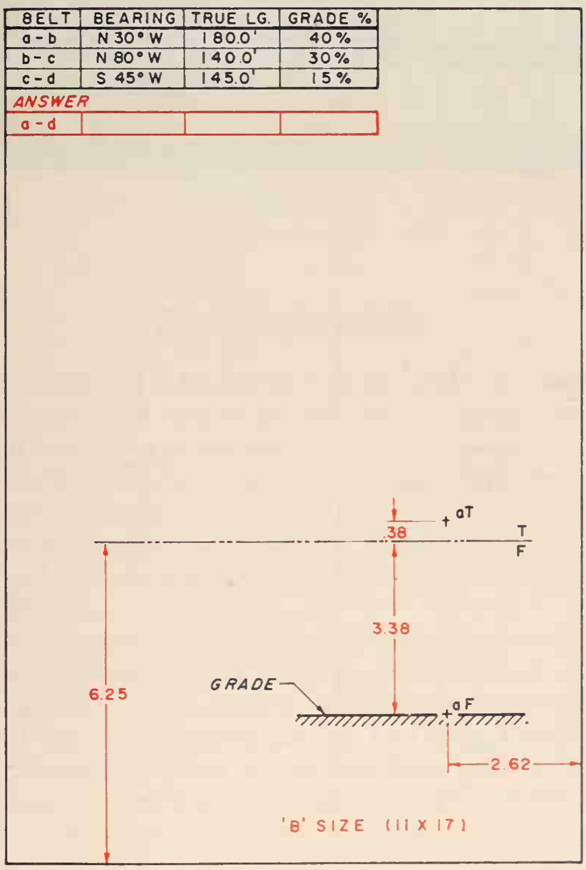
Given: Location of grade, starting point a, and fold line F/T.

Problem 7-47

On a B size paper, construct two tunnels, a and b. Tunnel a starts at point a and has a bearing of N 70° W. It is 240.0 feet long and has a plus (+) slope angle of 34°. Tunnel b starts at point b and has a bearing of N 60° E. It is 200.0 feet long and has a plus (+) slope angle of 19°. Use a 1 inch = 50 feet scale. Show all light construction work. Project from the front view. Answer the following questions:

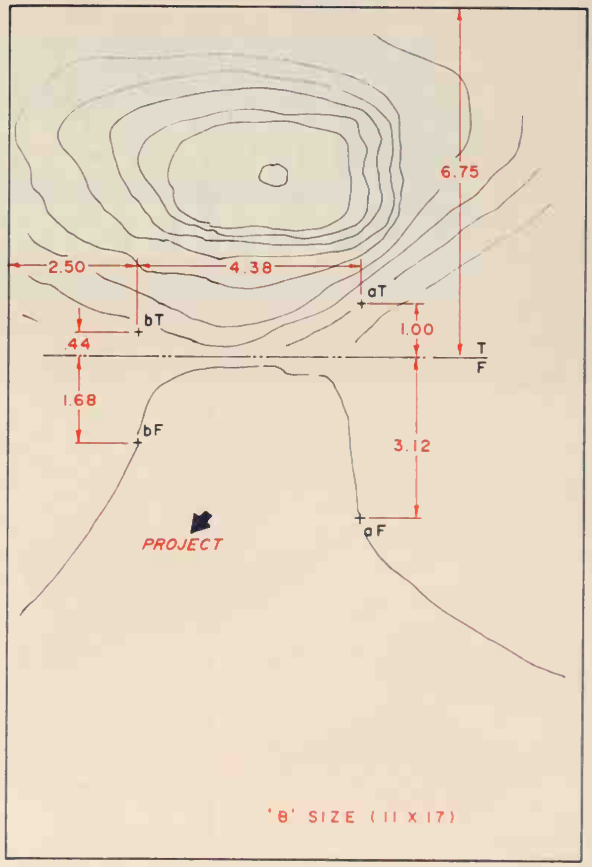
1. Do the tunnels ever intersect?
2. If *not*, how far apart are they?

Given: Locations of tunnel entrances a and b and fold line F/T.



BELT	BEARING	TRUE LG.	GRADE %
a - b	N 30° W	180.0'	40 %
b - c	N 80° W	140.0'	30 %
c - d	S 45° W	145.0'	15 %
ANSWER			
a - d			

Problem 7-46



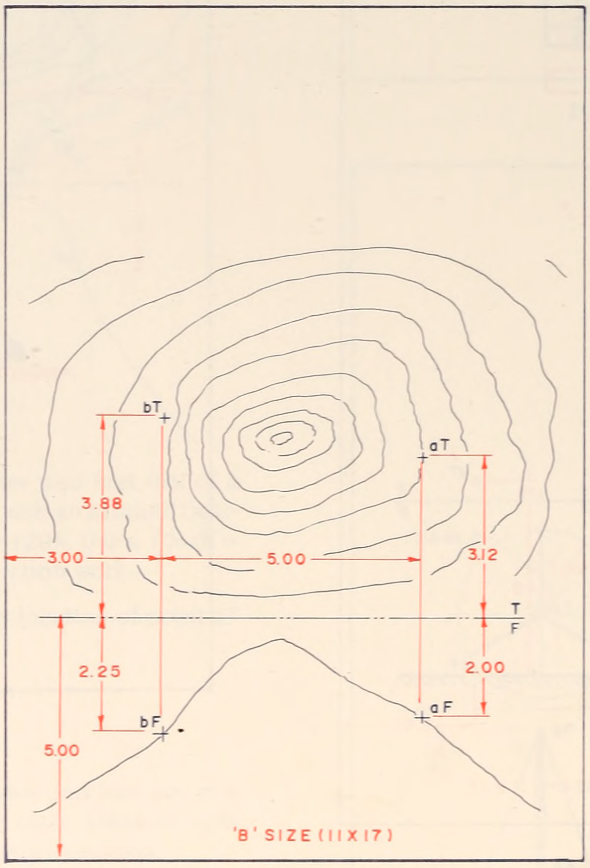
Problem 7-47

Problem 7-48

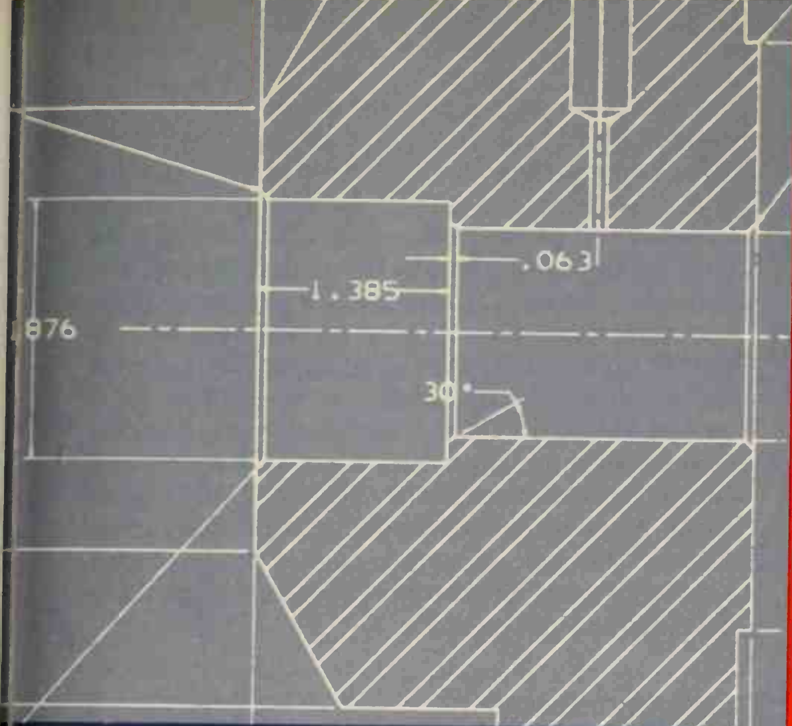
On a B size paper, construct two mining shafts into a mountain from two different directions and elevations. Both are cut straight into the mountain at different percents of grades. One shaft starts at point a and the other starts at point b. Shaft a has a bearing of S 60° W, with a grade of plus (+) 35%, and is 165.0 feet long. Shaft b has a bearing of S 45° E, with a grade of plus (+) 40%, and is 176.0 feet long. Use a 1 inch = 50.0 feet scale. Show all light construction work. Answer the following questions:

1. Do the shafts intersect?
2. What is the true distance from the entrance of shaft a to the entrance of shaft b?
3. What is the bearing and percent of grade from the two entrances?

Given: Locations of the shaft entrances a and b, fold line F/T, and mountain.



Problem 7-48



CHAPTER 8

The methods and techniques learned in Chapters 3, 4, 6 and 7 are used in solving sheet metal development problems. This chapter gives the student an opportunity to learn the use of parallel line, radial line, and triangulation developments. Laps, seams, and tabs are studied also, to determine how many are required and the best location for each. Extensive study is done on bend allowances, using the bend allowance charts found in Appendix B.

PATTERNS AND DEVELOPMENTS

Developments

A *development* is the pattern or template of a shape that is laid out in a single flat plane in preparation for the bending or folding of a material to a required shape. Surface developments are used in many different industries. Some examples of objects requiring developments are cereal boxes, tool boxes, funnels, air-conditioning ducts, and simple mail boxes.

Three major kinds of surface developments are parallel line development, radial line development, and triangulation development. *Parallel line developments* are used for objects having parallel fold lines. *Radial line developments* are those whose fold lines radiate from one point. See Figure 8-1. *Triangulation developments* are the development process of breaking up an object into a series of triangular plane surfaces, Figure 8-2. Each kind of development is explained here in full.

Surfaces

A *development surface* is the exterior and/or interior of the sheet material used to form an object. The various kinds of surfaces include plane surface, single-curved surface, and double-curved surface.

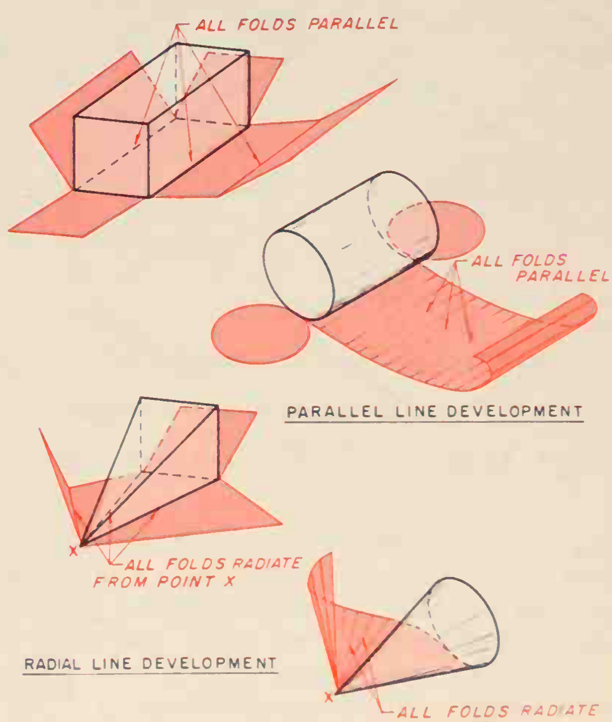


Figure 8-1 Parallel line development and radial line development

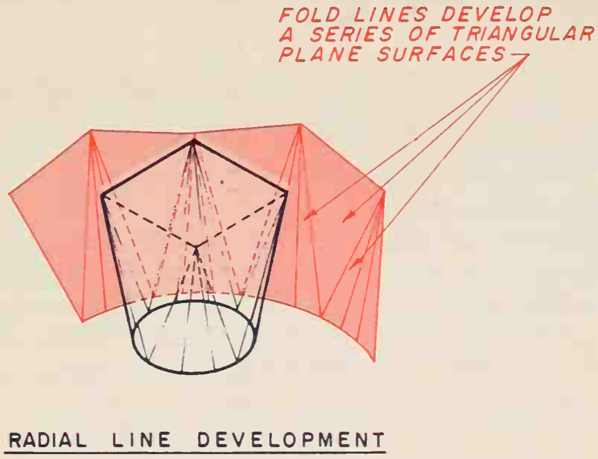


Figure 8-2 Triangular development

If any two points anywhere on a surface are connected to form a straight line, and that line rests upon the surface, it is a *plane surface*. If all points on a surface can be interconnected to form straight lines without exception, it is a *flat-plane surface*. The top of a drawing board is an example of a flat-plane surface. A flat-plane surface can have three or more straight edges. Such objects as a cube or a pyramid are bounded by plane surfaces. If a surface can be unrolled to form a plane, it is a *single-curved surface*. A cylinder or a cone is an example of a *single-curved surface*.

A surface that cannot be developed because it is neither a plane surface nor a curved surface is a *warped surface*. An automobile fender is an example of a warped surface. This kind of surface is usually stamped or pressed into shape. An object fully formed by curved lines with no straight lines is a *double-curved surface*. A sphere is an example of a double-curved surface. This type of surface cannot be developed exactly by using flat patterns; only an approximate development can be made.

Laps and Seams

Extra material must be provided for laps and seams. Many kinds of seams are available, Figure 8-3.

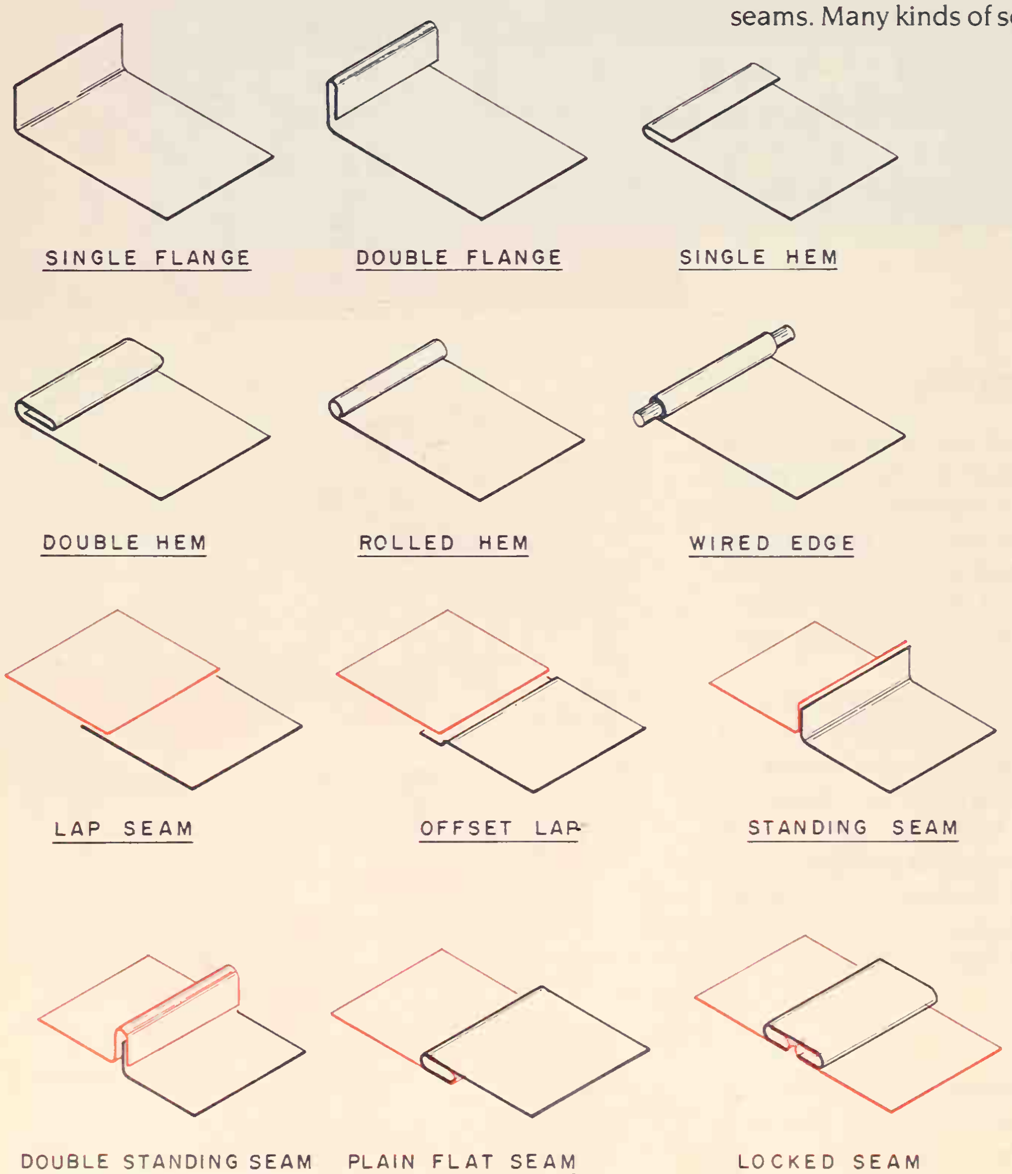


Figure 8-3 Many types of seams are available

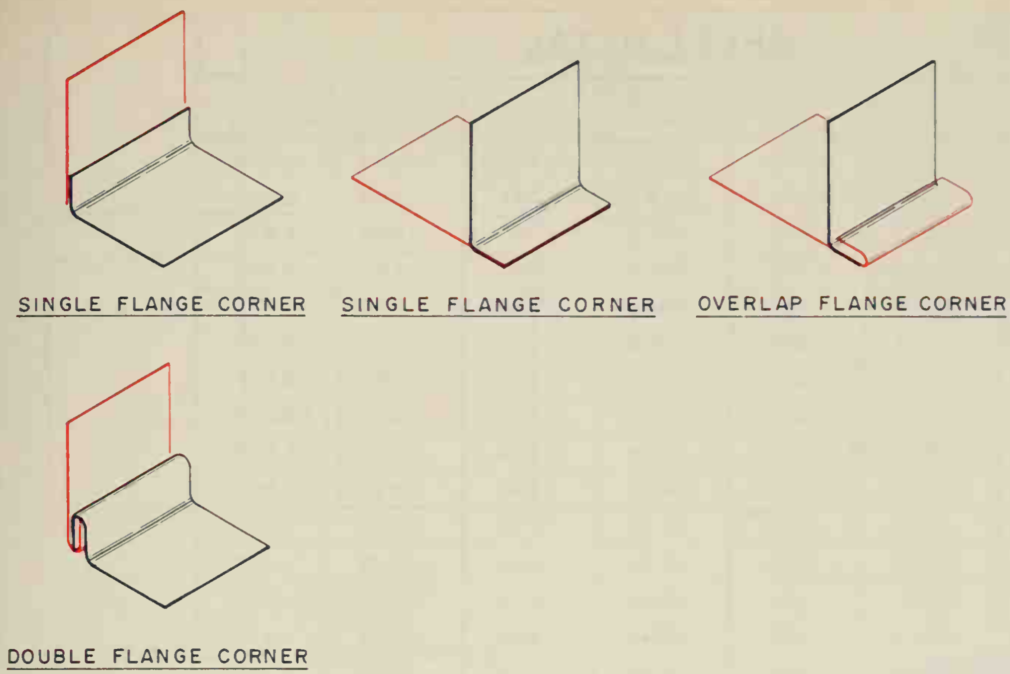


Figure 8-3 (Continued)

When making a choice, the drafter must take into account the thickness of the metal so that crowding of the metal at the joints is not a problem. Allowance must be made for the gluing, soldering, riveting or welding processes for joints. The method of fastening joints together varies with the material and, accordingly, the elimination of rough or sharp edges. Tabs for the drawing problems at the end of this chapter should be designed to support the joining surface, Figure 8-4.

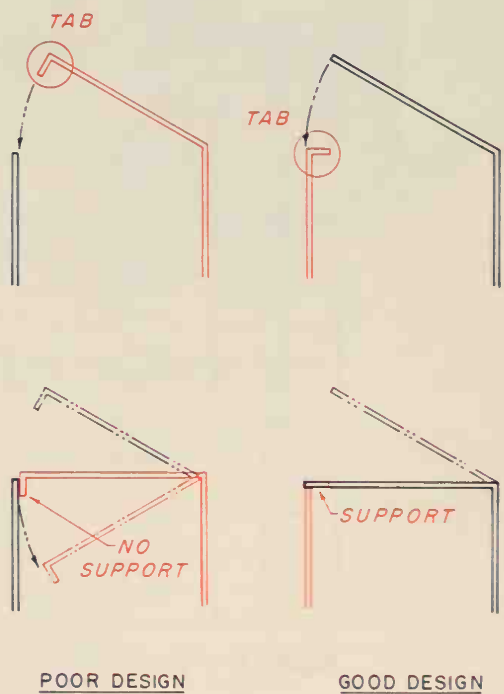


Figure 8-4 Tabs should support the joining surfaces

Design Practices

The drafter should lay out developments according to the dimensions of stock materials for economy and the best use of materials and labor. The stock material area required to cut a pattern should be kept to the smallest convenient size. It is good practice to put the seam at the shortest joint, and to attach tops and bottoms along the longest possible seam or bend to reduce the length requiring soldering, riveting or welding. It is assumed that the inside surface of the final object is the side that the pattern defines. (The important dimension sizes are usually the inside surfaces.) Fold or bend locations in the material are shown on the pattern with thin solid lines, and are locations that are also assumed to occur on the inside surface of the final object.

Thickness of Material

The actual thickness of sheet metal is specified by gage numbers. Each gage number indicates a particular thickness of material. Figure 8-5 lists the gage number and gage sizes for sheet and plate steel. These are nominal thicknesses, subject to permissible tolerances. Today, there is considerable confusion when using the gage numbering system.

In 1893, Congress established the United States Standard Gage, and it was primarily a *weight* gage rather than a *thickness* gage. It was derived from the weight of wrought iron. At that time, the weight of

SHEET METAL						
GAGE	ALUMINUM		BRASS		STEEL	
	THICKNESS	WT./SQ FT.	THICKNESS	WT./SQ. FT.	THICKNESS	WT./SQ FT.
8	.1285	1.812	.1285	5.662	.1644	6.875
9	.1144	1.613	.1144	5.041	.1494	6.250
10	.1019	1.440	.1019	4.490	.1345	5.625
11	.0907	1.300	.0907	3.997	.1196	5.000
12	.0808	1.160	.0808	3.560	.1046	4.375
13	.0720	1.020	.0720	3.173	.0897	3.750
14	.0641	.907	.0641	2.825	.0747	3.125
15	.0571	.805	.0571	2.516	.0673	2.812
16	.0508	.720	.0508	2.238	.0598	2.500
17	.0453	.639	.0453	1.996	.0538	2.250
18	.0403	.580	.0403	1.776	.0478	2.000
19	.0359	.506	.0359	1.582	.0418	1.750
20	.0320	.461	.0320	1.410	.0359	1.500
21	.0285	.402	.0285	1.256	.0329	1.375
22	.0253	.364	.0253	1.119	.0299	1.250
23	.0226	.318	.0226	.996	.0269	1.125
24	.0201	.289	.0201	.886	.0239	1.000
25	.0179	.252	.0179	.789	.0209	.875
26	.0159	.224	.0159	.700	.0179	.750
27	.0142	.200	.0142	.626	.0164	.688
28	.0126	.178	.0126	.555	.0149	.625
29	.0113	.159	.0113	.498	.0135	.562
30	.0100	.141	.0100	.441	.0120	.500
31	.0089	.126	.0089	.392	.0105	.438
32	.0080	.112	.0080	.353	.0097	.406
33	.0071	.100	.0071	.313	.0090	.375
34	.0063	.089	.0063	.278	.0082	.344
35	.0056	.079	.0056	.247	.0075	.312
36	.0050	.071	.0050	.220	.0067	.281
37	.0045	.063	.0045	.198	.0064	.266
38	.0040	.056	.0040	.176	.0060	.250
39	.0035	.050	.0035	.154	-	-
40	.0031	.044	.0031	.137	-	-

Figure 8-5 Thickness of material

wrought iron was calculated at 480 pounds per cubic foot; thus, a plate 12 inches square and 1 inch thick weighs 40 pounds. A No. 3 U.S. gage represents a wrought iron plate weighing 10 pounds per square foot. Therefore, if a weight per square foot 1 inch thick is 40 pounds, the plate thickness for a No. 3 gage equals 10 ÷ 40 = 0.25 inch, which is the original thickness equivalent for a No. 3 U.S. gage. Since this and all other gage numbers were based on the weight of wrought iron, they are not correct for steel. To add to the confusion, there is considerable variation in the gage thickness for different kinds of material. For example, a gage used for such nonferrous materials as brass and copper is sometimes also used to specify a thickness for steel or vice versa.

Today, to help eliminate the problems, the decimal or metric system of indicating gage size is now replacing the older gage size numbering system.

Parallel Line Development

In parallel line developments all fold lines are parallel. (Refer back to Figure 8-1.)

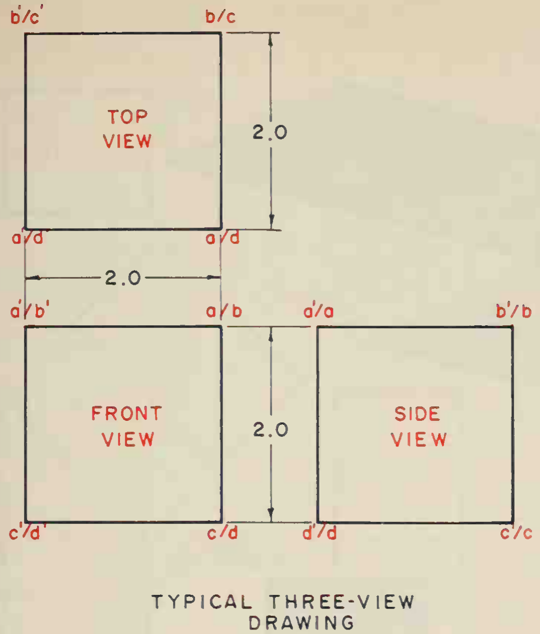


Figure 8-6 Simple multiview drawing of a cube

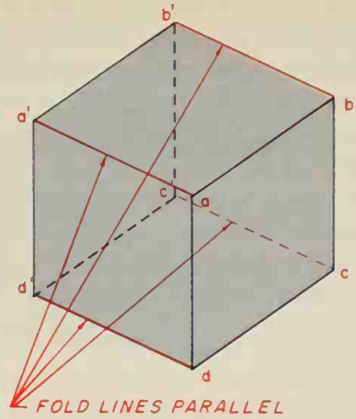


Figure 8-7A All fold lines are parallel

A three-view drawing of a simple 2-inch cube is shown in Figure 8-6. A cube is a specific kind of prism. Notice that all the fold lines that form the lateral surfaces of a prism are parallel, Figure 8-7A. If the cube were to be unfolded, it would appear as it does in Figures 8-7B, 8-7C, and 8-7D. The finished development is shown in Figure 8-7E.

Notice that the cube was developed or laid out from a baseline, sometimes referred to as the *stretchout line*. Fold lines are always oriented 90° from the baseline, as illustrated. If the pattern were to be cut from a flat sheet of material, tabs would be needed to fasten the cube together. Tabs must be positioned

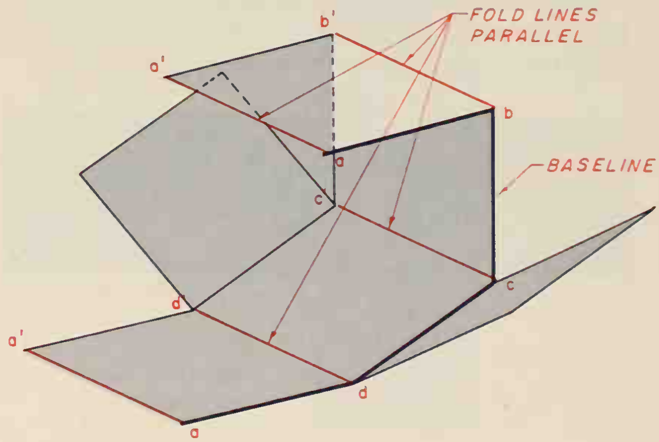


Figure 8-7B Cube as it unfolds

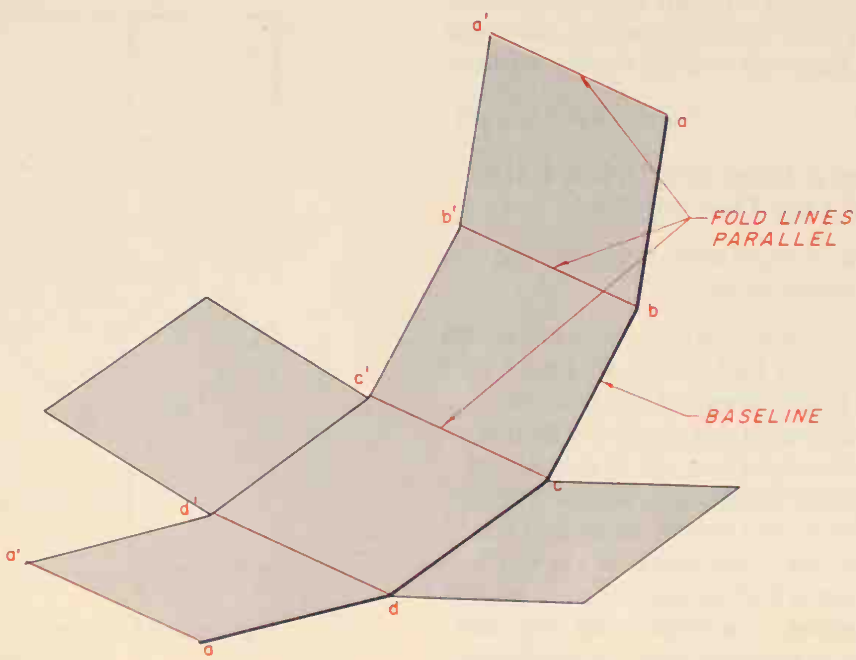


Figure 8-7C Cube as it unfolds further

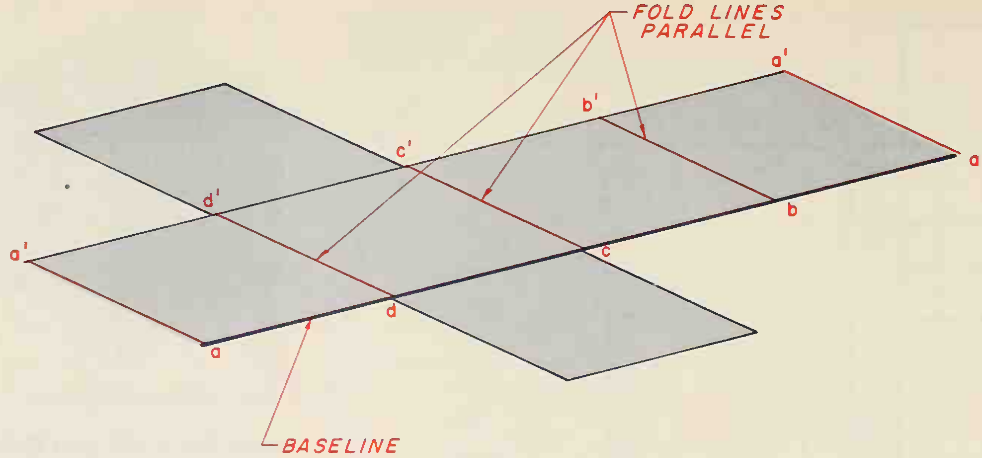


Figure 8-7D Cube flattened out

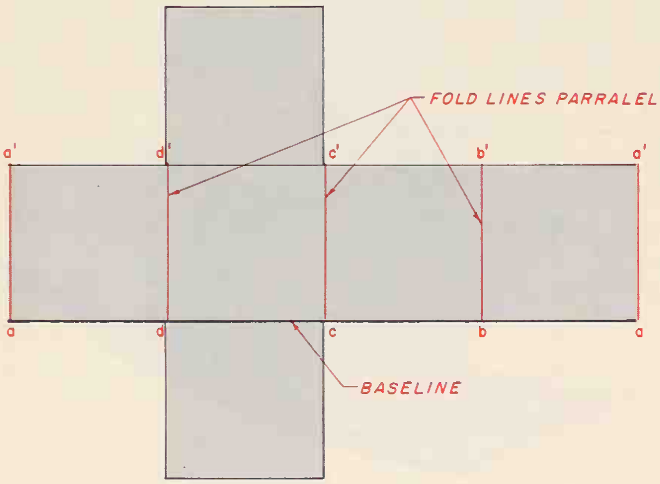


Figure 8-7E Cube in the finished development

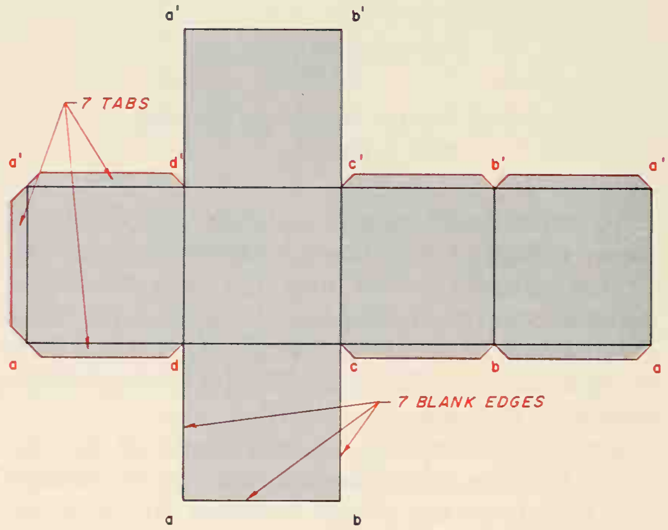


Figure 8-7F Cube flattened out with tabs added

so as to make each meet with an untabbed edge, Figure 8-7F. Notice that there are seven tabs and seven blank edges. Each tab folds to meet a particular blank edge.

How To Develop a Truncated Prism Using Parallel Line Development

Given: A prism with a front view, top view, and auxiliary view, Figure 8-8A.

Step 1. Locate the baseline, which must always be 90° from the parallel fold lines. Label each fold line clockwise in alphabetical or numerical order. Always start with the shortest fold line, Figure 8-8B. Either fold line a-a' or b-b' would be eligible, and a-a' is selected. Notice that the starting fold line is also the finishing fold line, and each is labeled at the same location. The finishing fold line is a-a'. All real (or true) lengths of the fold lines are seen in the front view and the real distances between their locations are seen in the top view.

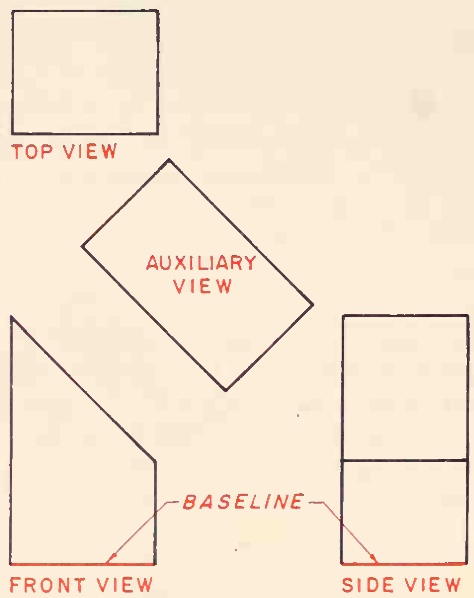


Figure 8-8A Development of a truncated prism using parallel line development

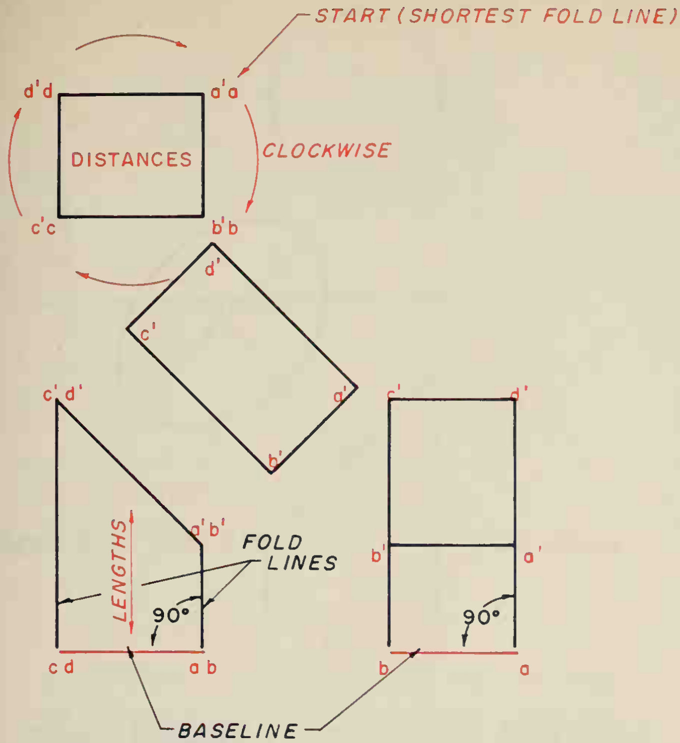


Figure 8-8B Step 1

Step 2. On a separate sheet of paper, construct a pattern baseline, allowing enough space for the complete development, top and bottom surfaces, and the required tabs. At the left end of the baseline, draw a line perpendicular to the baseline. This is the first fold line and is also a seam edge. Transfer the true length from fold line a-a' (as measured from the three-view drawing in Figure 8-8A). Label this line a-a' also, as illustrated in Figure 8-8C.

Step 3. From the top view of Figure 8-8A, obtain the true distance from the first fold line location at a-a' to the second fold line location at b-b'. On the pattern baseline, transfer this distance, measuring from the first fold line a-a', and draw the next fold line parallel to the first fold line. Label it b-b', Figure 8-8D.

Step 4. Repeat the first three steps, alternating true fold line lengths and true distances between fold lines until all the true lengths and true distances are transferred. Each of the true

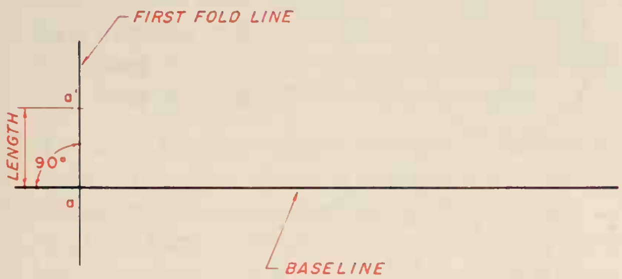


Figure 8-8C Step 2

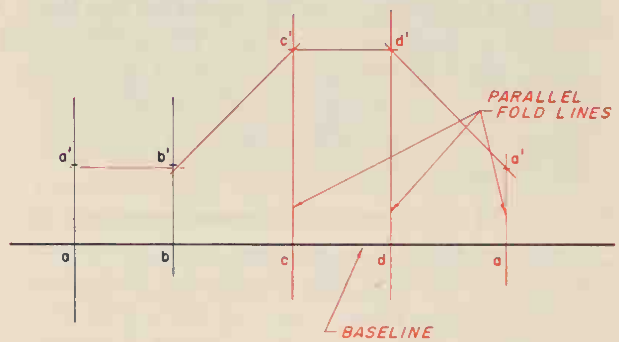


Figure 8-8E Step 4

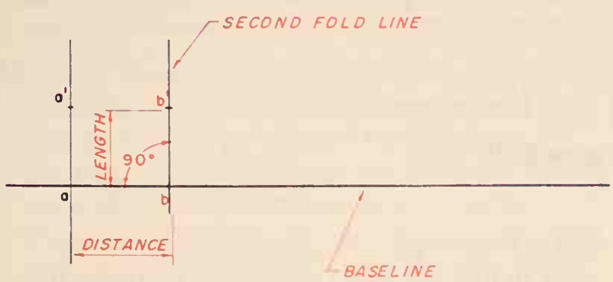


Figure 8-8D Step 3

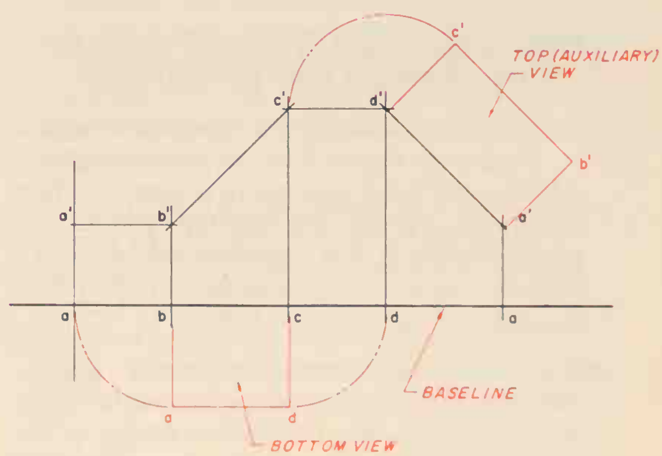


Figure 8-8F Step 5

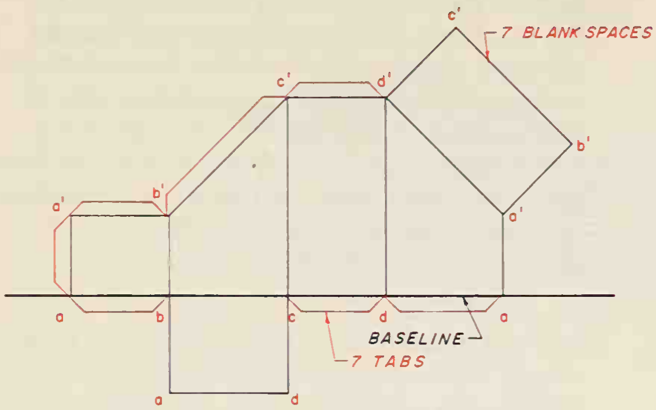


Figure 8-8G Step 6 completed development of the prism

lengths a-a' through e-e' are transferred from the front view, and the true distances between them are found from the top view of Figure 8-8A. connect the points as illustrated in Figure 8-8E.

Step 5. The edge selected for attachment of the top surface should be made to keep the rectangle size from which the whole pattern is cut as small as possible. Line a'b' would be the best, except an acute angle cutout c'b'a' is difficult to make. The fold line a'd' is next best, as shown. From Figure 8-8A, transfer the true size and shape of the top surface (auxiliary view) and the bottom surface, Figure 8-8F.

Step 6. Add tabs enough to fasten the edges. The locations should be selected so as not to enlarge the material area needed for the pattern cutout, Figure 8-8G. Check to verify that the number of tabs equals the number of blank edges in the same manner as is illustrated in Figure 8-7F. This completes the parallel line development of the object in Figure 8-8A.

How To Develop a Truncated Cylinder Using Parallel Line Development

Given: A cylinder with a front view, top view, and auxiliary view, Figure 8-9A. In developing a cylinder, the exact procedure is used as when developing a prism. Because the cylinder has a rounded surface, line segments called *station lines* must be assumed or chosen on the lateral surface. This is explained in Step 1.

Step 1. Locate a baseline which must always be 90° from the fold lines, sometimes referred to as *parallel station lines*. The bottom corner of the lateral surface is selected as a convenient location because it already exists. In the view where

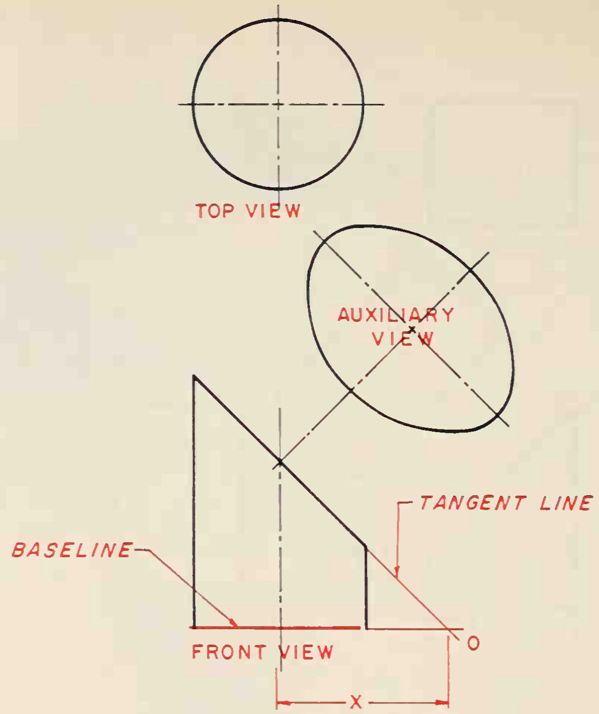


Figure 8-9A Development of a truncated cylinder using parallel line development

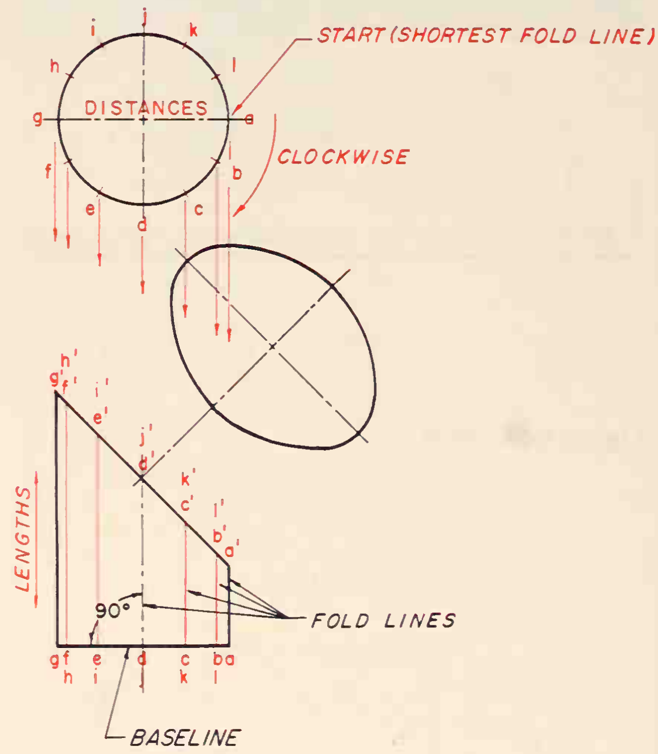


Figure 8-9B Step 1

the cylinder appears as a diameter (the top view in this example), divide the diameter into equal divisions, Figure 8-9B. This example uses 12 equal divisions, but any number of appropriate equal divisions would do. These divisions

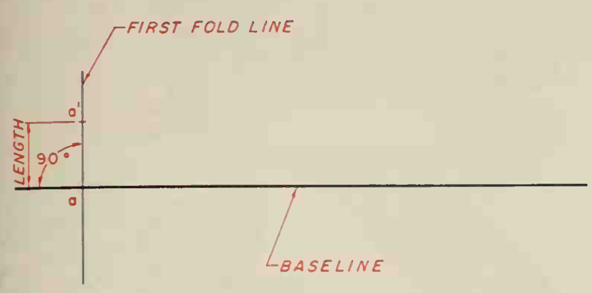


Figure 8-9C Step 2

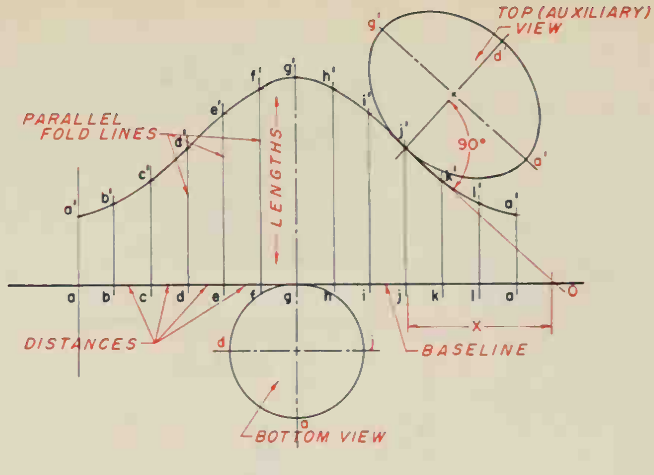


Figure 8-9D Steps 3 and 4

locate fold line positions, which are used only for construction and layout purposes. Starting with the shortest fold line, consecutively label each division; in this example, a through l. Note that a-a' marks the beginning and ending of the same line which meets from opposite directions. The true "distances" between station lines can be approximated in this top view. Project each point into the next (front) view in order to find the true "lengths" of the fold lines. It should be reemphasized that the fold lines must be 90° from the baseline.

Step 2. On a separate sheet of paper, construct a pattern baseline allowing enough space for the complete development, both ends, and the required tabs. At the left end of the pattern baseline draw a line perpendicular to the baseline. This is the first fold line location a-a'. Transfer the true length a-a' from the front view of Figure 8-9B. Label this line as illustrated in Figure 8-9C.

Step 3. Two methods are used for finding the distances between station lines. Method A is an approximate method that assumes the cylinder to be a prism, whereas Method B is mathematically correct.

Method A: From the top view of Figure 8-9B, obtain the direct chordal distance from the first station line a-a' to the second fold line b-b'. On the pattern baseline, draw the second fold line parallel to the first station line a-a' at the chordal distance found from the top view, and label it b-b', Figure 8-9D. Repeat these steps, alternating chordal lengths and true distances until all station lines have been located and drawn. Note that the last fold line length a-a' is a duplicate of the first.

Method B: The required length to form the cylinder's circumference can be calculated using the following formula: circumference = cylinder diameter x pi. (Pi = 3.1416, approximately.) The baseline is extended to this length, and divided into the same number of divisions as was done at Step 1 in the top view of the cylinder, Figure 8-9B. The division can best be performed as a construction exercise, rather than mathematically. Refer back to Chapter 3, "Geometric Construction." Each of the 13 division locations (from 12 spaces) is the correct location of the required station lines, and can be successively labeled.

Step 4. Add the true size and shape of the bottom surface (bottom view), and the top surface (auxiliary view). The attachment locations of these surfaces are particularly difficult, as the mathematical point of tangency is not easily isolated on the pattern. The top surface location is chosen to allow the widest access of cutting to this point. The bottom surface can be added to any of the fold lines. In order to locate the top surface, the distance X from center to point 0 is transferred from Figure 8-9B to the development, and projected 90° as illustrated in Figure 8-9D.

Step 5. Add the tabs necessary for edge attachments. In cylinders, a notched tab must be used in order to accommodate crowding by surface curvature. A tab must also be added at fold line a-a' in order to attach edge a-a' to the other edge a-a'; the top (auxiliary) and bottom fold to meet the notched tabs, Figure 8-9E.

Regardless of the shape, whether it be a cylinder or a prism, parallel line developments are used with

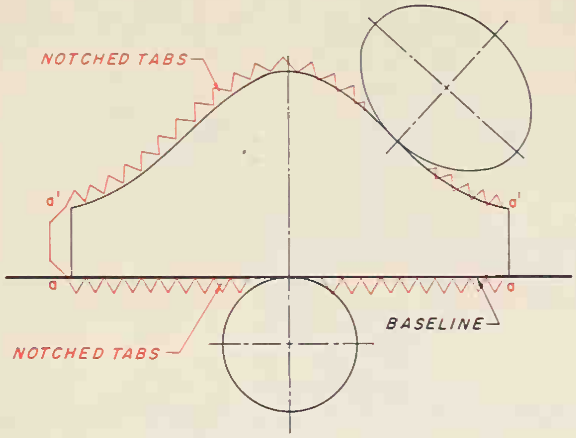


Figure 8-9E Step 5 completed development of the cylinder

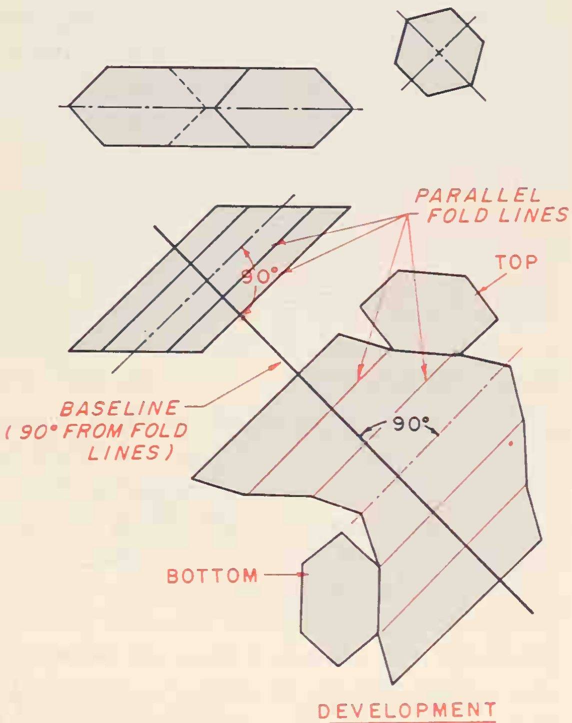


Figure 8-10 Creating a new baseline

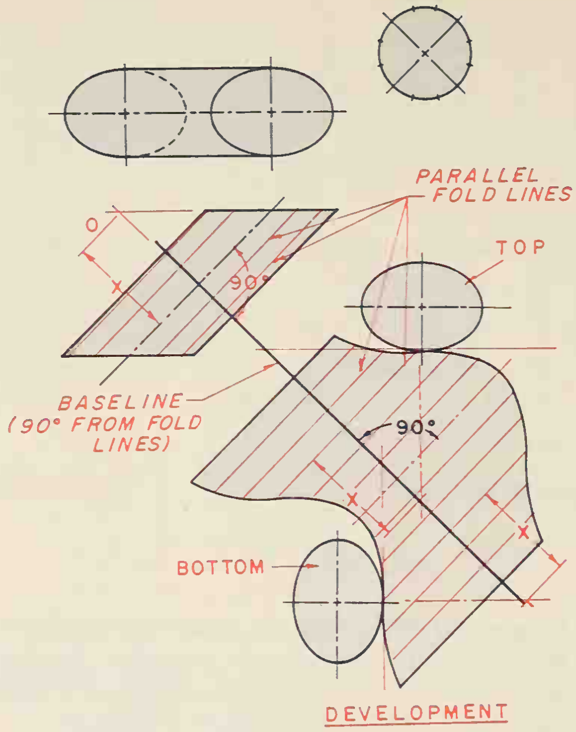


Figure 8-11 Using station lines instead of fold lines

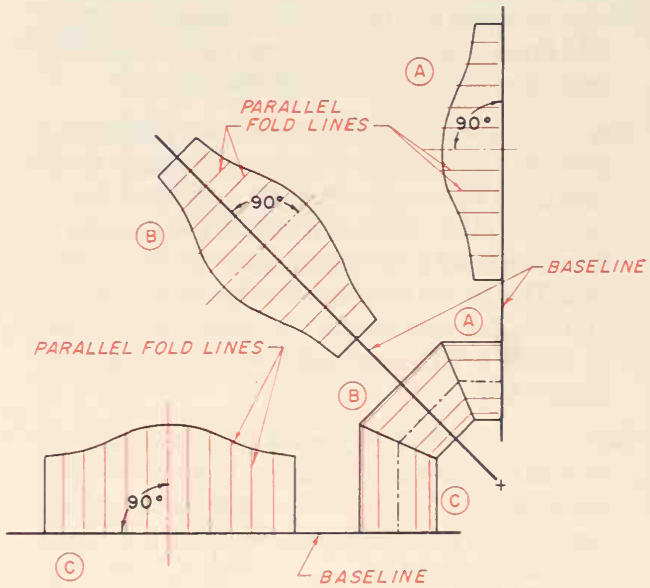


Figure 8-12 Series of patterns used to form an elbow

essentially the same procedure. Figure 8-10 shows a prism truncated at both ends, which necessitates creating a new baseline other than a part edge to ensure that all fold lines (instead of station lines) are at 90° to the baseline. Figure 8-11 is a cylindrical prism, truncated at each end, which requires the selection of station lines instead of using existing fold lines. Figure 8-12 shows a series of truncated cylinders, similar in construction to the preceding views, whose patterns are used to form an elbow.

Radial Line Development

Radial line development is different from parallel line development in that all fold lines or line segments radiate from one point. (Review Figure 8-1.) As in all patterns, true lengths and true distances must be used in laying out the developments.

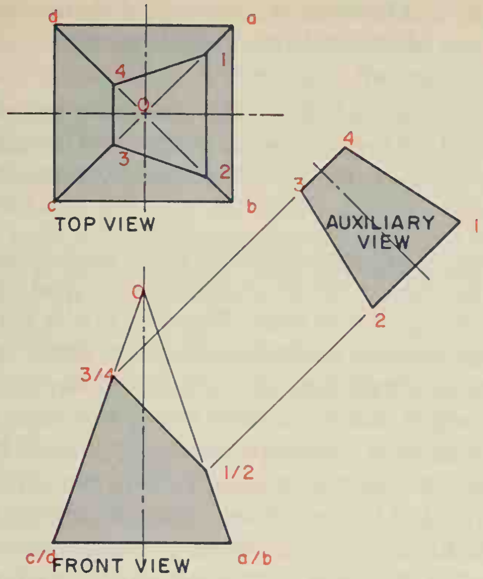


Figure 8-13A Development of a pyramid using radial line development

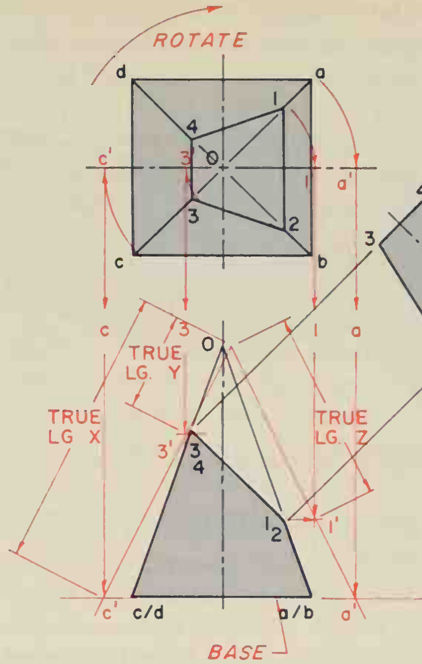


Figure 8-13B Step 1

How To Develop a Truncated Pyramid Using Radial Line Development

Given: A two-view drawing, and an auxiliary view of a pyramid with the top cut off at an angle (truncated), Figure 8-13A. Label points clockwise starting with the shortest fold line. In this example, either a-1 or b-2 could be used. Line a-1 is selected, but the fold line location a-1 is also the meeting corner of edges a-1 and a-1. True distances between the end points of the fold lines are evident in the top view. For example, a-b, b-c, c-d, and d-a are true length.

Step 1. To find the true lengths of the fold lines, they must be rotated to a position that is parallel to the frontal viewing plane, Figure 8-13B. In the top view, point a is rotated as shown, and projected into the front view. This revolved line from a' to 0 is its true length. Similarly, point c in the top view is rotated and projected into the front view, giving the true length of c'-0. The same procedure is used to find the true lengths 3'-0 and 1'-0. To construct a development of this object, continue with the following steps.

Step 2. Using the true length from 0 to a (a'-0), swing the arc as shown in Figure 8-13C. On this arc, mark off as chord lengths the true distances between the fold line end points a to b, b to c, c to d, and d to e, as transferred from the top view of Figure 8-13B. Label all points as shown. Connect the fold lines a to 0, b to 0, c to 0, d to 0, and a to 0.

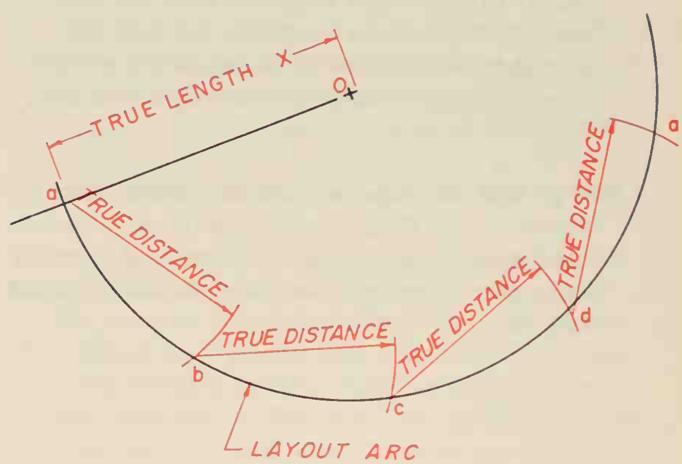


Figure 8-13C Step 2

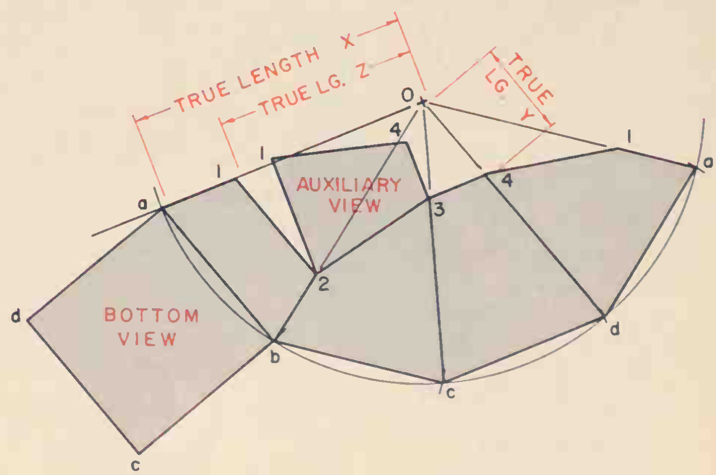


Figure 8-13D Step 3

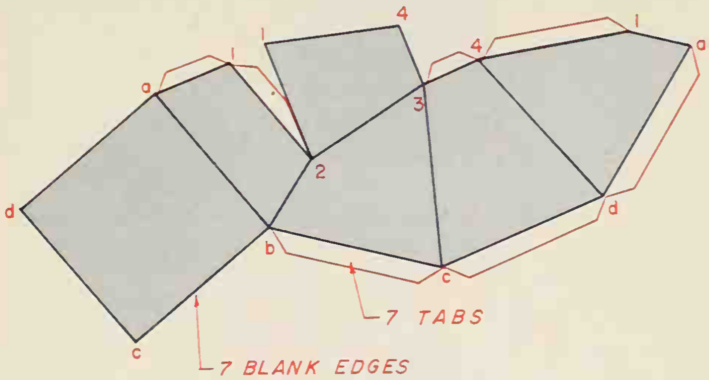


Figure 8-13E Step 4 completed development of a pyramid

Step 3. Using the true lengths found in Figure 8-13B, locate points 1, 2, 3, 4, and 1 on the respective fold lines 0-a, 0-b, 0-c, and 0-a. Note that 0-1 is the same length as both 0-2 and 0-1, and 0-3 is the same length as 0-4. Add the auxiliary and bottom views, transferring them directly from the original drawing 8-13A. See Figure 8-13D.

Step 4. Add the required tabs as illustrated in Figure 8-13E. Check to be sure the number of tabs equals the number of blank edges. In this example, there are seven tabs and seven blank spaces.

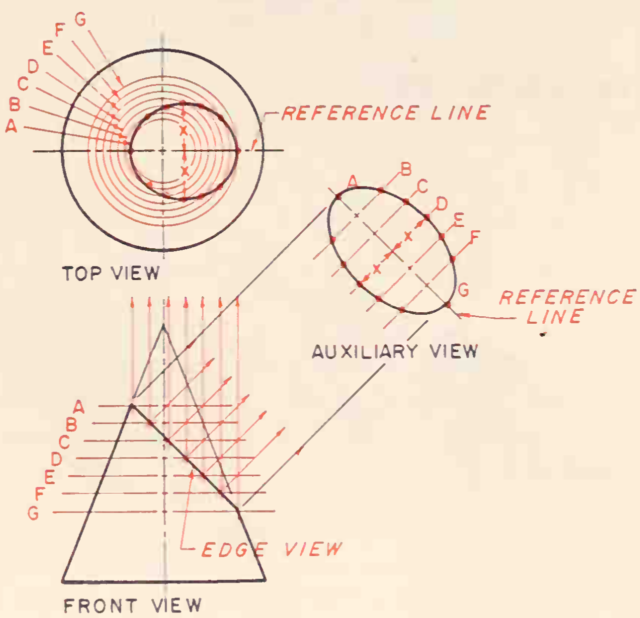


Figure 8-14A Development of a truncated cone using radial line development

How To Develop a Truncated Cone Using Radial Line Development

As with cylindrical parallel line developments, station lines are line segments which must be positioned on the lateral surface in order to draw a development.

Given: A two-view drawing of a round cone, with the top cut off at an angle (truncated), and having no fold lines, Figure 8-14A. It is necessary to first complete the given views, and to draw a true view of the inclined flat surface. To project the flat surface to the top view, the front view is sliced at points A through G. These seven slices are projected into the top view and appear as circles, correspondingly labeled A through G. The points of intersection of the edge view with each slice is projected into the top view. To construct the auxiliary view, project from the seven point intersections perpendicular from the edge view of the flat surface to any convenient distance for the auxiliary view. Draw and use the center line as a reference line, and transfer all point-to-center line distances from the top view to the auxiliary view; refer to reference distances X.

Step 1. To construct a development of this object, station lines need to be established, and their true lengths and true distances must be determined. In the top view of Figure 8-14B, divide the base circle into 12 equal parts, and label each point. In this example, numbers 1 through

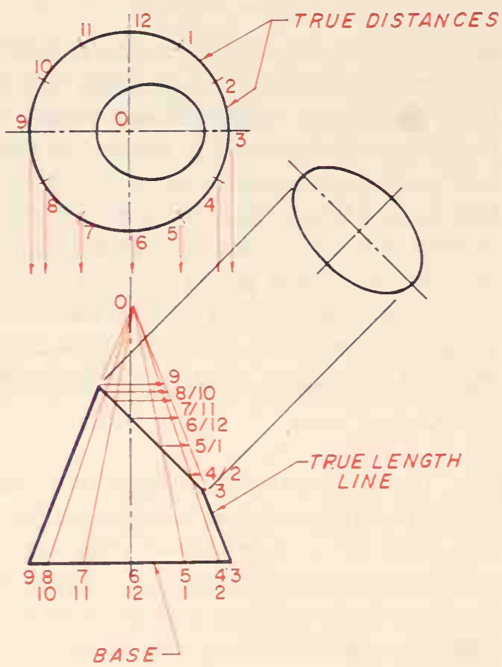


Figure 8-14B Step 1

12 are arbitrarily used, positioned as illustrated. The station line 0-3 must have two identities as two edges will meet at this point. The true distances between station lines are located between their end points on the cone base, seen in the top view. Project the 12 points down into the base of the front view. These are the end points of the station lines in the front view. Draw a line from each of these end points up to point 0.

Step 2. There are two methods of drawing the pattern outline. Each begins with swinging an arc whose radius is the true length of the lateral distance from the apex to the base, or length 0-3 or 0-9. The compass radius can be set to this distance on Figure 8-14B. This distance can also be derived mathematically if the diameter of the base of the cone is known, and the altitude (perpendicular distance from base to apex) is known. The formula is:

$$\text{radius} = \text{the square root of } [(\tfrac{1}{2}\text{ cone base diameter})^2 + (\text{altitude})^2]$$

After swinging this arc, choose Method A, which approximates the cone as a pyramid, or Method B, which is mathematically correct.

Method A: In the top view of Figure 8-14B, the direct chordal distance between any two station line end points, say 5 and 6 (they are all equal), is an approximation of the arc length between them. On the 0-3 radius just drawn, strike off this chordal distance between station line end points repeatedly to equal the same number of spaces on the arc as the top view of the cone was divided into in Step 1, and ending at point 3, Figure 8-14C. Connect the station line end points from point 0 to each of these arc intersections, and proceed to Step 3.

Method B: The central angle of the pattern is determined by a pattern arc length needed to equal the circumference of the base of the cone. The ratio of the central angle (A°) to a full-circle 360° is the same as the circumference of the base of the cone is to the full circumference generated by the pattern's radius.

$$\frac{A^\circ}{360^\circ} = \frac{\text{circumference of base of cone}}{\text{circumference of pattern}}$$

$$\frac{A^\circ}{360^\circ} = \frac{\text{pi} \times \text{cone diameter at base}}{\text{pi} \times \text{pattern diameter}}$$

$$\frac{A^\circ}{360^\circ} = \frac{\text{cone base diameter}}{2 \times \text{pattern radius}}$$

$$A^\circ = \frac{180 \times \text{cone base diameter}}{\text{pattern radius } (a'-0)}$$

After the central pattern radius A° is found, the angle between successive station lines (a°) is found by dividing the same number of conic divisions done in Step 1 into A°. The chordal lengths (D) of these divisions is found by using the formula:

$$D = 2 \times \text{pattern radius} \times [\sin(\tfrac{1}{2}a^\circ)]$$

This chordal distance can then be struck off on the pattern radius to form the same number of spaces as the conic divisions in Step 1, and labeled accordingly. See Figure 8-14C. Connect these station line end points from point 0 to each of the intersections, and proceed to Step 3.

Step 3. To draw the edge of intersection that the cone's lateral surfaces makes with the upper flat surface, true lengths from the apex to this edge at each station line must be determined. Only 3′-0 and 9′-0 are visible as true lengths in the front view of Figure 8-14B. To find the other true lengths, each segment must be rotated to a position parallel to the frontal viewing plane:

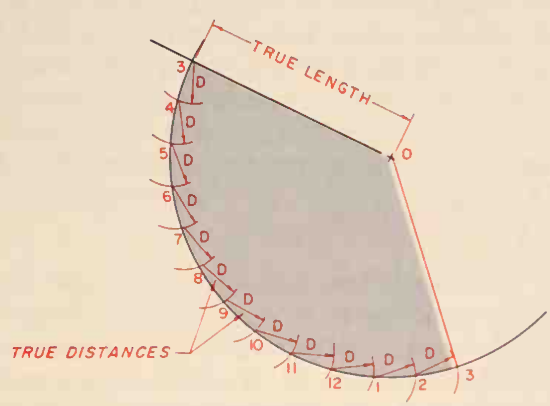


Figure 8-14C Step 2

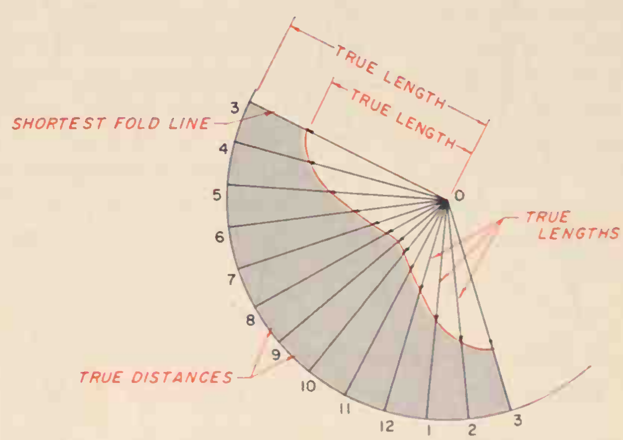


Figure 8-14D Step 3

in this example, on line 3-0. Project the intersection of each station line at the truncated surface edge to line 3-0 on the cone profile in the front view (on line 3-0).

Starting with the shortest line segments of the cone, swing true lengths arc 0-3' on the corresponding pattern station lines, as illustrated in Figure 8-14D. Swing the apex-to-edge true length found for each station point, at the corresponding station line on the pattern. Repeat for all 13 stations, 3 through 12 and back to 3. Label each point as illustrated.

Draw light line segments between each of the station line intersection positions found on the corresponding pattern station lines. This completes the true contour of the top edge, Figure 8-14D.

Step 4. Add the top, bottom, and split tabs, as illustrated in Figure 8-14E.

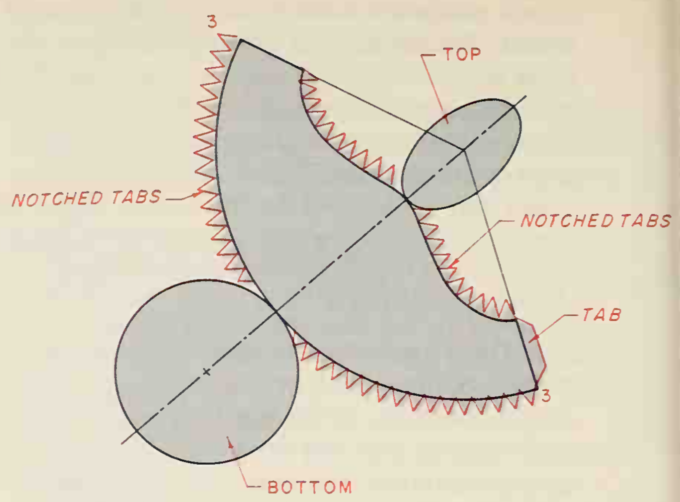


Figure 8-14E Step 4 completed development of a pyramid

Triangulation Development

Triangulation is the third major method used to lay out a surface development. *Triangulation* is a method of dividing a surface into a number of triangles and then transferring each triangle's true size and shape to the development. (Review Figure 8-2.) As with parallel line and radial line developments, *true lengths* and *true distances* must be used exclusively in pattern constructions.

True-Length Diagram

Before any layouts can be started, true lengths and true distances of the object's boundary edges must be determined. A true-length diagram is usually used to develop true lengths and true distances of these edges. A true-length diagram is often a more rapid method to obtain the needed projections than by descriptive geometry methods.

How To Develop a Transitional Piece Using Triangulation Development

Given: Figure 8-15A describes a transitional piece using a top view, front view, and isometric view. Each of the object's corners are labeled as illustrated. Note that the true distances A to B, B to C, C to D, D to A, 1 to 2, 2 to 3, 3 to 4, and 4 to 1 can be measured directly from the top view. As drawn, the lengths A-1, B-1, B-2, C-2, C-3, D-3, D-4, and A-4 are not shown in their true lengths. A true-length diagram must be used to find these.

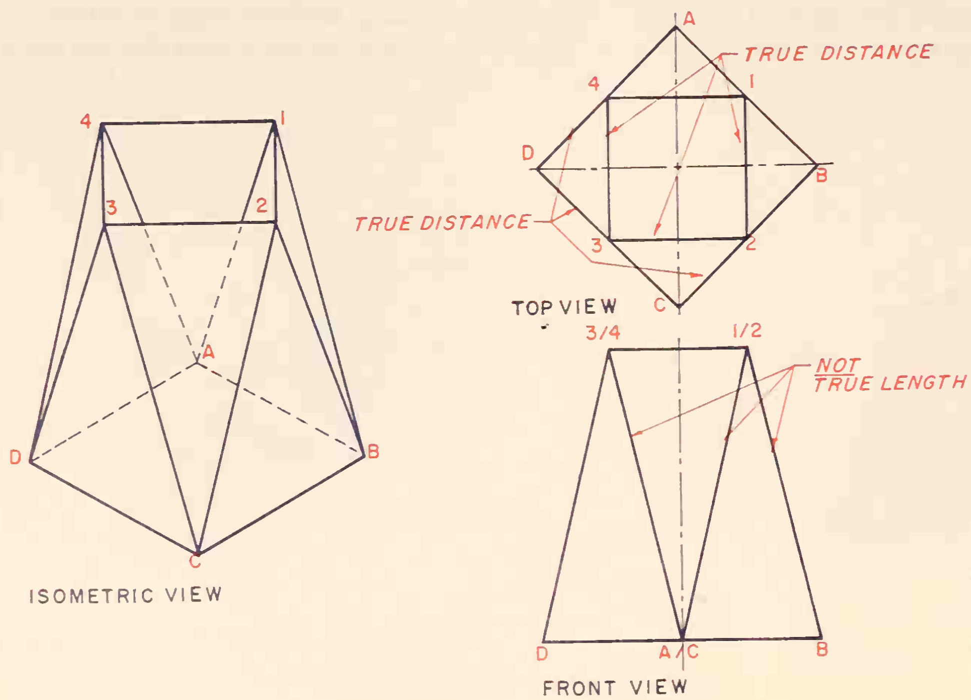


Figure 8-15A Development of a transitional piece using triangulation development

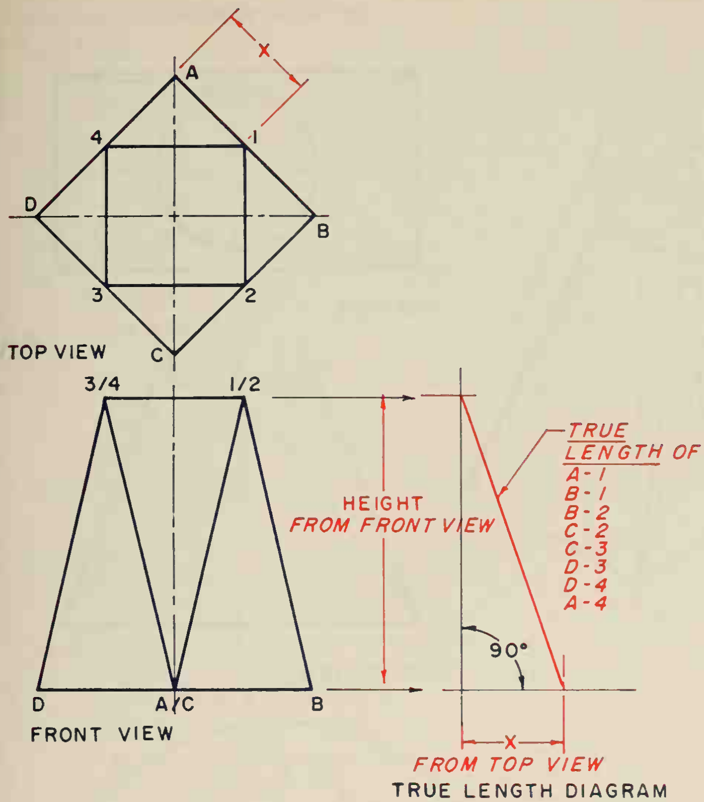


Figure 8-15B Step 1 true-length diagram

Step 1. A true-length diagram is a combination of two views. In this example, it is a combination of the top view and the front view, Figure 8-15B. The height between points A and 1 is shown projected from the front view to the true-length diagram. The distance X between corresponding line end points A and 1 is found in the top view, and transferred to the true-length diagram. The illustrated diagonal line, drawn in the true-length diagram, is the true length of A-1. As all the heights and top-view distances between end points are the same for each of the lateral edges, then A-1 is also the same length as B-1, B-2, C-2, C-3, D-3, D-4, and A-4. These true lengths are needed to lay out the development.

Step 2. Starting from line A-1 and using true lengths and true distances, reconstruct each triangle representing a surface of the object, as illustrated in Figure 8-15C. (Review Chapter 2 for aid in transferring a triangle.) Notice in this example that all true distances are transferred from the top view, and all true distances are transferred from the true-length diagram. A tab

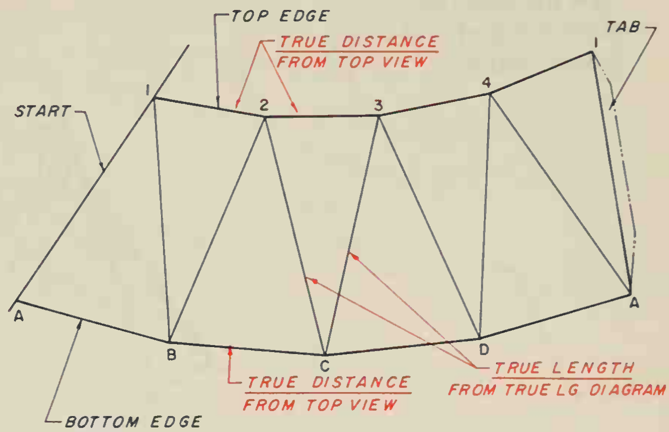


Figure 8-15C Step 2

is added to join A-1 to A'-1'. This completes the transitional piece development as drawn in Figure 8-15A.

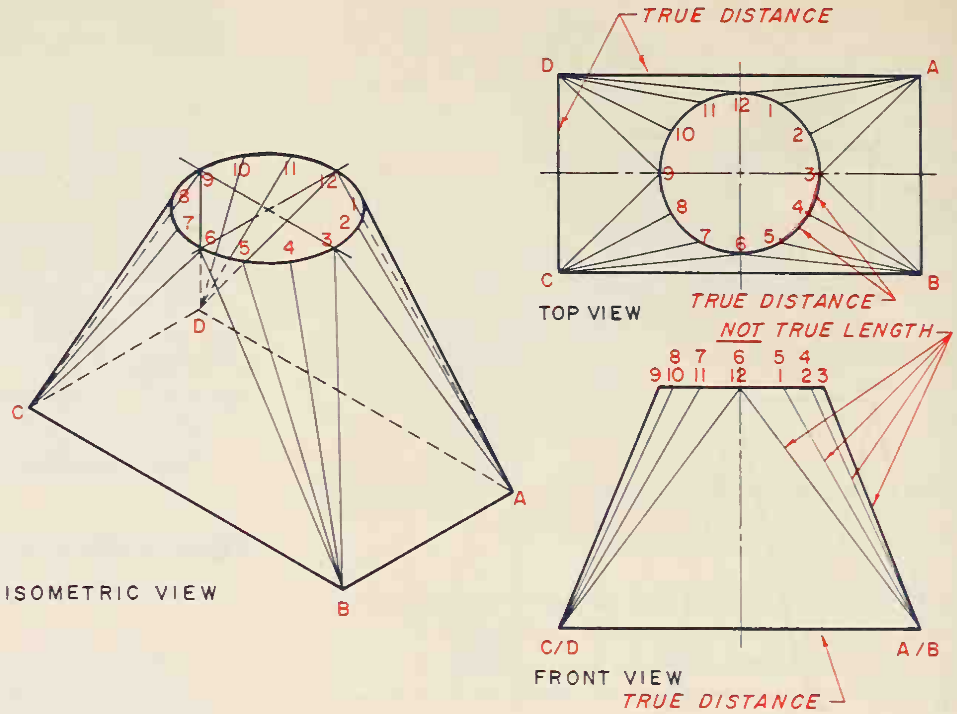
How To Develop a Transitional Piece with a Round End Using Triangular Development

A transitional piece that is square or rectangular at one end and round at the other is laid out using a procedure very similar to the one outlined previously. The only difference is that station lines must be positioned on the lateral surface of the round-to-corner transitions. Figure 8-16A illustrates a two-view transitional piece with a round top end and a rectangular bottom end. In this example, the top end is divided into 12 equal spaces. Each point is numbered clockwise as illustrated. The bottom four corners making up the bottom rectangle are labeled A through D, Figure 8-16B. The true distances from A-B, B-C, C-D, and D-A' are found in the top view. Station lines W, X, Y, and Z are not true lengths, but the true lengths must be determined with a true-length diagram. Note that in the true-length diagram, the true length of line W, from A' to 0, is also the same lengths for B-6, C-6, and D-12. Lines X, Y, and Z are also used four times at corresponding locations. Segment the object into triangles and develop the pattern using true lengths and true distances to reconstruct each adjoining segment, Figure 8-16C.

How To Develop a Transitional Piece with No Fold Lines Using Triangular Development

Figure 8-17A shows a transitional piece with no evident fold lines or line segments. It is developed in the same manner as any other triangulation development.

Figure 8-16A Development of a transitional piece with a round end using triangulation



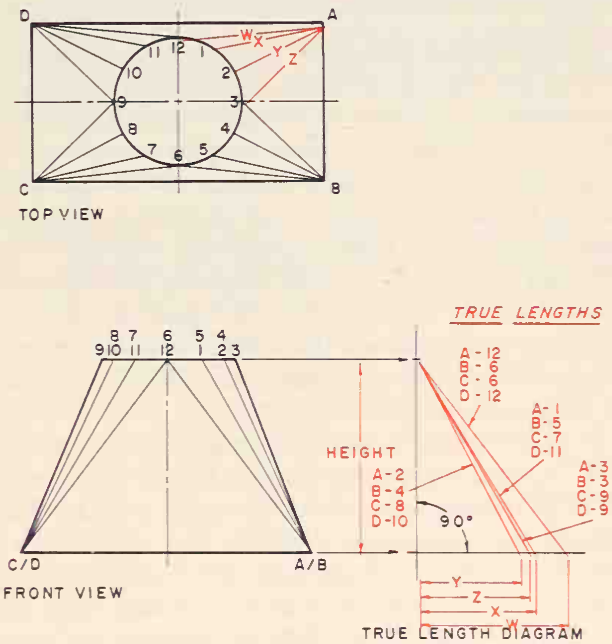


Figure 8-16B True-length diagram

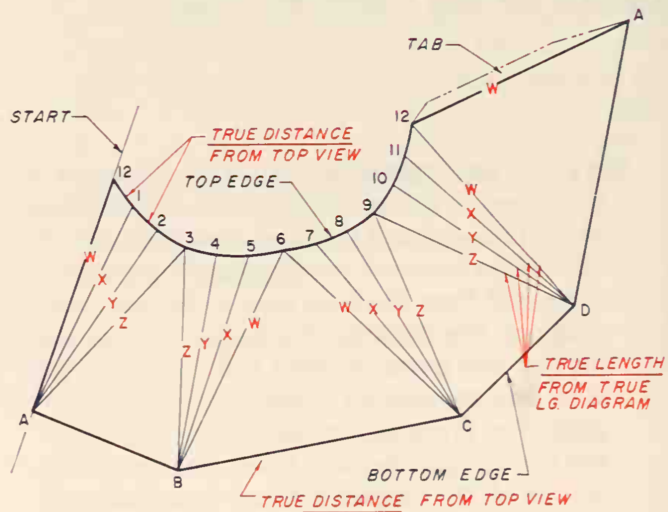
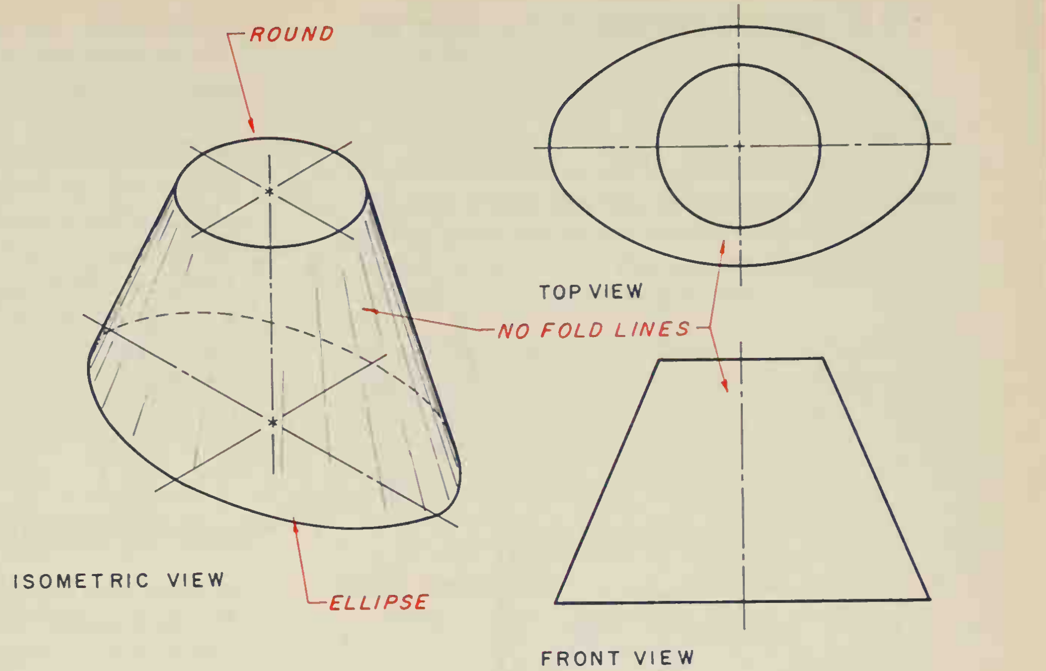


Figure 8-16C Completed development of a transitional piece with a round end

Figure 8-17A Development of a transitional piece with no fold lines



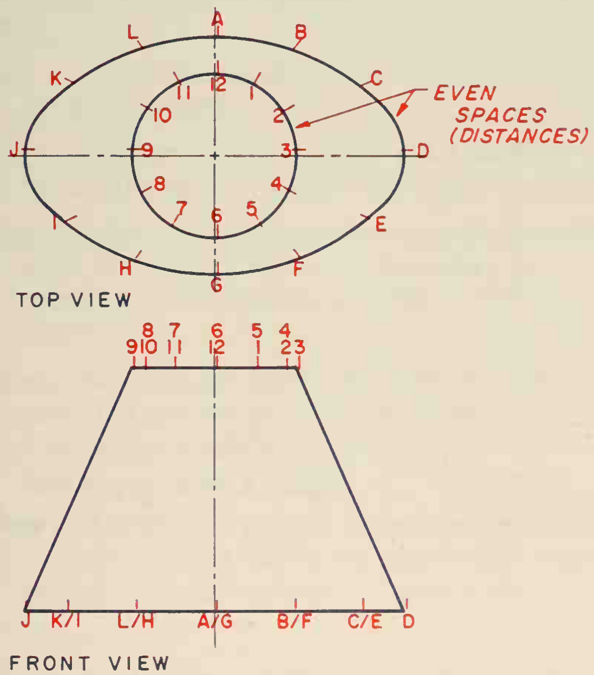


Figure 8-17B Step 1

Step 1. Divide the top and bottom surfaces into equal spaces as illustrated in Figure 8-17B. In this example, the top edge is divided into 12 equal spaces, 0 through 12. The bottom edge is divided into the exact same number of equal spaces, and lettered A through L to A.

Step 2. Connect points 12 to A, 1 to B, 2 to C, and consecutively to points L to 11 with solid lines, as illustrated in Figure 8-17C. Dash lines are added to segment the object into various triangles.

Step 3. True distances from 1 to 2, 2 to 3, 3 to 4, and so on through 11 to 12, and the true distances from A to B, B to C through to L to A' are found in the top view, Figure 8-17C. The other fold lines, connecting the top and bottom are not true lengths and, therefore, true-length diagrams must be made, one for the solid lines and the other for the dash lines, Figure 8-17D. The development is laid out by constructing connecting triangles using the lengths of each leg of each triangle, Figure 8-17E.

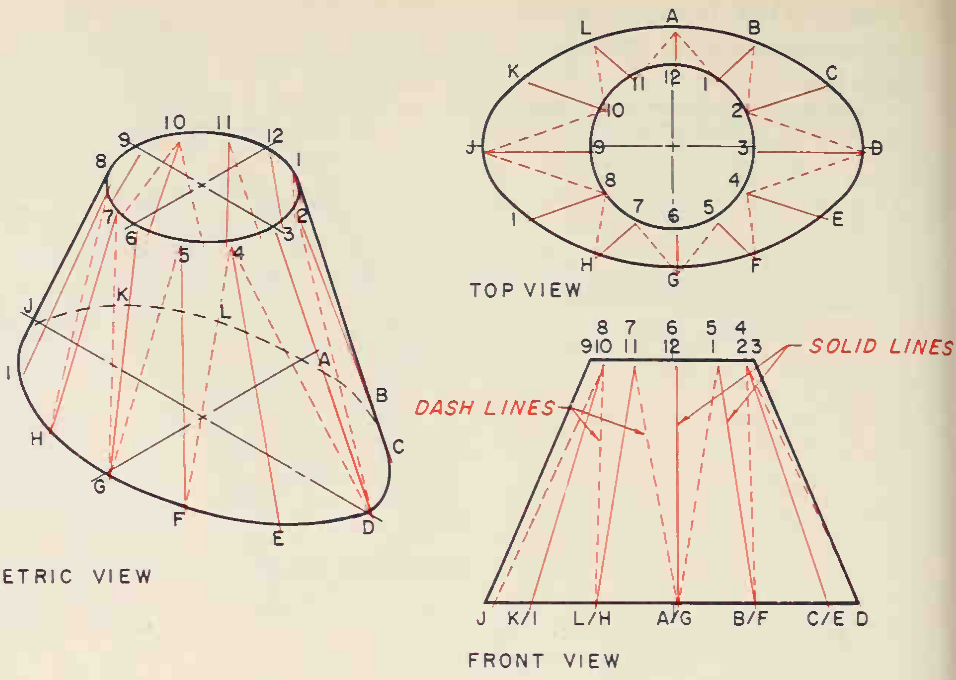
Notches

Some developments require notches. Two major types of notches are usually used: a sharp V or a rounded V, Figure 8-18. The sharp V is used only if a minimal force is tending to part the material. The sharp point of the V will tear or crack under stress. The rounded V is used where parts would be under greater stress. The radius of the vertex of the rounded V should be at least twice the thickness of the metal used, and larger if possible.

Bends

When bending sheet metal to form a corner, rib, or design, the outer surface stretches and the inner surface compresses. The length of material needed by each bend must be calculated and added to the straight unbent portions of the pattern. The material needed by each bend is the length of the neutral

Figure 8-17C Step 2



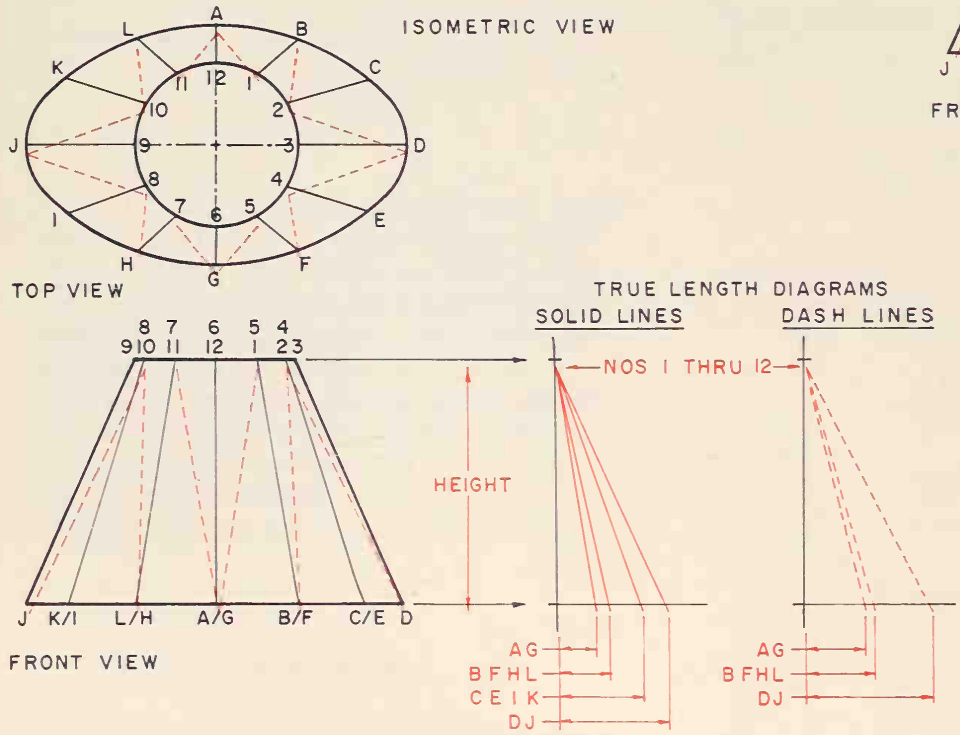


Figure 8-17D Step 3 true-length diagram

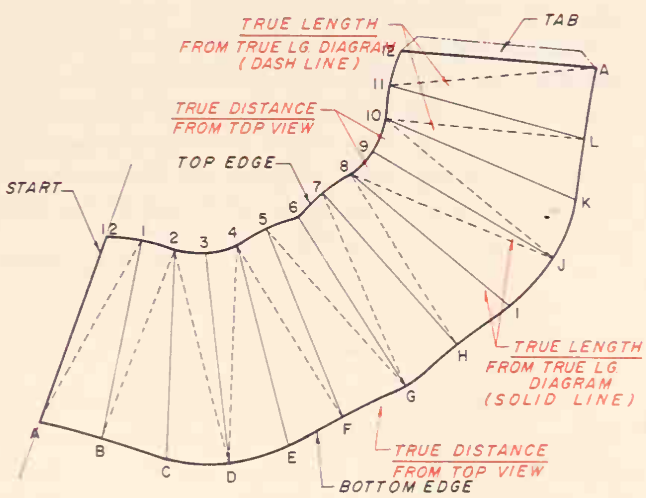


Figure 8-17E Completed development of a transitional piece

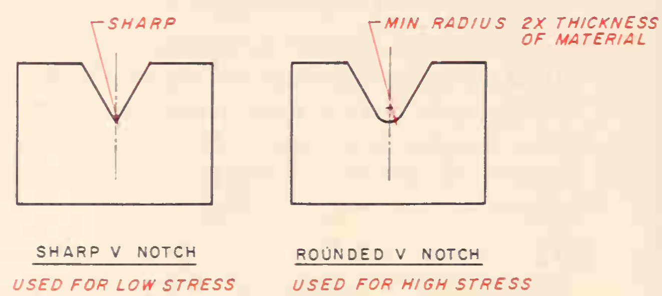


Figure 8-18 Notches

axis within the material, where neither compression nor stretching occurs. This is calculated either by formulas or by using various charts available for this purpose.

Bend allowance charts are included in the Appendix of this text, and are much faster to use than a formula. Two basic kinds of charts are used to calculate bend allowance, in both the English and metric systems. One type is used for 90° bends; the other for bends from 1° through 180°. The total length of a pattern is called the *developed length*. To determine the developed length, the stretched-out flat pattern must include all straight sides, plus the calculated bend allowances.

How To Find All Straight Sides of a 90° Bend

Figure 8-19A shows a simple 90° bend with an inside radius of .25, a sheet metal thickness of .125, and legs of 2.0 and 3.0 (the English system inch is used in this example). Bend radii are always measured from the surface closest to the bend radius center.

Step 1. Locate the tangent points at the ends of the straight sides.

Step 2. Add the thickness of the sheet metal to the bend radius .25 (.125 + .25 = .375).

Step 3. Subtract the sum of the sheet metal thickness .125 and the radius .25 from the 3.00 overall length of the object (3.00 − .375 = 2.625).

Step 4. Subtract the sum of the sheet metal thickness .125 and the bend radius .25 from the 2.00 overall height of the object (2.00 − .375 = 1.625).

Step 5. Add the two straight sides together (2.625 + 1.625 = 4.250). This is the total length of the straight sides of this object, Figure 8-19B.

How To Find the Bend Allowance of a 90° Bend

Review Figure 8-19A.

Step 1. Note the metal thickness, in this example .125, and the inside radius, in this example .25.

Step 2. Refer to the bend allowance chart in inches for 90° bends in the Appendix at the end of this text.

Step 3. The left-hand column gives various metal thicknesses. Go down the left-hand column until the required size or the closest size is found. In this example .125.

Step 4. Along the top of the chart is listed various inside radii; go across the top of the chart to the required size or the closest radius, in this example .25.

Step 5. From the .125 number in the left-hand column project across to the right; from the .25 number along the top of the chart, project down to where the two columns intersect. Given is the bend allowance for material .125 thick with a .25 radius. In this example the bend allowance is .480, Figure 8-19C.

Step 6. The stretched-out dimension is found by adding the straight sides to the bend allowance; in this example, 4.250 + .480 = 4.730 (see Figure 8-19C).

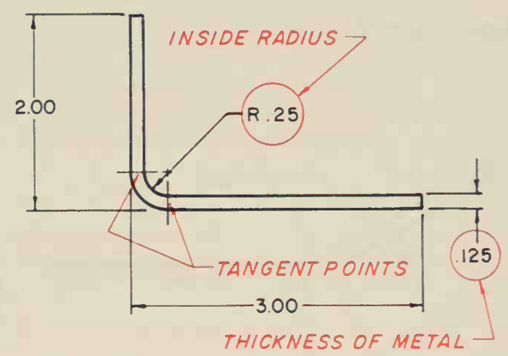


Figure 8-19A Bend allowance of 90° bend

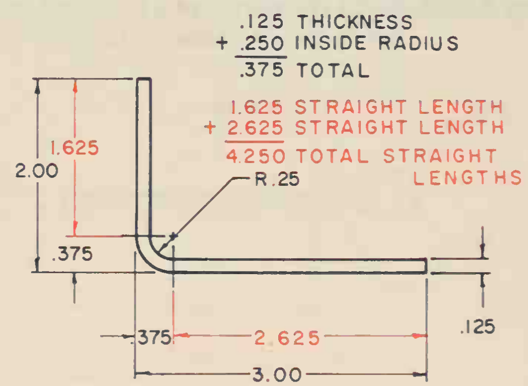


Figure 8-19B Total of straight lengths

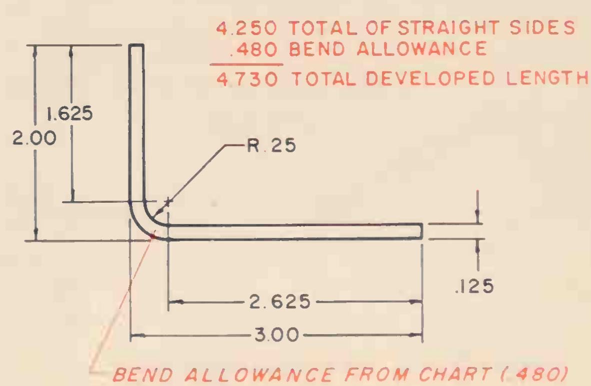


Figure 8-19C Total length including straight lengths and bend allowance

How To Find the Total Straight-Side Length Adjoining a Bend Other Than 90°

Figure 8-20A shows a simple 30° bend with an inside radius of 6.35 and a sheet metal thickness of 3.175 (the metric system is used in this example).

Step 1. Locate the tangent points at the ends of the straight sides.

Step 2. Determine the length of the straight sides and add them together (64.0 + 50.0 = 114.0). This is the total length of the straight sides of this object.

How To Find the Bend Allowance of Other Than a 90° Bend

Review Figure 8-20A.

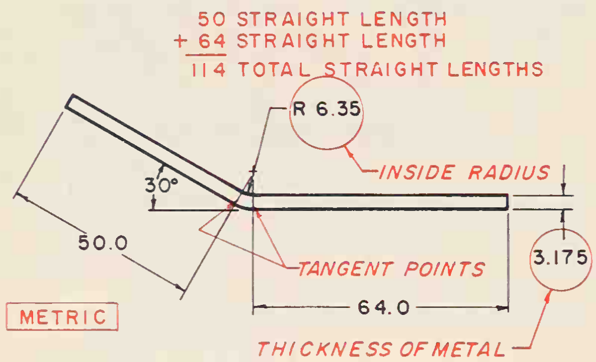


Figure 8-20A Bend allowance of a bend other than 90° – total of straight lengths

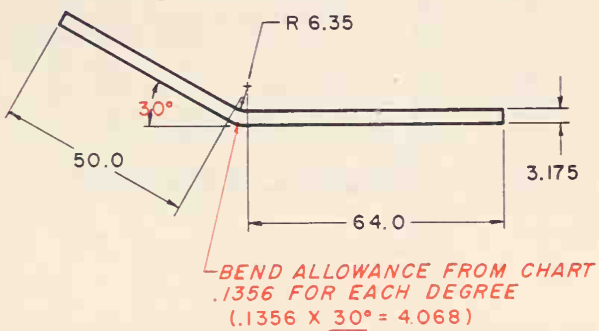


Figure 8-20B Total length of bend allowance

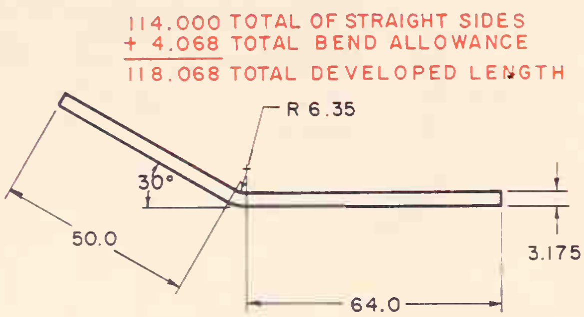


Figure 8-20C Total length including straight lengths and bend allowance

Step 1. Note the metal thickness, in this example 3.175, and the inside radius, in this case R6.35.

Step 2. Refer to the bend allowance chart in millimetres for 1° bends in the Appendix at the end of this text.

Step 3. The left-hand column gives various metal thicknesses. Go down the left-hand column until the required size or the closest size is found. In this example 3.175.

Step 4. Along the top of the chart is listed various inside radii. Go across the top of the chart to the required size or closest radius, in this example 6.35.

Step 5. From the 3.175 number of the left-hand column, project across to the right; from the 6.35 number along the top of the chart, project down to where the two columns intersect. Given is the factor used to calculate the bend allowance. In this example .1356.

Step 6. Multiply this factor times the actual degrees in the bend, from a straight 180° line, Figure 8-20B. This is the bend allowance (.1356 x 30° = 4.068).

Step 7. Add the straight-side lengths to the bend allowance to get the total developed length: 114.0 + 4.068 = 118.068, Figure 8-20C.

Note: A 30° bend dimension as illustrated in Figure 8-21A is actually 150° (180° – 30° = 150°). See Figure 8-21B. The total bend must be calculated from a straight piece that is actually 180° before bending.

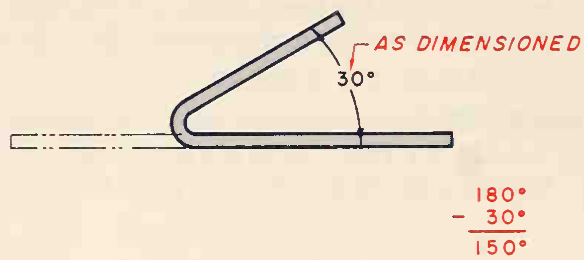


Figure 8-21A Total bend must be calculated from straight line dimension – given is 30°

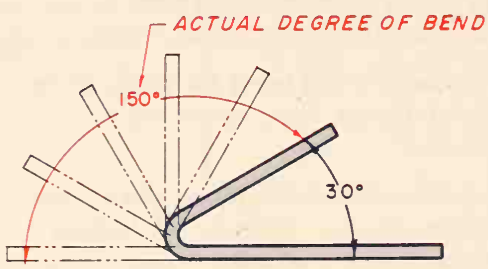


Figure 8-21B As dimensioned 30° is actually a 150° bend from a straight line

Review

1. What is a transitional piece and which kind of development would be used to develop a pattern?
2. What are the two major kinds of notches used in a development?
3. What does a gage number represent?
4. In parallel line development, at what angle to the fold lines must the baseline be projected?
5. Why is it important to develop the pattern or template with the inside surface up?
6. List the three major kinds of developments used to develop a pattern of an object.
7. Why are tabs used?
8. What is bend allowance, and why is it used?
9. Explain what must be done if a transitional piece does not have fold lines.
10. What is a true-length diagram and why is it used?
11. Why is the gage system of calling out the thickness of a material being phased out?
12. What two elements must be located or laid out before a development can be actually started?

Chapter Eight Problems

The following problems are intended to give the beginning drafter practice in sketching, laying out auxiliary views if required, and drawing the stretched-out development of various objects. These problems will use one or more of the three standard methods of development: *parallel line developments, radial line developments* and *triangulation developments.* The student will also practice calculating developed lengths using various charts to determine full length before bending.

The steps to follow in laying out any object that is to be developed are:

Step 1. Study the problem carefully.

Step 2. Determine which method or methods of development will be used (parallel line/radial line/triangulation).

Step 3. On a scrap sheet of paper, draw to scale enough views as required to lay out *all* true lengths and true distances. Add the end view and auxiliary views, in scale, if necessary. Draw with a *sharp* 4-H lead, and work as accurately as possible.

Step 4. Label each point, if necessary, in order to keep track of progress.

Step 5. Check all lengths, and auxiliary views if included.

Step 6. Starting from a baseline, lightly lay out the development. Use *true lengths* and *true distances* for *all* measurements. (Be sure to *start* the seam at the *shortest* fold line possible.)

Step 7. Label each point, if necessary, in order to keep track of progress.

Step 8. Use *phantom lines* to represent all *fold lines.*

Step 9. Add tabs as required, and check to see that there are enough but without duplications.

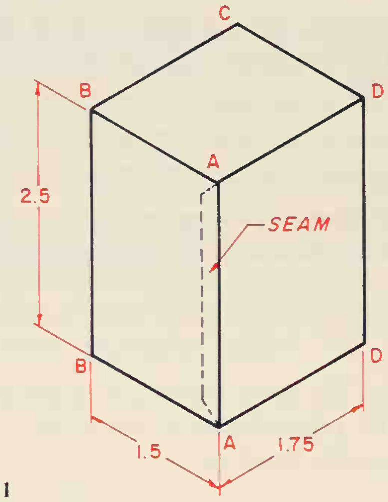
Step 10. Recheck all true lengths and true distances.

Step 11. Darken in all lines.

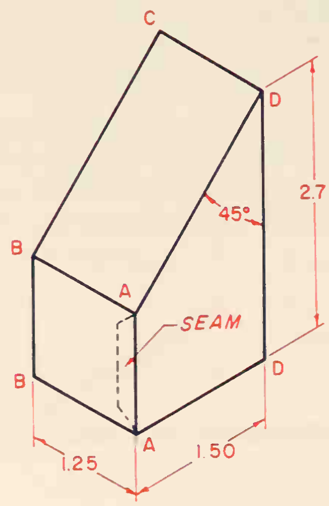
Problems 8-1 through 8-18

Using the parallel line development method, develop each object starting from the given *seam*. Label each point clockwise; add ends and/or auxiliary views as necessary to develop a complete object. Add tabs .125 (3) × 45° to suit. Use phantom lines for all fold lines.

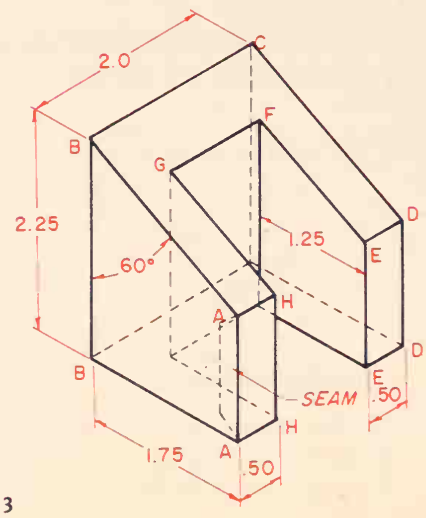
Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



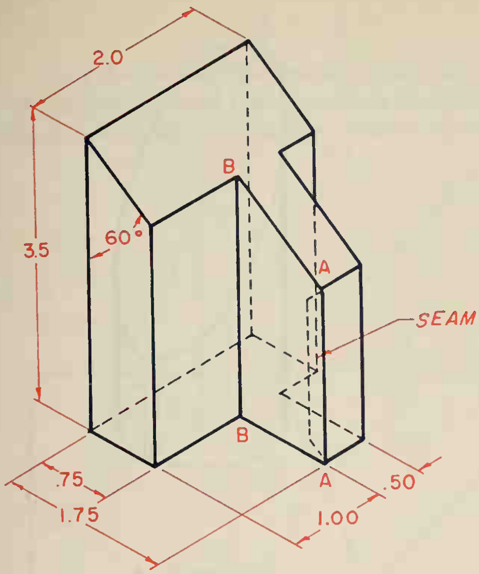
Problem 8-1



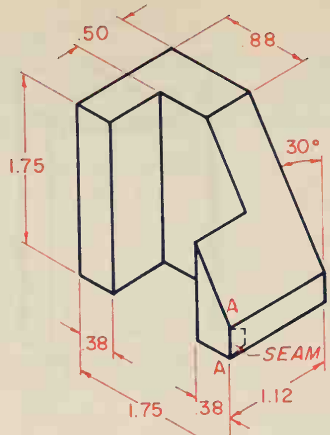
Problem 8-2



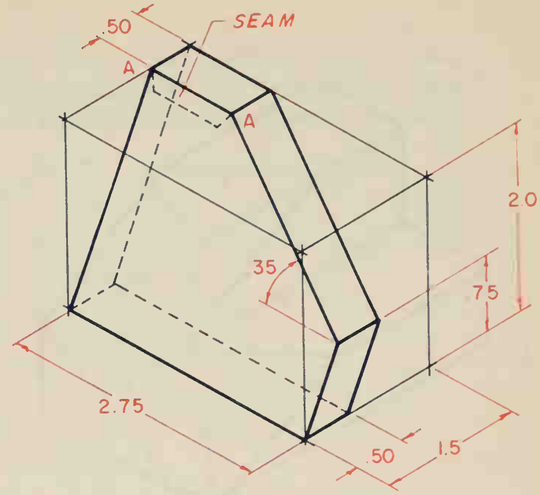
Problem 8-3



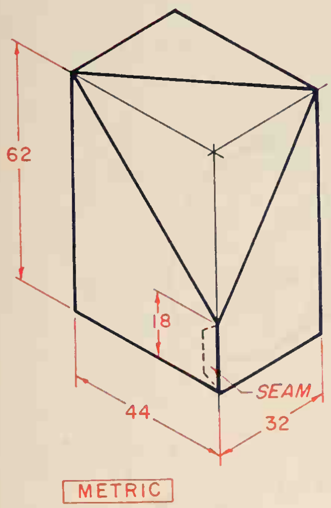
Problem 8-4



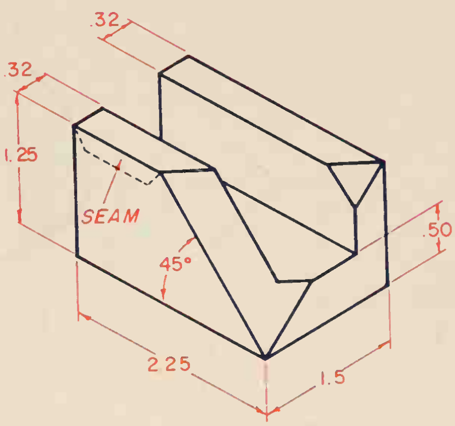
Problem 8-5



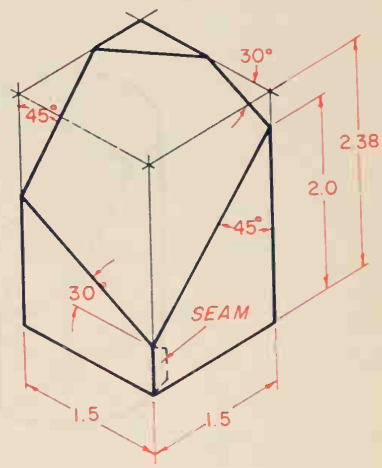
Problem 8-6



Problem 8-7



Problem 8-8



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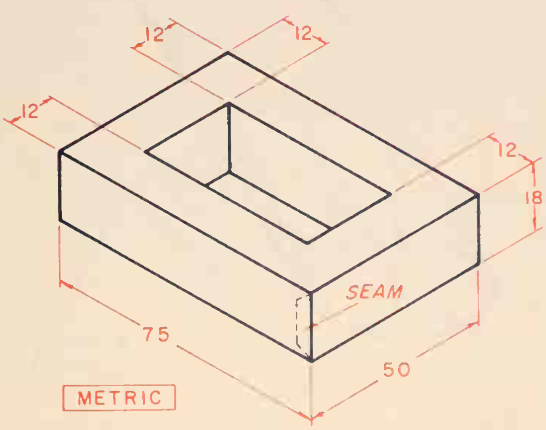

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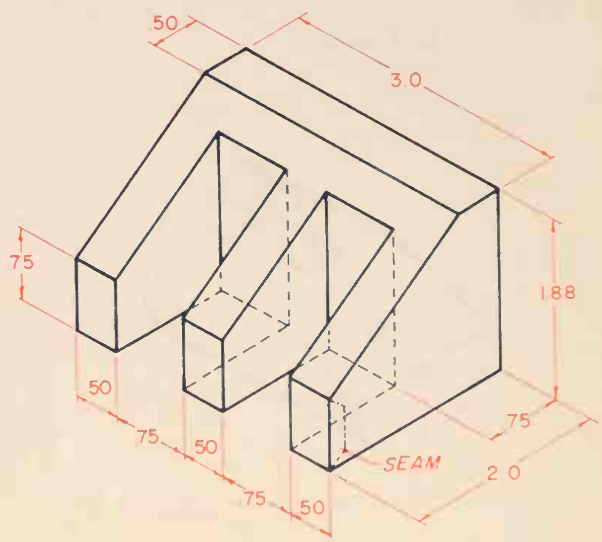
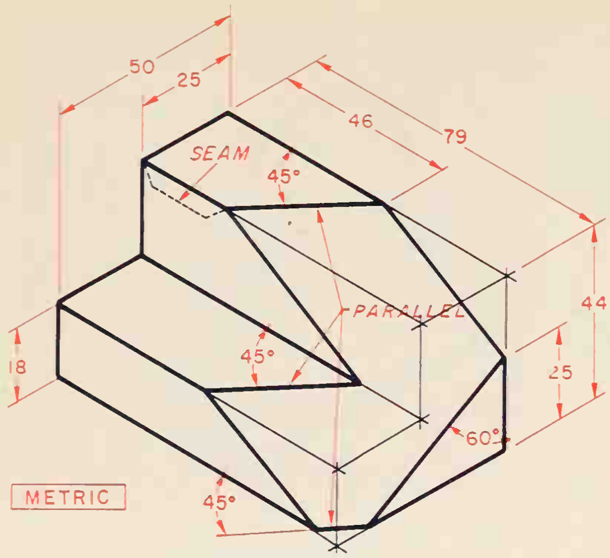
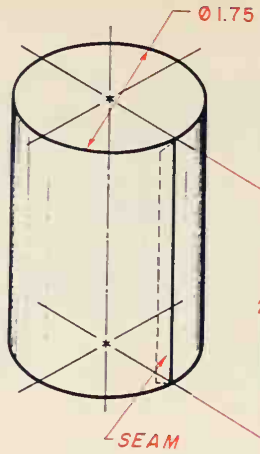


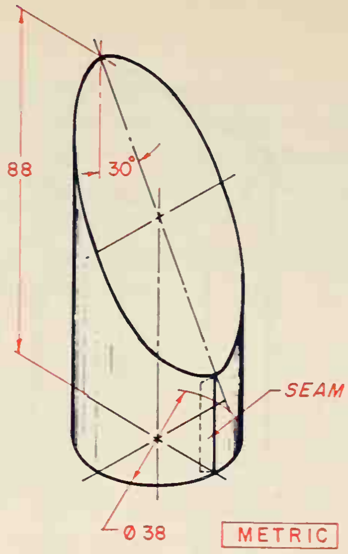
Problem 8-11



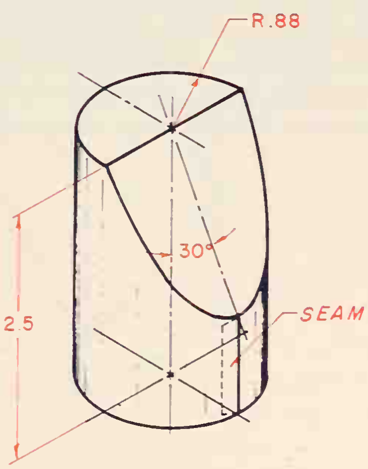
Problem 8-12



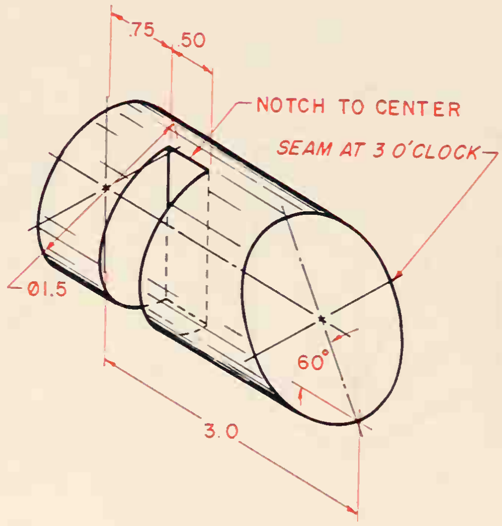
Problem 8-13



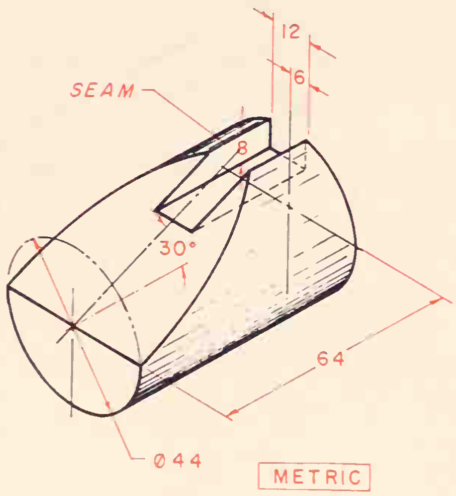
Problem 8-14



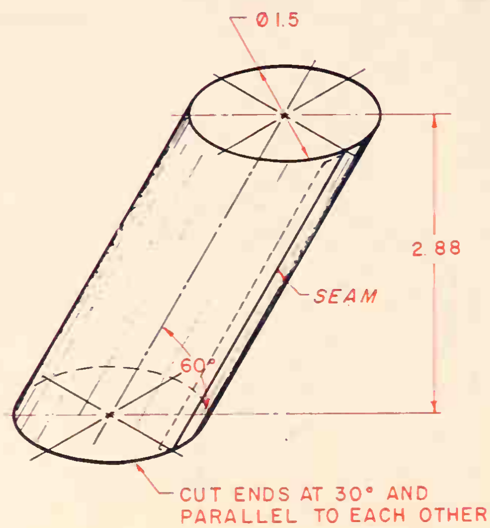
Problem 8-15



Problem 8-16



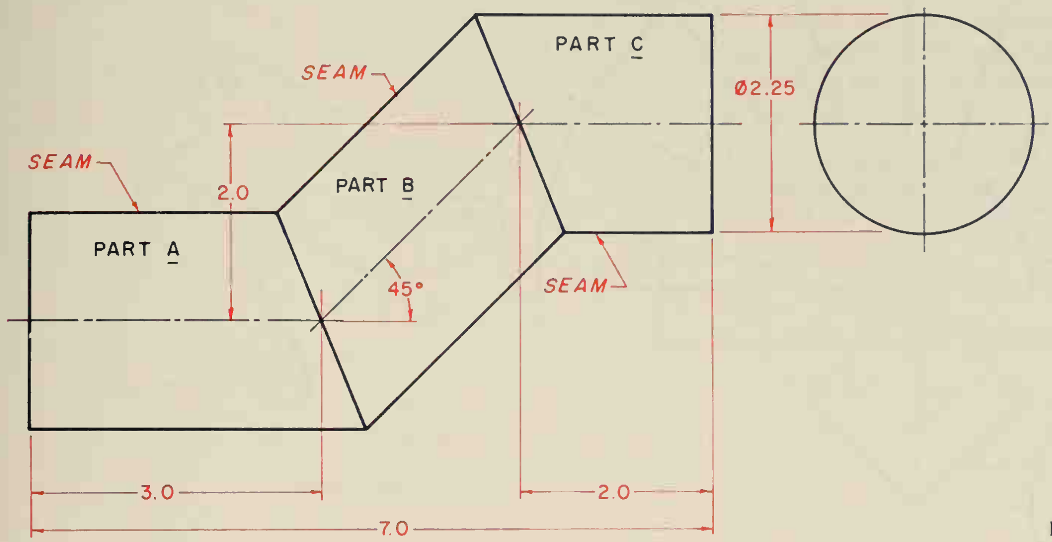
Problem 8-17



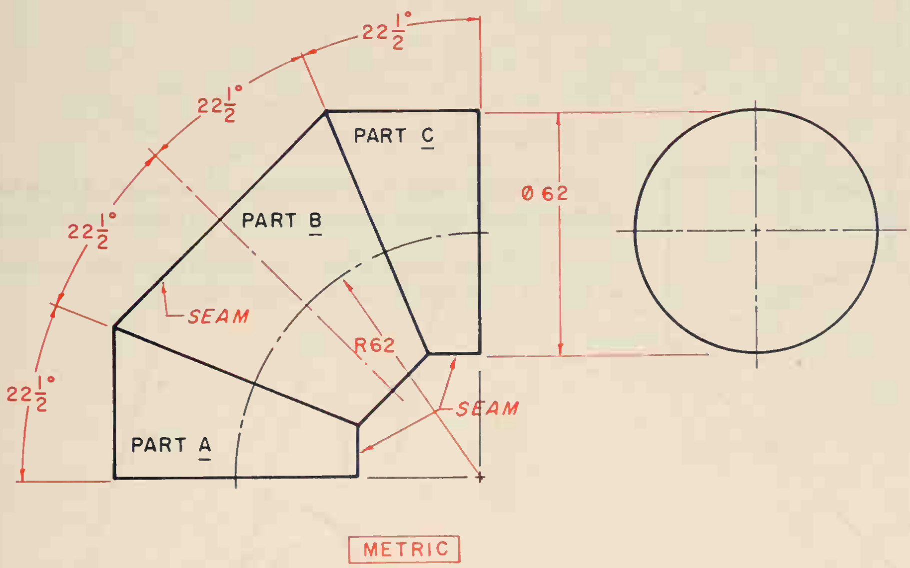
Problem 8-18

Problems 8-19 through 8-23

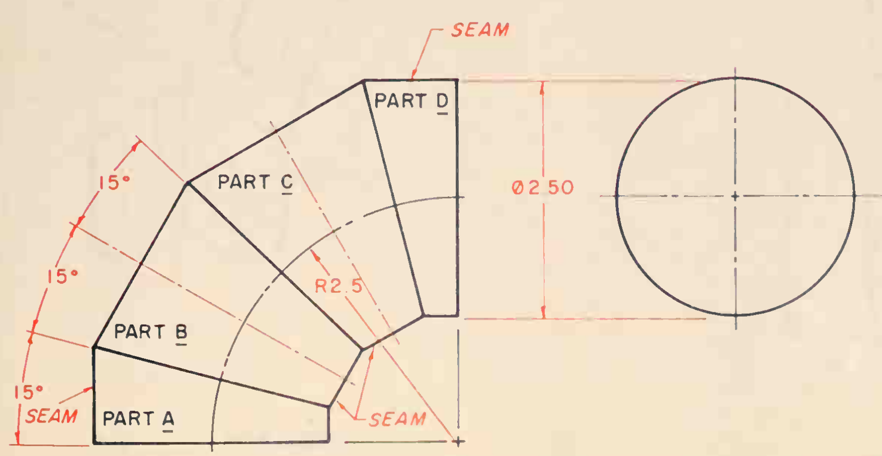
Using the parallel line development method, develop each object starting from the given *seams*. Add .125 (3) × 45° tabs as required to hold parts together. Design parts so there are as many identical parts as possible. Use phantom lines for all fold lines. Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



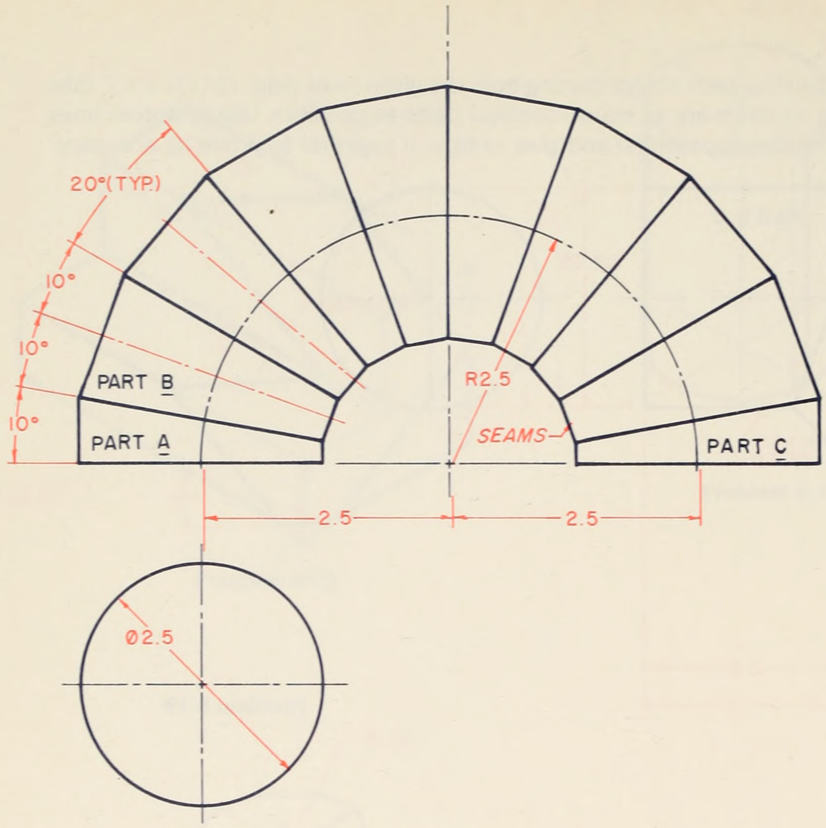
Problem 8-19



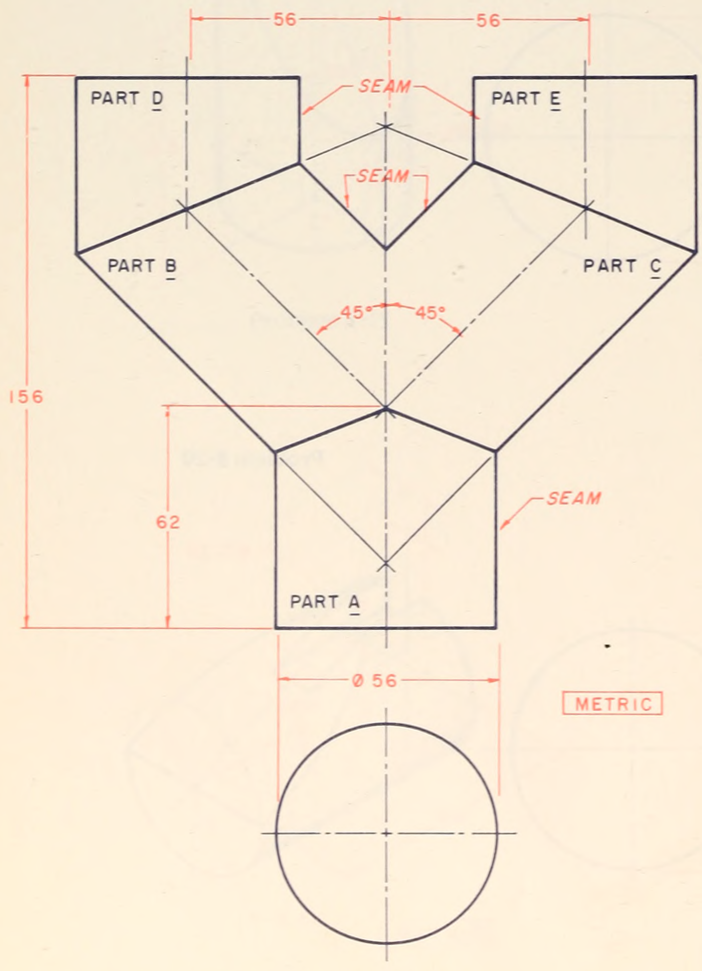
Problem 8-20



Problem 8-21



Problem 8-22

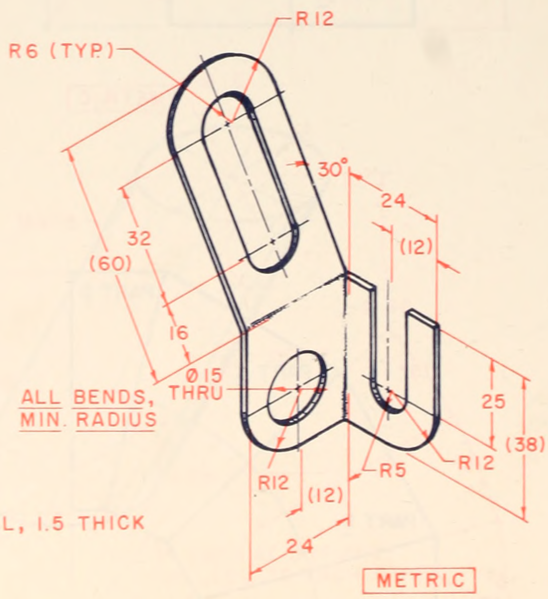


Problem 8-23

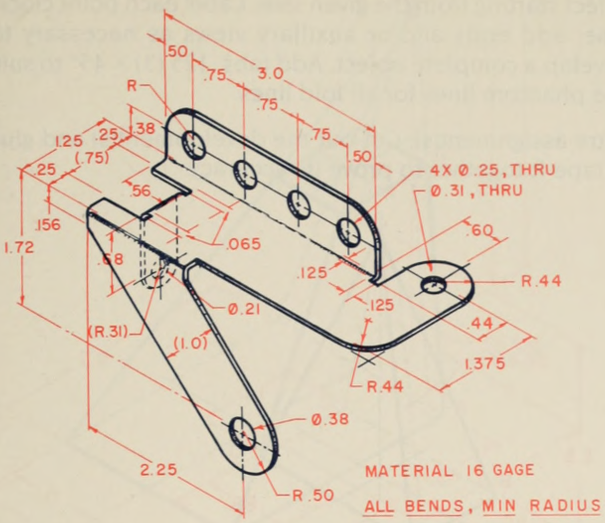
Problems 8-24 through 8-26

Develop the objects, using given dimensions. Using *bend allowance charts*, design layouts to include material for bends.

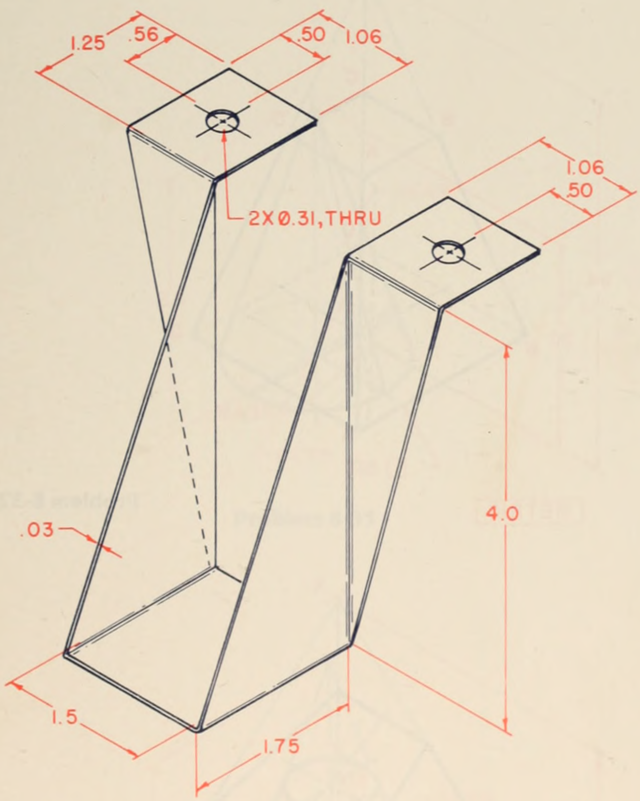
Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



Problem 8-24



Problem 8-25

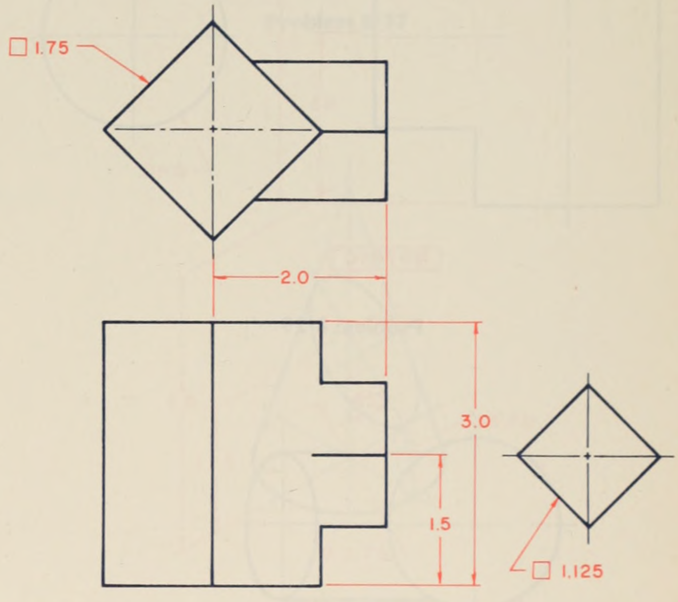


Problem 8-26

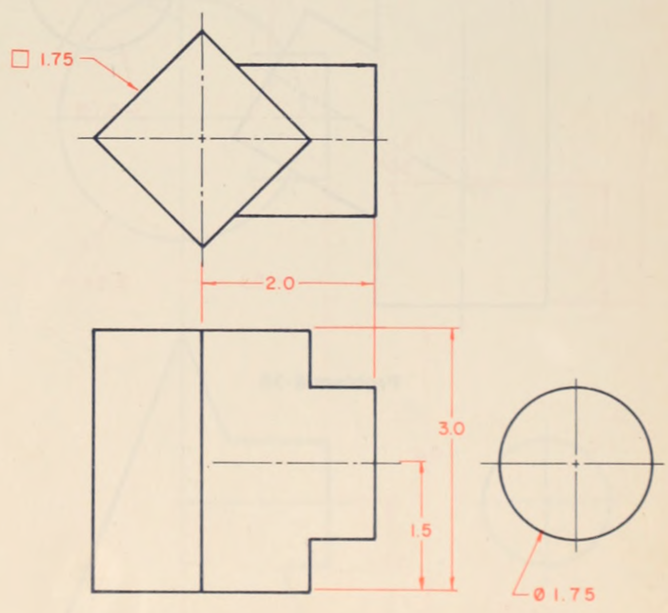
Problems 8-27 through 8-30

Carefully lay out a full-size multiview drawing of the object, include all intersection lines. Make a full-size development of the object. Add tabs .125 (3) × 45° as required to hold parts together.

Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



Problem 8-27



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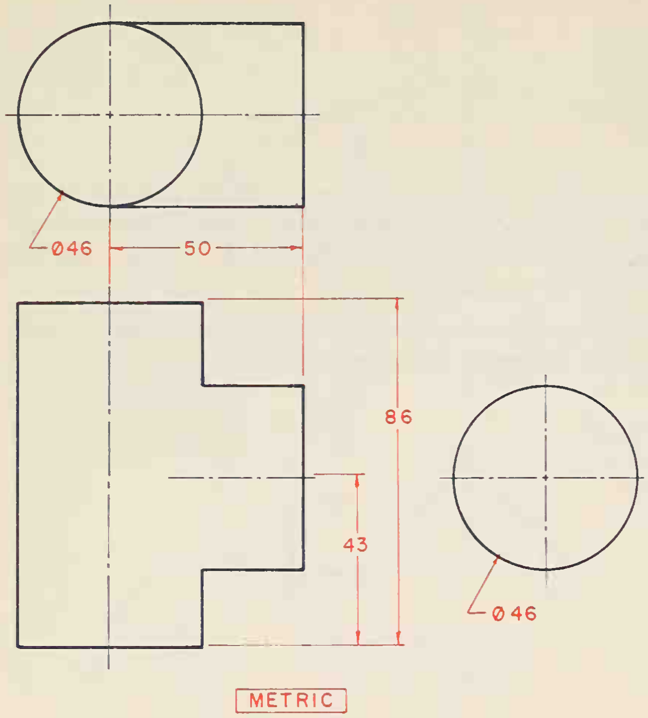

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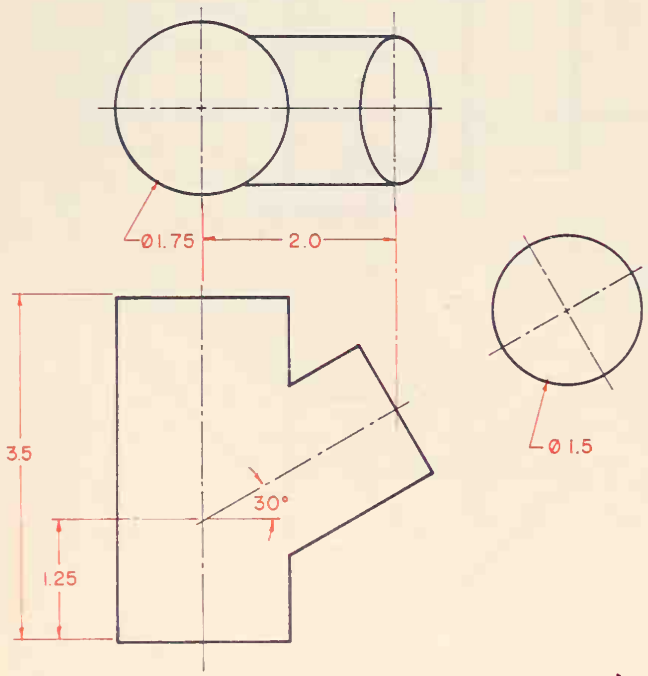
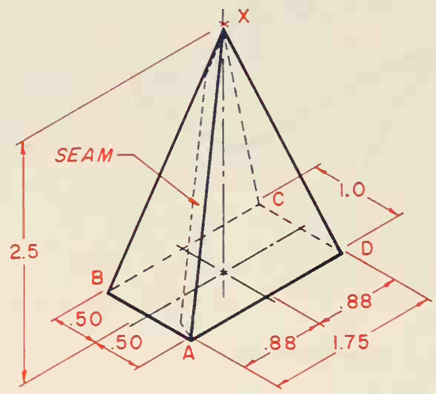


Problem 8-30

Problems 8-31 through 8-42

Using the radial line development method, develop each object starting from the given *seam*. Label each point clockwise: add ends and/or auxiliary views as necessary to develop a complete object. Add tabs .125 (3) × 45° to suit. Use phantom lines for all fold lines.

Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



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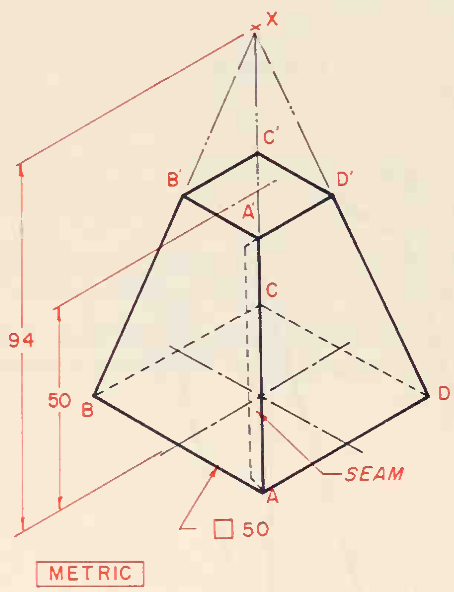

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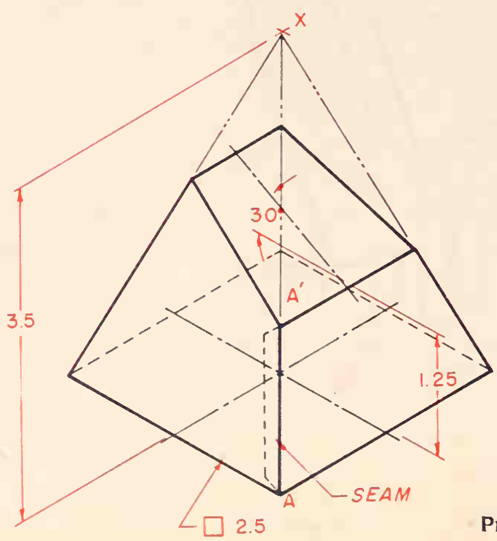

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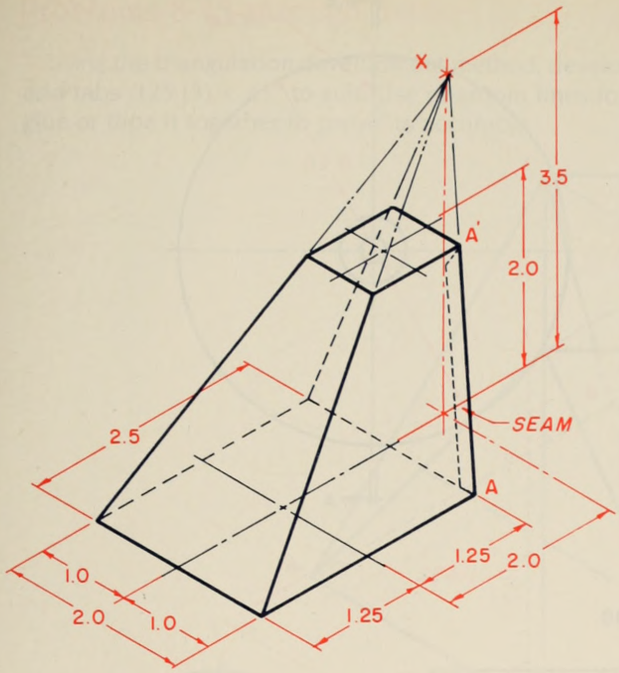

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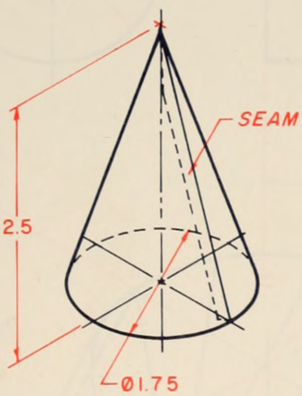

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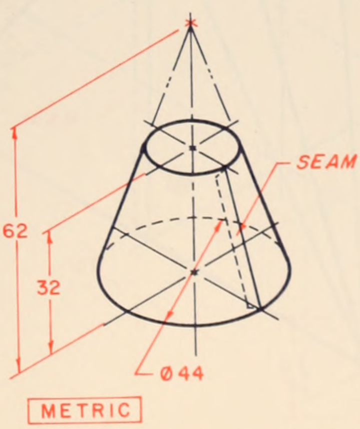

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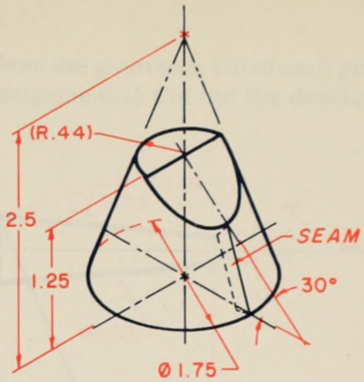

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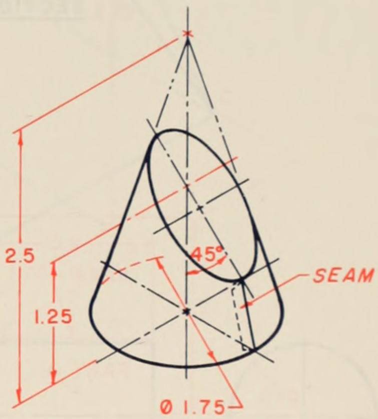

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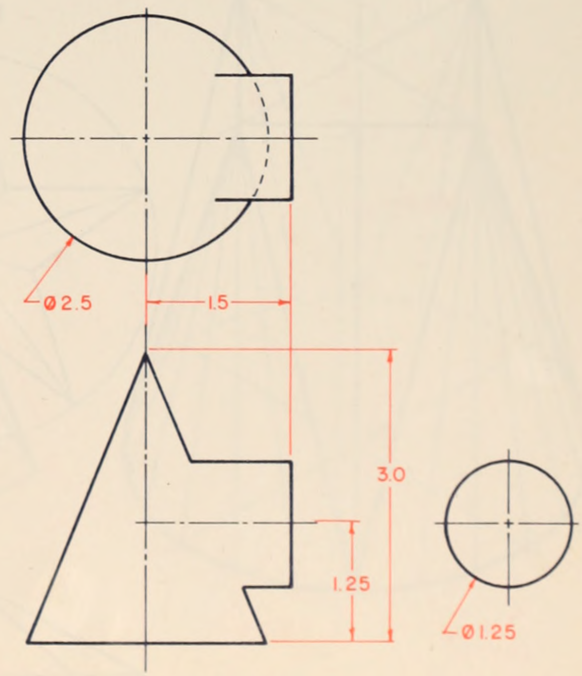

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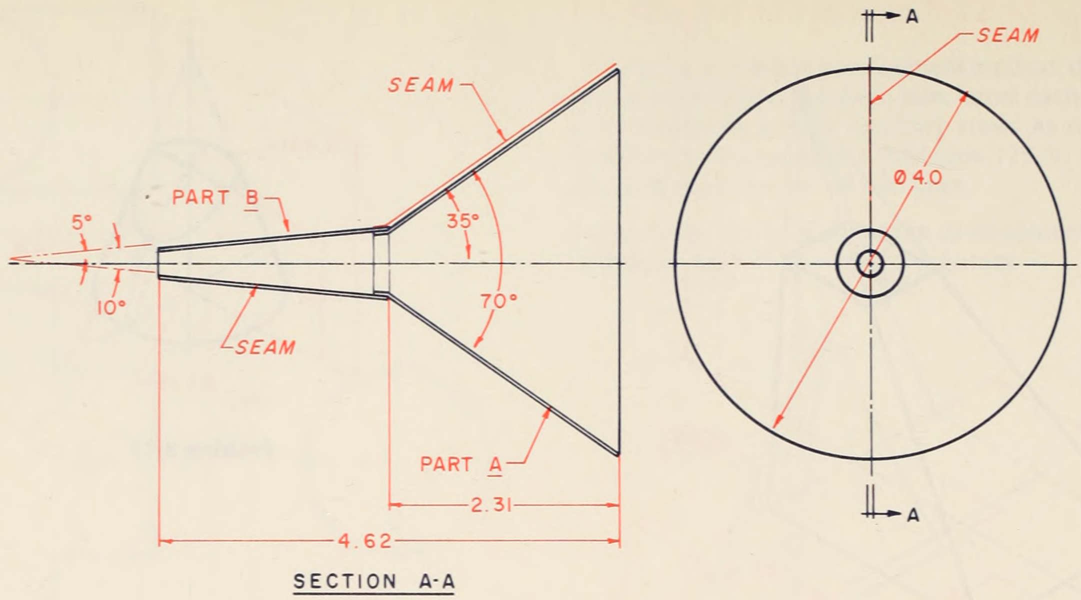

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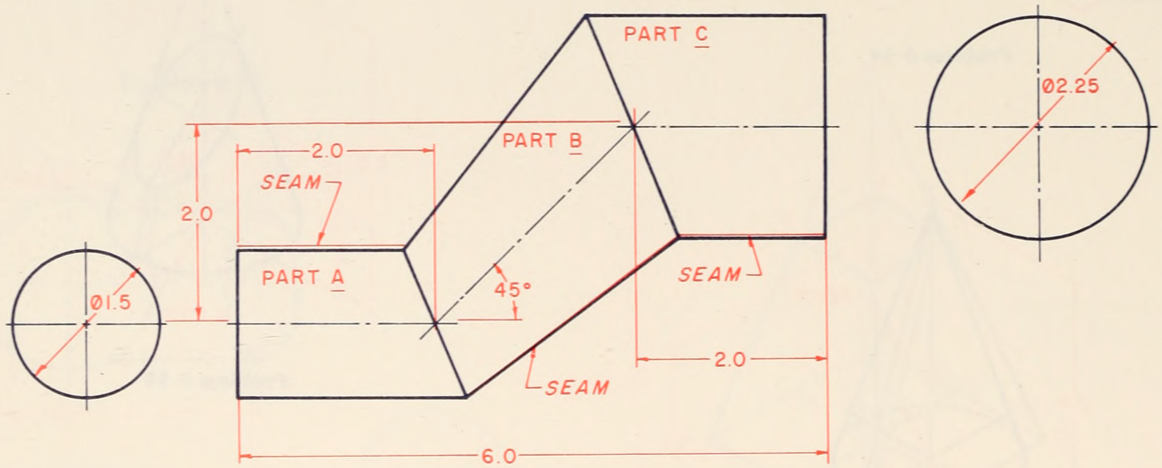
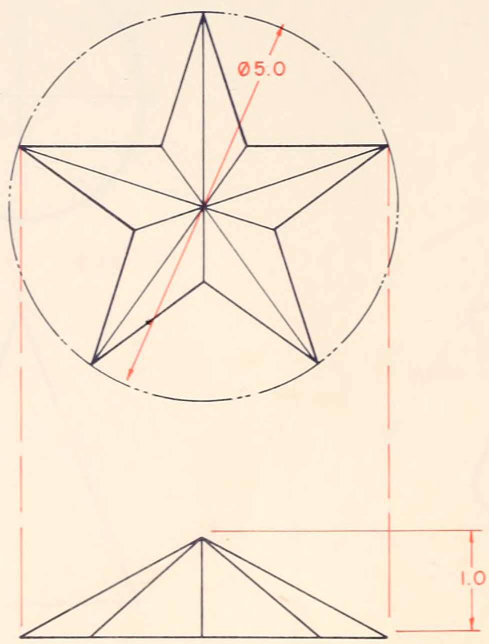


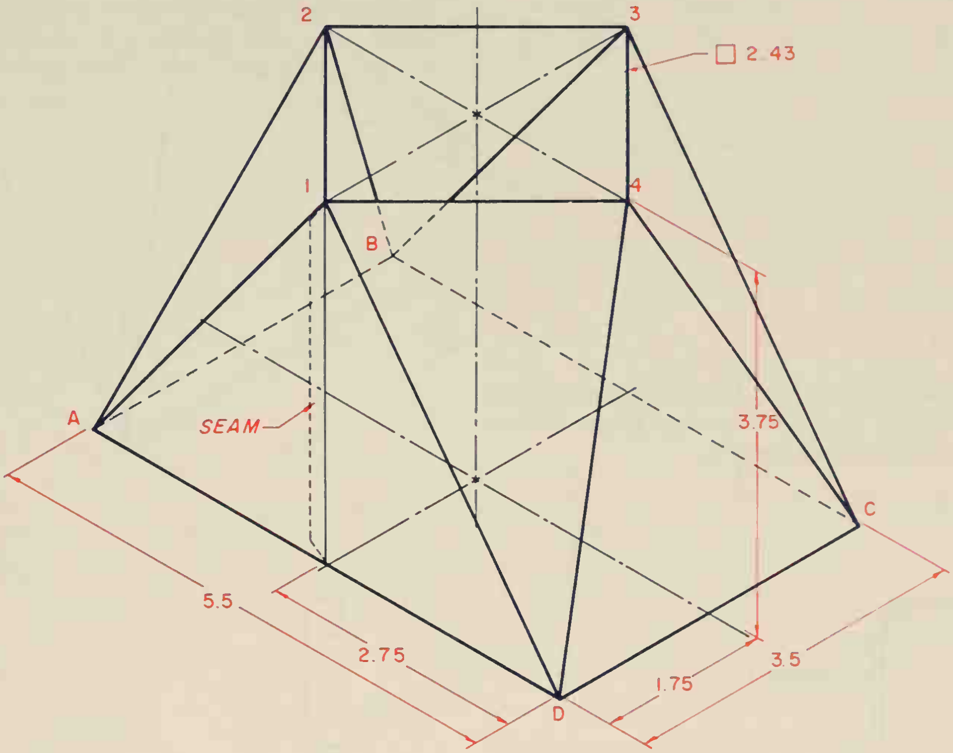
Problem 8-41



Problem 8-42

Problems 8-43 through 8-46

Using the triangulation development method, develop each object starting from the given *seam*. Label each point clockwise: add tabs .125 (3) × 45° to suit. Use phantom lines for all fold lines. Extra assignment(s): Cut out the development(s) and glue or tape it together to prove its accuracy.



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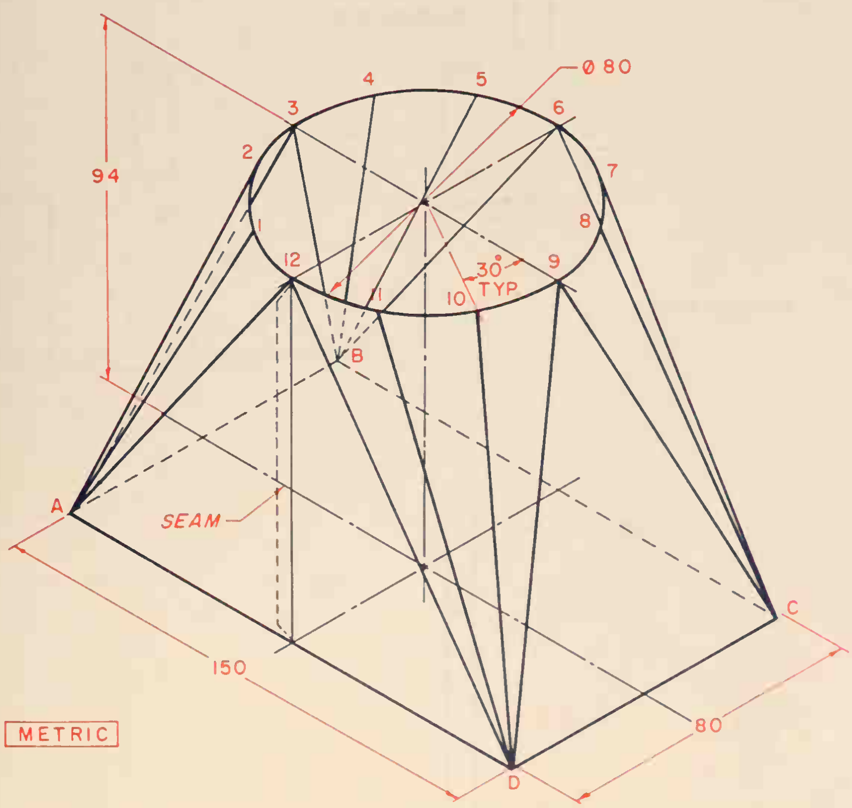

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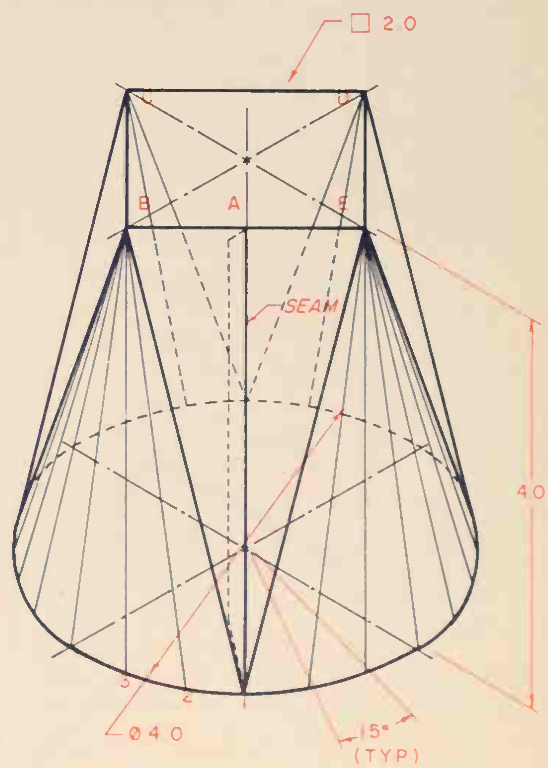
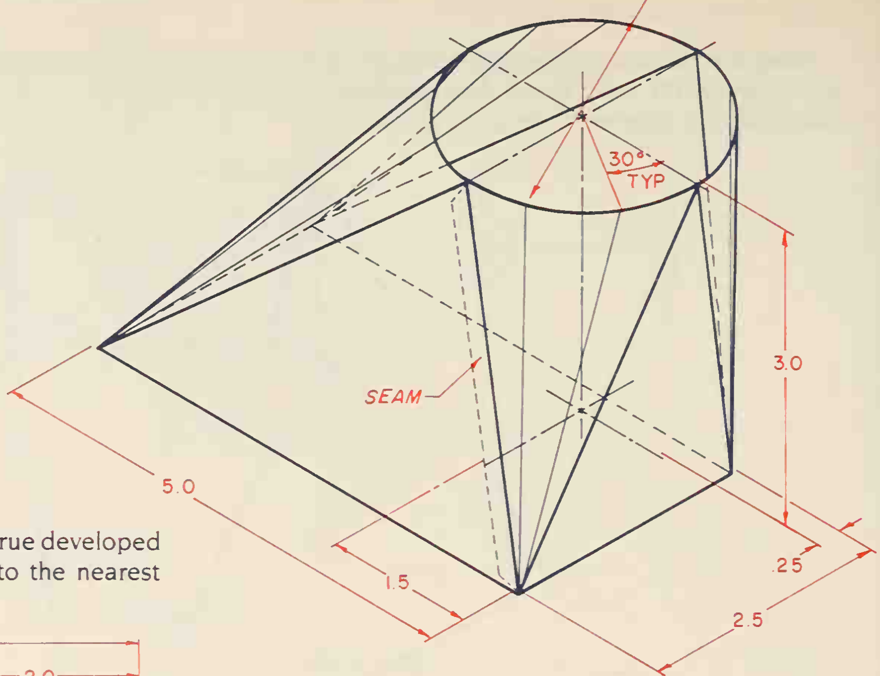


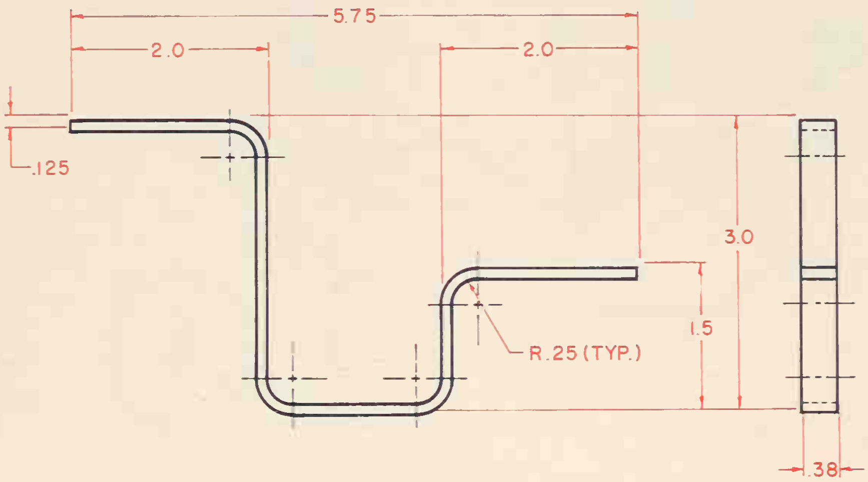
Problem 8-45

Problem 8-46



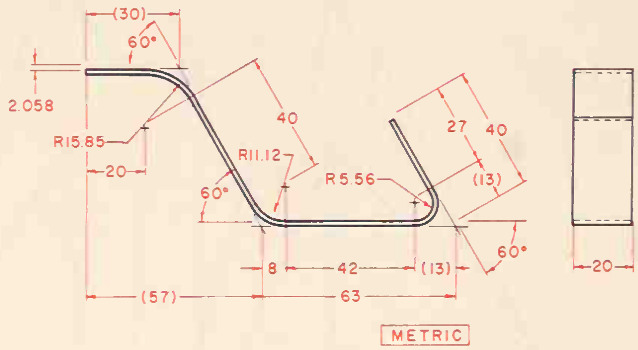
Problems 8-47 through 8-49

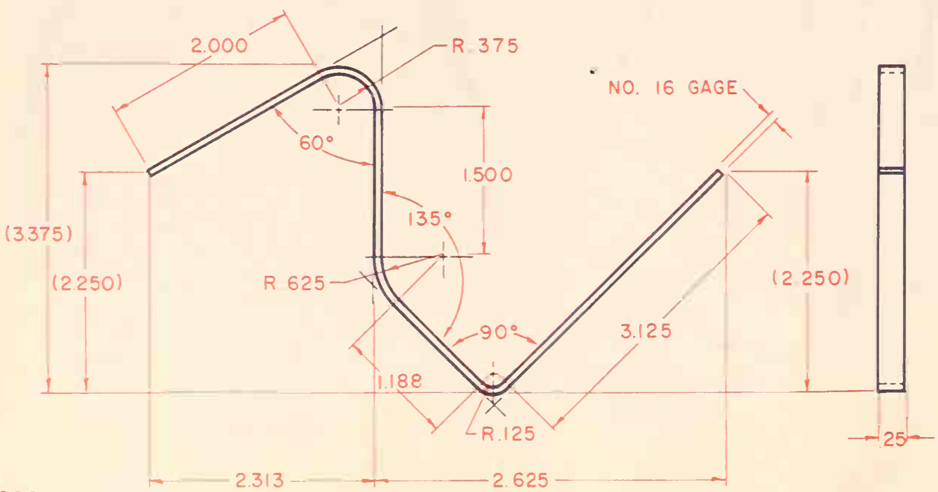
Using development charts, calculate the true developed length of each object. Round the answer to the nearest three places. Recheck all calculations.



Problem 8-47

Problem 8-48

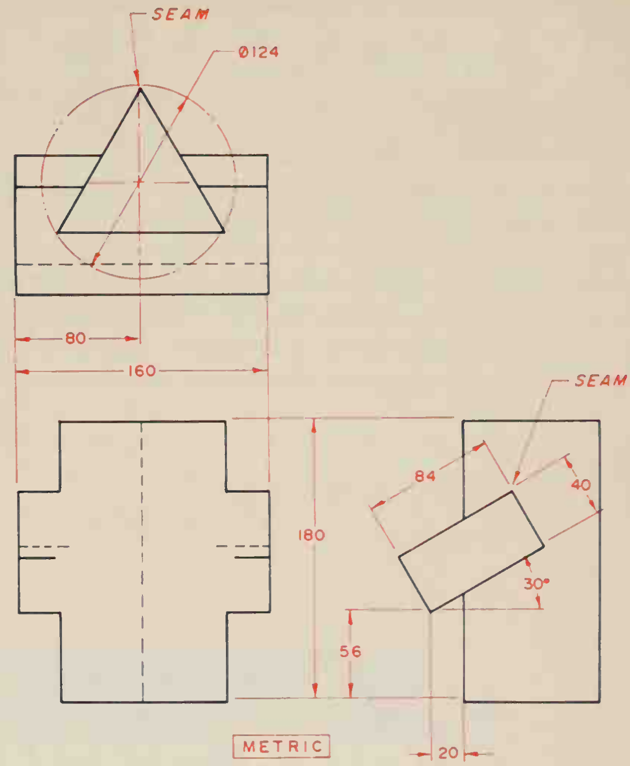




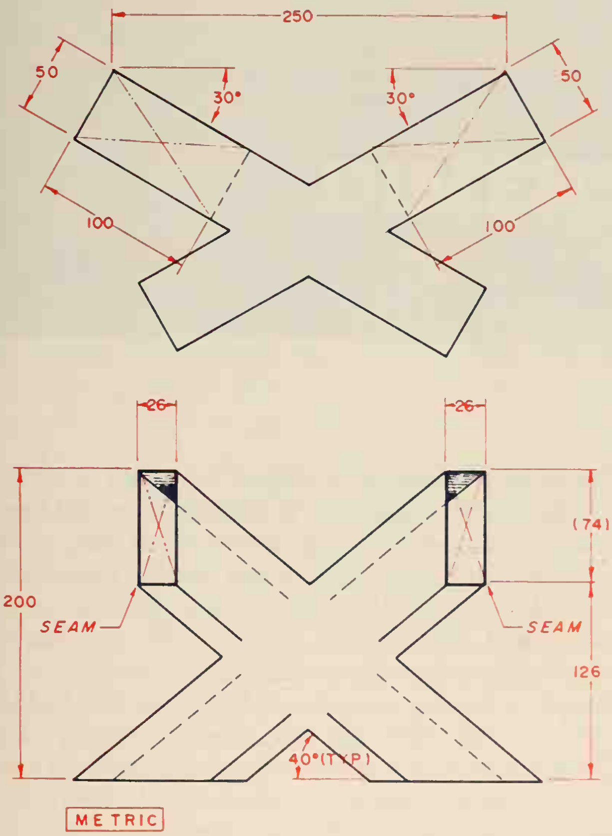
Problem 8-49

Problems 8-50 through 8-54

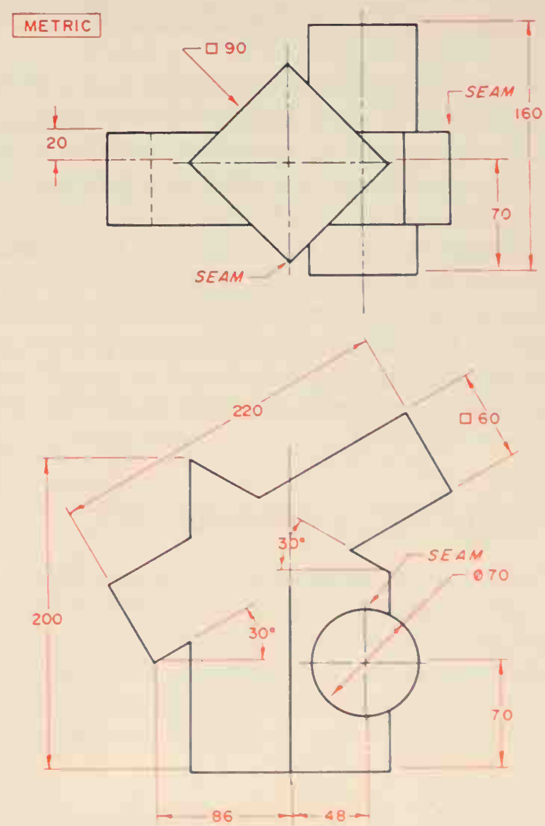
Using either the parallel line, the radial line, or the triangulation development method, develop each object. Be sure to leave a seam and to add all required tabs to suit as required. Use phantom lines for all fold lines. Extra assignment(s): cut out the development and glue or tape it together to prove its accuracy.



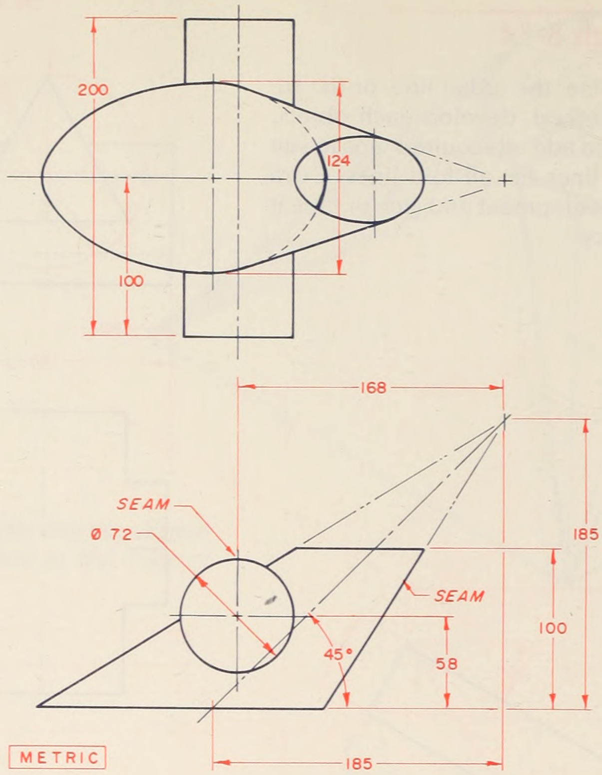
Problem 8-51



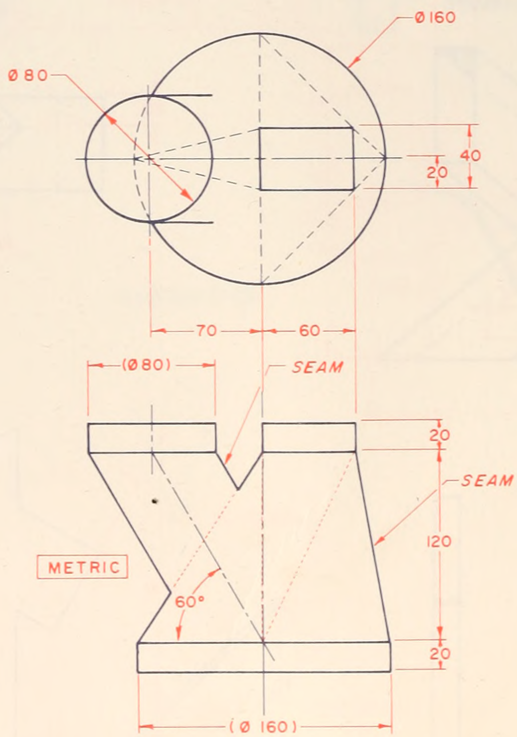
Problem 8-50



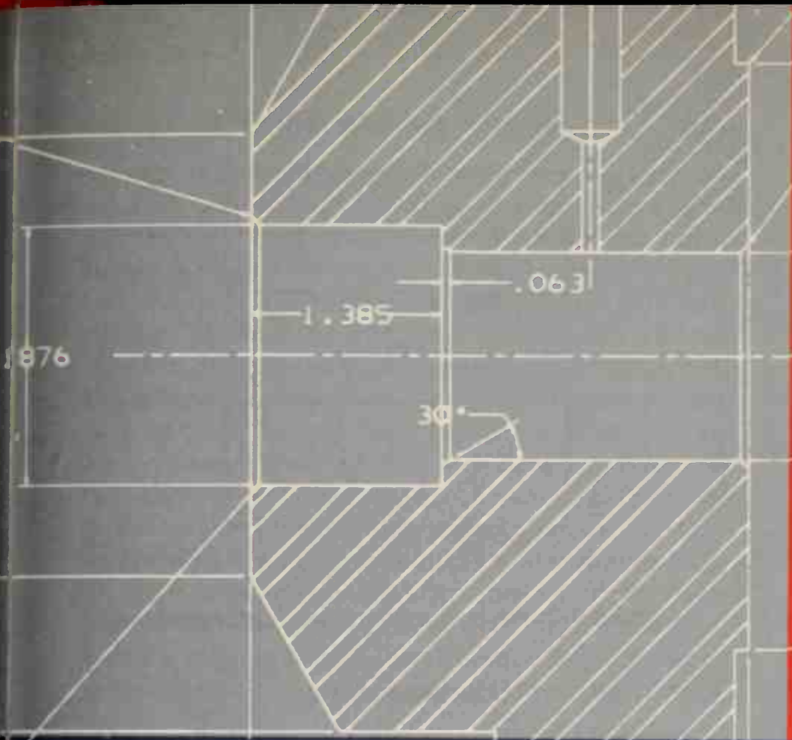
Problem 8-52



Problem 8-53



Problem 8-54



CHAPTER 9

This chapter covers in depth the fundamentals of dimensioning and notation. All dimensioning techniques presented are in accordance with ANSI Y14.5M-1982, the latest edition of the dimensioning standard. Major topics covered include specifying the scale, dimensioning systems, general rules of dimensioning, specific dimensioning techniques, rules for applying notes on drawings, general notes, detail notes, writing notes, note specifications, and sample notes.

DIMENSIONING AND NOTATION

One of the most fundamental drafting tasks is to meet the requirements of the engineering definition of the part while providing for the most economical production process and interchangeability considerations. All of this is accomplished by the use of proper dimensions and notation on drawings. *Dimensioning* is the process whereby size and location data for the subject of a technical drawing are provided. *Notation* is the process whereby needed information not covered by dimensions is placed on a technical drawing.

It is critical that drafters, designers, and engineers be proficient in standard dimensioning practices. The most widely accepted dimensioning standard is American National Standards Institute document Y14.5M-1982 (ANSI Y14.5M-1982). Similar standards are produced by the International Standards Organization (ISO). However, unless otherwise specified, ANSI Y14.5M-1982 is the standard used for guiding dimensioning practices.

Modern dimensioning practices described in ANSI Y14.5M-1982 apply in most instances in which interchangeability of parts is a major consideration. The concept dictates that parts produced from a drawing at one manufacturing site should be interchangeable with those produced at another manufacturing site. Automotive parts are an excellent example of production for interchangeability. Some parts are manufactured in America, some in Europe, and some in Japan, but they must all fit together in one car during assembly. Although interchangeability is not a factor with all parts that are produced, the drafter should still use the basic dimensioning principles of ANSI Y14.5M-1982. This is particularly important when the parts will be produced using such ever-increasing automated, semiautomated, or integrated processes as numerical control, computer-aided manufacturing (CAM), or computer-integrated manufacturing (CIM).

Dimensioning Systems

Three dimensioning systems are used on technical drawings in the United States. Metric dimensioning, decimal-inch dimensioning, and fractional dimensioning. Certain rules of practice with which drafters should be familiar pertain to each of these dimensioning systems.

Metric Dimensioning

The standard metric unit of measurement for use on technical drawings is the millimeter (0.001 meter)

UNIT	MULTIPLE OF A METRE
METRE	1.0
DECIMETRE	0.1
CENTIMETRE	0.01
MILLIMETRE	0.001

Figure 9-1 Metric linear measurements

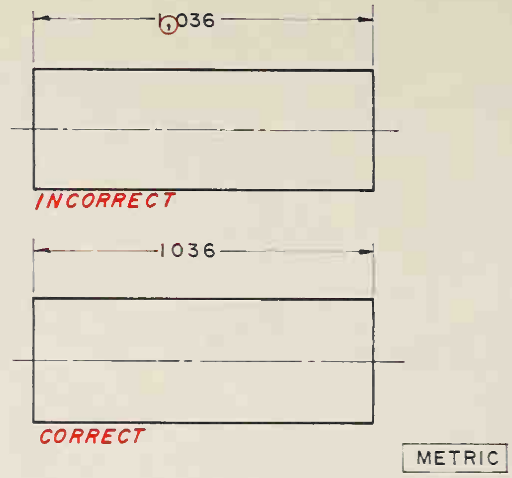


Figure 9-3 No commas in metric dimensions

or .039 inch. Figure 9-1 is a chart of various metric units of measurement of less than a meter that shows where the millimeter fits in.

When using metric dimensioning, several general rules should be observed. When a dimension is less than 1 millimeter, a zero must be placed to the left of the decimal point, Figure 9-2, Part A. When a metric dimension is a whole number, neither the zero nor the decimal is required, Figure 9-2, Part B. When a metric dimension consists of a whole number and a decimal portion of another millimeter, it is written as follows: whole number first, decimal point second, and finally, the decimal part of the number. The decimal part of the number is not followed by a zero in metric dimensioning, Figure 9-2, Part C. Individual digits in metric dimensions are not separated by commas or spaces, Figure 9-3. Drawings prepared with metric dimensions are identified with the word "metric" contained in a small rectangle below the part.

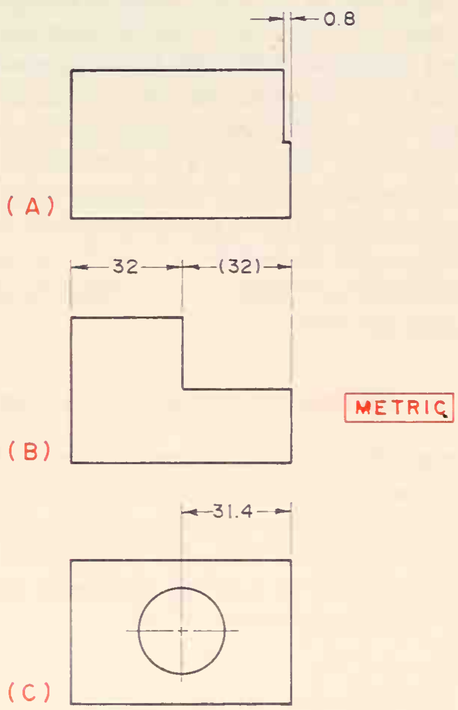


Figure 9-2 Metric dimensioning

Decimal-Inch Dimensioning

Decimal-inch dimensioning is frequently used in the dimensioning of technical drawings. It is a much less cumbersome system for mechanical drawings than is the fractional system, and it is still used more than the metric system. When using the decimal-inch dimensioning system, several rules should be observed. If a dimension is less than one inch, only a decimal point and the numbers of the decimal fraction are required. A zero is not required to precede the decimal point, Figure 9-4, Part A. The number of places beyond the decimal point that a decimal-inch dimension is carried is determined by the specified tolerance for the part in question, Figure 9-4, Part B. In this figure, a tolerance of .002 (±.001), three places to the right of the decimal, is specified. Consequently, the dimension of 1.637 is carried out three places to the right of the decimal.

There are no specified sizes for decimal points, but they should be made dark enough and large enough to be seen and to reproduce through any normal reproduction process (diazo, photocopy, or microfilm).

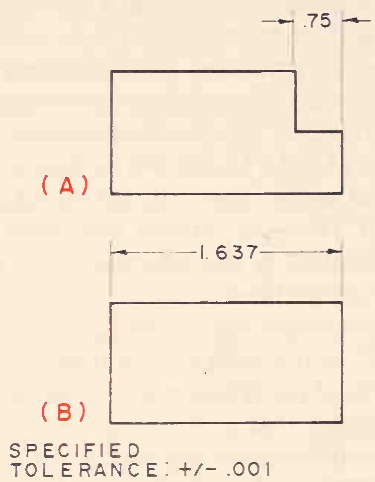


Figure 9-4 Decimal-inch dimensioning

Fractional Dimensioning

Fractional dimensioning is not frequently used on mechanical technical drawings. Its primary use is on architectural and structural engineering drawings. However, since it is occasionally still used on mechanical drawings, drafters should be familiar with this system. When using fractional dimensions on mechanical drawings, several rules should be observed. The line separating the numerator and denominator of a fraction should be a horizontal line, not an inclined line, Figure 9-5. Full-inch dimensions should be a minimum of one-eighth inch in height. The combined height of the numerator, denominator, and horizontal line of a fraction should be one-quarter inch, Figure 9-6, for A, B, and C size drawings, and a minimum of five-sixteenths inch for D, E, and F sizes. Also, be sure to leave a visible gap between the numerator, denominator, and the horizontal line of the fraction.

Figure 9-5 Horizontal line is the correct method

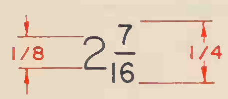


Figure 9-6 Proportions for fractions

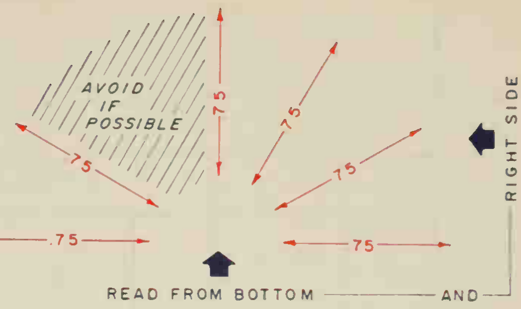


Figure 9-7 Aligned dimensioning system

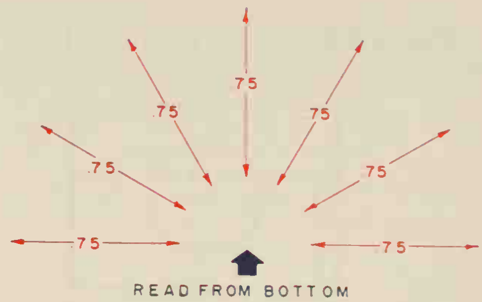


Figure 9-8 Unidirectional dimensioning system

Orienting Dimensions

Regardless of whether you are dimensioning in the metric, decimal-inch, or fractional dimensioning system, there are two subsystems for orienting dimensions. These orientation subsystems are known as the aligned system and the unidirectional system. The aligned dimensioning system is illustrated in Figure 9-7. In this system the dimensions are aligned with the dimension line so that they can be read either from the bottom of the drawing sheet or from the right-hand side. Notice in Figure 9-7 the area which has been marked off to be avoided if possible. Dimensions written in this area are difficult to read from either the bottom or the right-hand side of the drawing sheet and, therefore, should be avoided. The unidirectional dimensioning system is illustrated in Figure 9-8. In this system all dimensions are written so that they can be read from the bottom of the drawing sheet. This means that the guidelines used in entering the dimensions should always be parallel with the bottom of the page.

Dimension Components

Several components are common to all dimensioning systems. These include extension lines, dimension lines, arrowheads, leader lines, and the actual numbers or dimensions. Drafters and engineers should be knowledgeable in the proper use of these components.

Extension Lines

An *extension line* is a thin, solid line that extends from the object in question or from some feature of the object. Several rules should be observed when placing extension lines on technical drawings. There should be a small but visible gap between the object or object feature and the beginning of an extension line, Figure 9-9, Part A. Extension lines should extend uniformly beyond dimension lines for a distance of approximately one-eighth inch, Figure 9-9, Part B. Extension lines that originate on the object, such as center lines, may cross visible lines with no gap required, Figure 9-10. Figure 9-11 is a fully dimensioned mechanical drawing which summarizes the basic rules drafters and engineers should remember about spacing of extension lines, dimension lines,

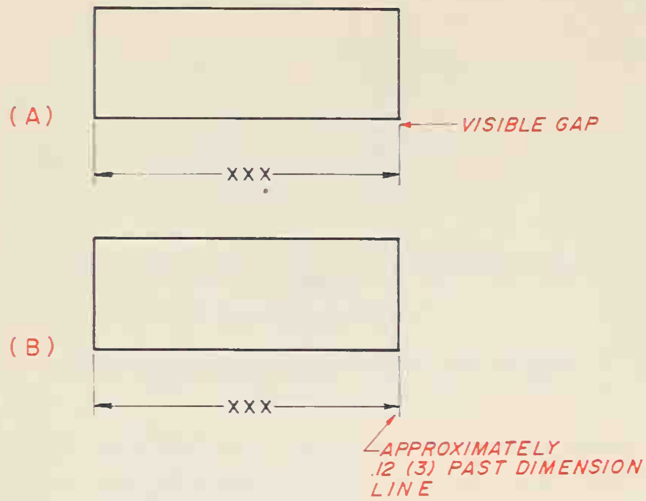


Figure 9-9 Drawing extension lines

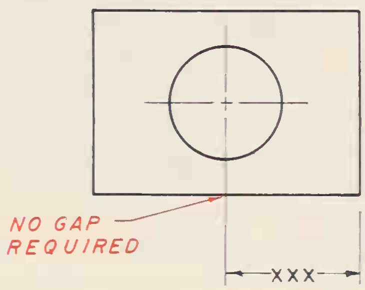
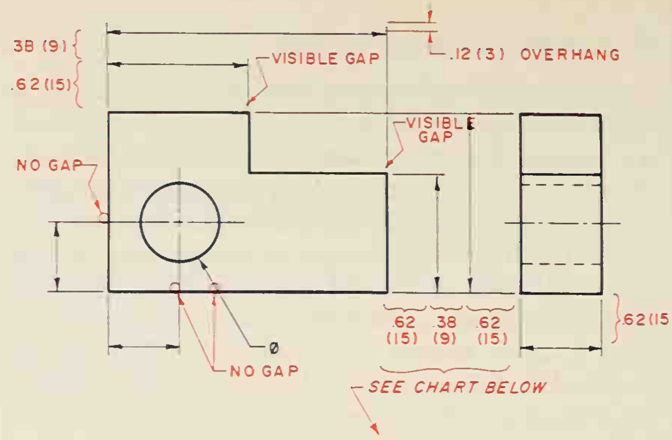


Figure 9-10 Center lines as extension lines

and dimensions. Notice in this figure that when center lines become extension lines there is no gap required as they cross object lines. Notice also that leader lines are not broken when they cross object lines. Note the visible gap between the object itself and the beginning of extension lines. Note the .12 or approximately one-eighth inch overhang of the extension line beyond dimension lines. Suggested spacing of dimension lines and distances between views are summarized in the chart that accompanies the drawing in Figure 9-11.

Dimension Lines

A *dimension line* is a thin, solid line used to indicate graphically the linear distance being dimensioned. Dimension lines are normally broken for placement of the dimension, Figure 9-12, Part A. If a horizontal dimension line is not broken, the dimension is placed above the dimension line with guidelines parallel to it, Figure 9-12, Part B. Figure 9-13 illustrates the proper methods to be used for locating dimensions when space is limited on a drawing. *Notice from this illustration that one dimension can be written and then leaders can be used to point to where the dimension applies.* A dimension may be written within the extension lines with dimension lines extending inward rather than outward. Dimension lines may be bent at a 90° angle; and extension lines, when necessary, can be drawn



REQUIRED DIMENSIONS BETWEEN VIEWS	SUGGESTED DISTANCE BETWEEN VIEWS	
1	1.25	30
2	1.62	39
3	2.00	48
4	2.38	57
5	2.75	66
6 MAX	3.12	75

Figure 9-11 Spacing for extension lines, dimension lines, and dimensions

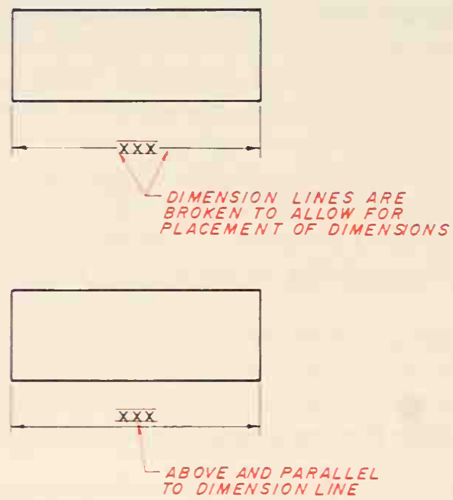


Figure 9-12 Placement of dimensions

at an oblique angle. Double arrowheads can be used on a dimension line when a long or short break line has been used.

When dimensioning multiple features of an object, dimensions should be aligned uniformly rather than staggered or randomly scattered about the object, Figure 9-14. Figure 9-15 illustrates another rule for proper placement of dimensions. When dimensioning several views of the same object, always place the dimensions between the views, and always include the overall size, length, height, and depth of the object.

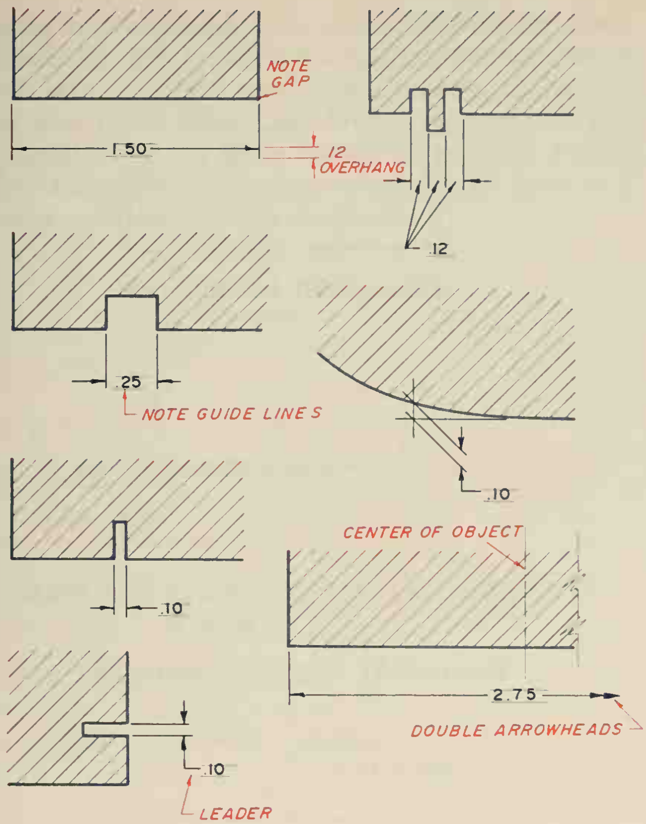


Figure 9-13 Placement of dimensions when space is limited

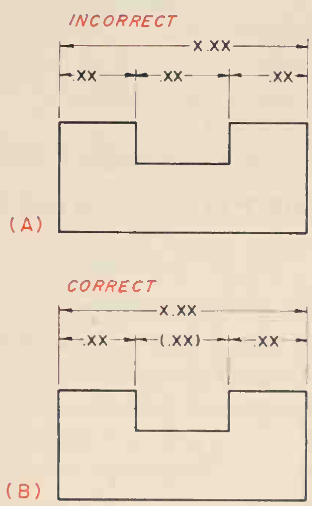


Figure 9-14 Proper placement of dimensions when dimensioning multiple features

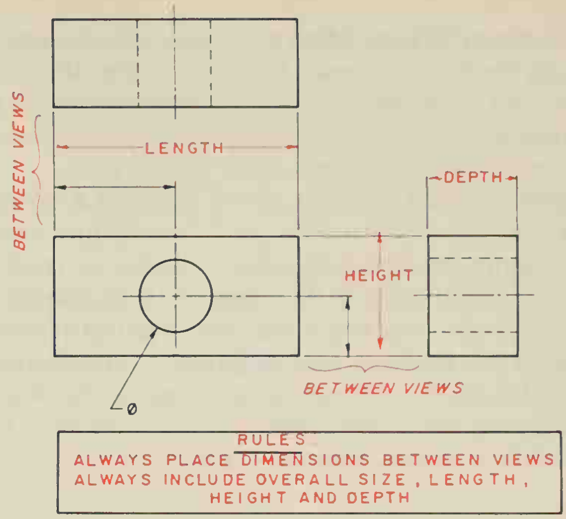


Figure 9-15 Dimensioning between views

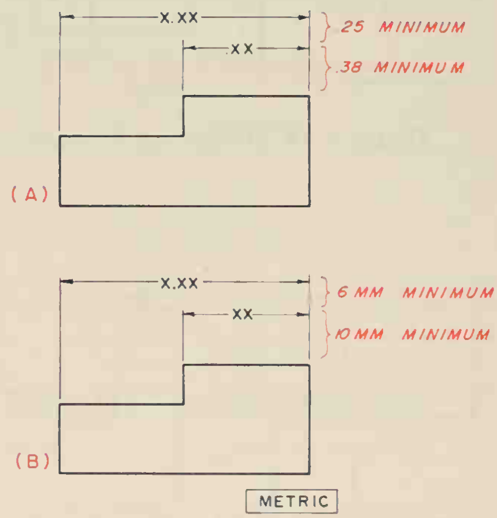


Figure 9-16 Successive dimension lines

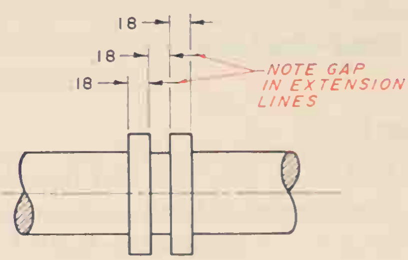


Figure 9-17 Successive dimension lines in close areas

Dimension lines are drawn parallel to the direction of measurement. Sufficient distance between the object and the dimension lines, and between successive dimension lines, is important so that cramped and crowded dimensions do not result. First dimension lines should be at least .38 inch from the object, Figure 9-16, Part A. Successive dimension lines should be at least .25 inch apart. If using metric dimensions, the first dimension lines should be at least ten millimeters away from the object. Successive lines should have at least six millimeters between them, Figure 9-16, Part B. Figure 9-17 illustrates the methods to be used when successive dimensions are called for in close areas. Notice how the dimension lines and corresponding dimensions are offset, and notice also the gap left in the extension lines to accommodate crossover of dimension lines.

When the shape of an object requires a series of parallel lines, the breaks and dimensions should be slightly staggered to make it easier to read the dimensions, Figure 9-18. Figure 9-19 illustrates the proper way of stacking a successive group of dimension lines. Drafters and engineers should always place the shortest dimensions closest to the objects, and always keep dimensions outside and away from the object, as illustrated in Figure 9-19.

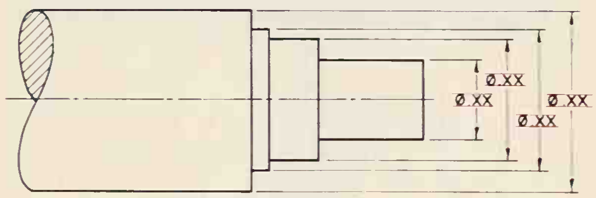


Figure 9-18 Staggering dimensions

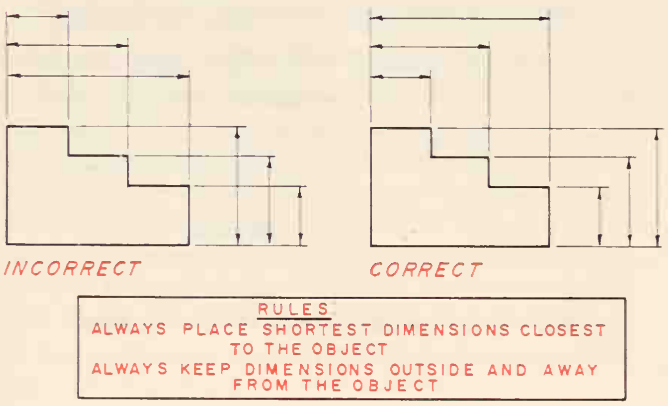


Figure 9-19 Stacking dimension lines

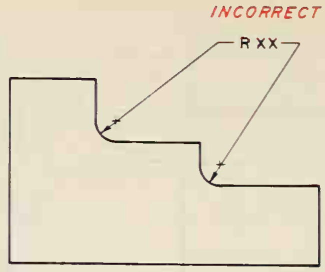


Figure 9-20 Leader lines

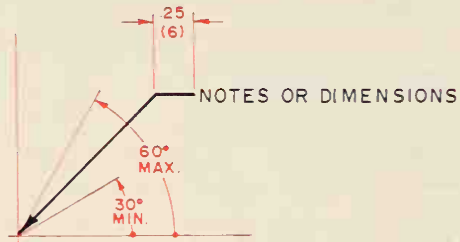


Figure 9-21 Angle of a leader line

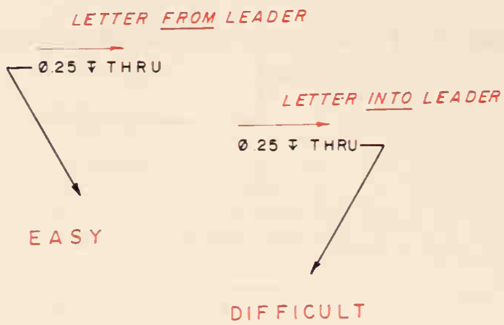


Figure 9-22 Lettering and leaders

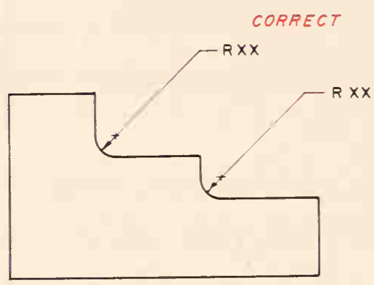


Figure 9-23 One dimension per leader line is preferred

Leader Lines

A *leader line* is a thin line that begins horizontally, breaks at an angle, and terminates in an arrowhead, or, on occasion, a dot, Figure 9-20. Leaders which terminate at an edge or at some other specific point on a drawing should have an arrowhead. Leaders that terminate inside an object on a flat surface should end in a dot. The preferred angle of a leader line is from a minimum of 30° to a maximum of 60°, Figure 9-21. The horizontal portion of a leader should be from .125 inch to .25 inch in length, Figure 9-21. To avoid confusion, leader lines should not be drawn parallel to extension lines or dimension lines. When placing a dimension and/or note at the end of a leader line, it is easier to letter from the leader than into the leader, Figure 9-22.

When using a leader line to direct a dimension to its appropriate feature on a drawing, one dimension for each leader is the preferred method, Figure 9-23.

More than one leader line extending from the same dimension can create a confusing situation that is difficult to interpret. Leader lines pointing to the center of a circle should be directed toward but not extended into the circle center, Figure 9-24. Figure 9-25 illustrates the proper use of leader lines in a variety of dimensioning situations.

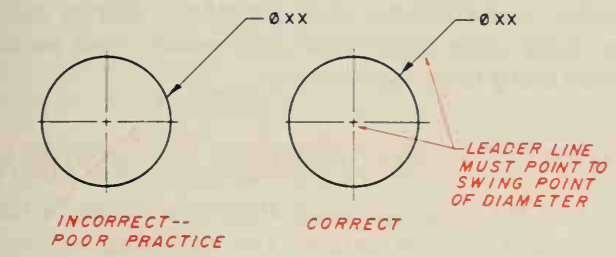


Figure 9-24 Leader lines point at the center of a circle

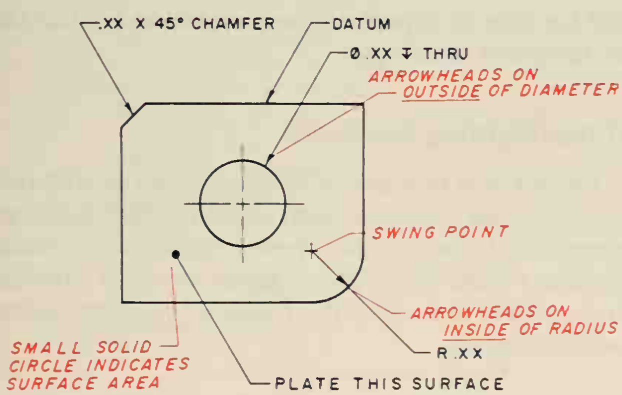


Figure 9-25 Proper use of leader lines

Arrowheads

An *arrowhead* is the most commonly used termination symbol for dimension and leader lines. Arrowheads should be approximately three times as long as they are wide. They should be large enough to be seen but small enough that they do not detract from the appearance of the drawing. A commonly accepted length for arrowheads is .12 inch. Arrowheads may be slightly larger or smaller than this, but, regardless of their size, they should be uniform throughout a drawing, Figure 9-26. Although the same standard applies to drawings prepared on a CAD system, arrowheads do not have to be filled in on drawings prepared using automated processes. Some CAD systems fill in arrowheads and some do not. Both open and filled-in arrowheads have been considered acceptable since the advent of CAD.

Figure 9-27 illustrates the three steps used in drawing arrowheads.

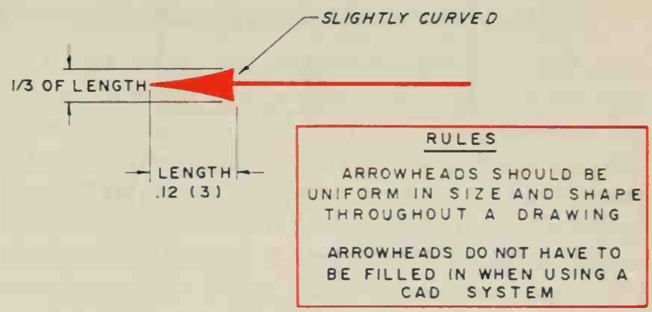


Figure 9-26 Proper size and shape of arrowheads

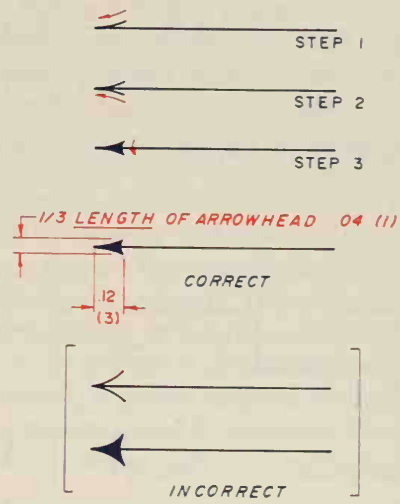


Figure 9-27 Drawing arrowheads

Laying Out Dimensions

Figure 9-28 illustrates the four steps in laying out dimensions for an object. First, place light layout lines on the drawing sheet. Second, draw in light guidelines for the dimensions. Third, darken your extension lines, dimension lines, and dimensions. Fourth, add arrowheads.

Steps in Dimensioning

There are two basic steps in dimensioning objects, regardless of the type of object.

Step 1. Apply the size dimensions. These are dimensions which indicate the overall size of the object and the various features which make up the object.

Step 2. Apply the locational dimensions. Locational dimensions are dimensions which locate various features of an object from some specified datum or surface. Figure 9-29 gives examples of size and location dimensions.

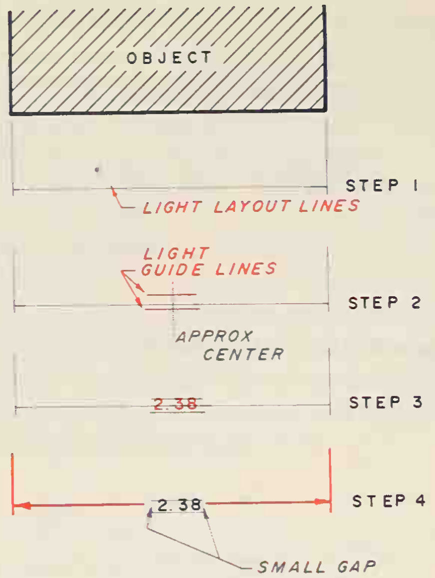


Figure 9-28 Laying out dimensions

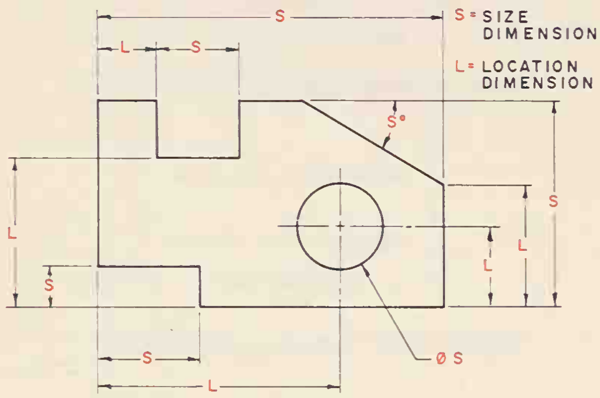


Figure 9-29 Size and location dimensions

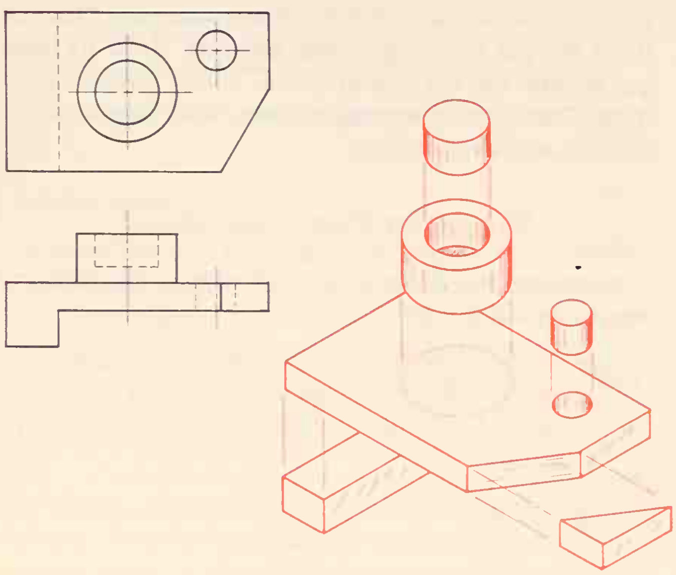


Figure 9-30 Geometric breakdown of an object

In order to properly dimension an object, drafters and engineers must be able to mentally break the object down into component parts and subelements. Figure 9-30 illustrates graphically how this is done. On the left side of the figure is a two-dimensional representation of the object containing a top and front view. On the right side of the figure is a three-dimensional geometric breakdown of the object. This three-dimensional breakdown shows the drafter and engineer what geometric shapes must be sized using dimensions and which must be located using dimensions.

Specific Dimensioning Techniques

All of the information on dimensioning so far has been of a general nature. The following sections deal with techniques used for applying dimensions to specific situations that are recurrent in drafting. With a thorough knowledge of the general information presented earlier, and the specific information presented in these sections, drafters and engineers will be able to dimension any situation confronted on technical drawings.

Dimensioning Symbols

There are a number of symbols used in different dimensioning situations with which drafters and engineers should be familiar. These symbols are summarized in Figure 9-31. Review these symbols carefully and commit them and their uses to memory before proceeding.

R	RADIUS
Ø	DIAMETER
2X	NUMBER OF TIMES-PLACES
↧	DEEP OR DEPTH
⌵	COUNTERSINK
⌴	COUNTERBORE OR SPOTFACE
SF	SPOTFACE
□	SQUARE
( )	REFERENCE DIMENSION
$\underline{25}$	NOT TO SCALE DIMENSION
◺	SLOPE
▷ (cone)	CONICAL TAPER
⌒	ARC LENGTH
SR	SPHERICAL RADIUS
SØ	SPHERICAL DIAMETER
[-x-]	BASIC DIMENSION

Figure 9-31 Dimensioning symbols

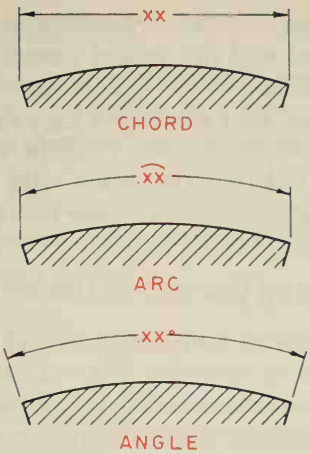


Figure 9-32 Dimensioning chords, arcs, and angles

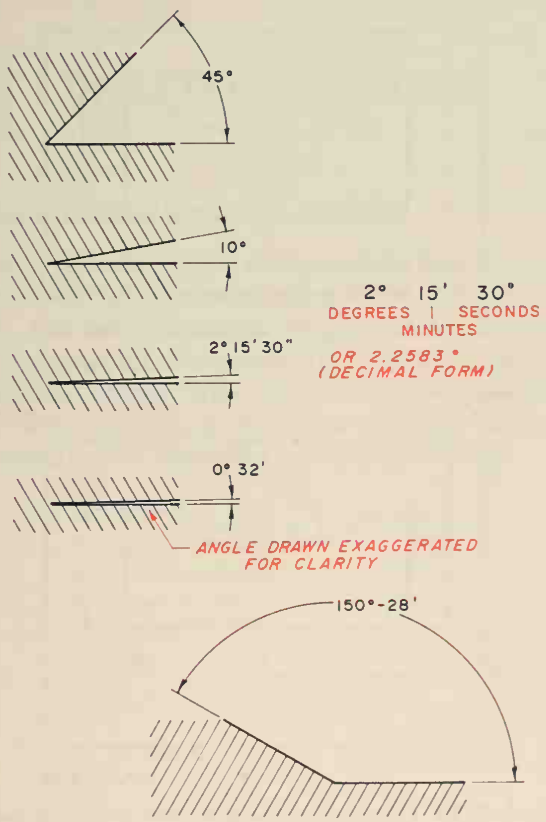


Figure 9-33 Dimensioning angles

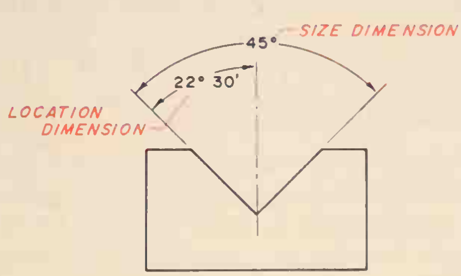


Figure 9-34 Dimensioning angles

Dimensioning Chords, Arcs, and Angles

Chords, arcs, and angles are dimensioned in a similar manner. When dimensioning a chord, the dimension line should be perpendicular and the extension lines parallel to the chord. When dimensioning an arc, the dimension line runs concurrent with the arc curve, but the extension lines are either vertical or horizontal. An arc symbol is placed above the dimension. When dimensioning an angle, the extension lines extend from the sides forming the angle, and the dimension line forms an arc. These methods are illustrated in Figure 9-32. Figures 9-33 and 9-34 contain additional information relative to dimensioning angles.

Notice in Figure 9-33 that angles are normally written in degrees, minutes, and seconds. The symbols used to depict degrees, minutes, and seconds are also shown in this figure. Angular measurements may also be stated in decimal form. This is particularly advantageous when they must be entered into an electronic digital calculator. The key to converting angular measurements to decimal form is in knowing that each degree contains 60 minutes, and each minute contains 60 seconds. Therefore to convert a measurement stated in degrees, minutes, and seconds into decimal form is a two-step process. Consider the example of the angular measurement 2 degrees, 15 minutes, and 30 seconds. This measurement would be converted to decimal form as follows:

Step 1. The seconds are converted to decimal form by dividing by 60. Thirty seconds divided by 60 equals .50. The 15 minutes are added to this so that the minutes are expressed in decimal form or 15.50.

Step 2. The minutes stated in decimal form are converted to decimal degrees by dividing by 60. The number 15.50 divided by 60 equals .25833. The 2 degrees are added to this number to have the measurement stated in decimal form or 2.2583 degrees. Figure 9-34 illustrates how angles can be dimensioned for size and location. The size dimension gives the overall size of the angular cut. However, it does not locate the angular cut in the object. This is done by using a locational dimension off of the center line of the object. Figure 9-35 shows

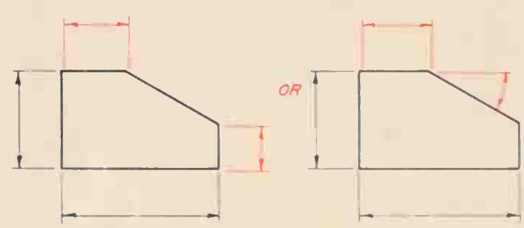


Figure 9-35 Using normal linear dimensions for effecting the proper angle

how normal linear dimensions can be used for effecting the proper angle. When this method is used in the example on the left, all surfaces are dimensioned except the angular surface. When this method is used the angular surface is defined by default. In the method on the right, three linear dimensions and one angular dimension define the angular surface.

Dimensioning a Radius

Dimension lines used to specify a radius have one arrowhead, normally at the arc end. An arrowhead should not be used at the center of the arc. Where space permits, the arrowhead should be placed between the arc and the arc center with the arrowhead touching the arc. If space permits, the dimension is placed between the arc center and the arrowhead. If space is not available, the dimension may be placed outside the arc by extending the dimension line into a leader. The arc center of a radius is denoted with a small cross. Figure 9-36 illustrates the preferred method for dimensioning a radius.

Dimensioning a Foreshortening Radius

On occasion the center of an arc radius will fall outside the drawing or will be so far removed from the drawing as to interfere with other views. When this is the case, the radius dimension line should be foreshortened and the radius center located using coordinate dimensions. This is done by relocating the arc center and placing a zig-zag in the radius dimension line, as shown in Figure 9-37. When this method is used it is important that the arc center actually lie upon the real center line of the arc.

Dimensioning Curved Surfaces

Curved surfaces containing two or more arcs are dimensioned by showing the radii of all arcs and locating the arc centers using coordinate dimensions. Other radii may be located using their points of tangency. This method is illustrated in Figure 9-38.

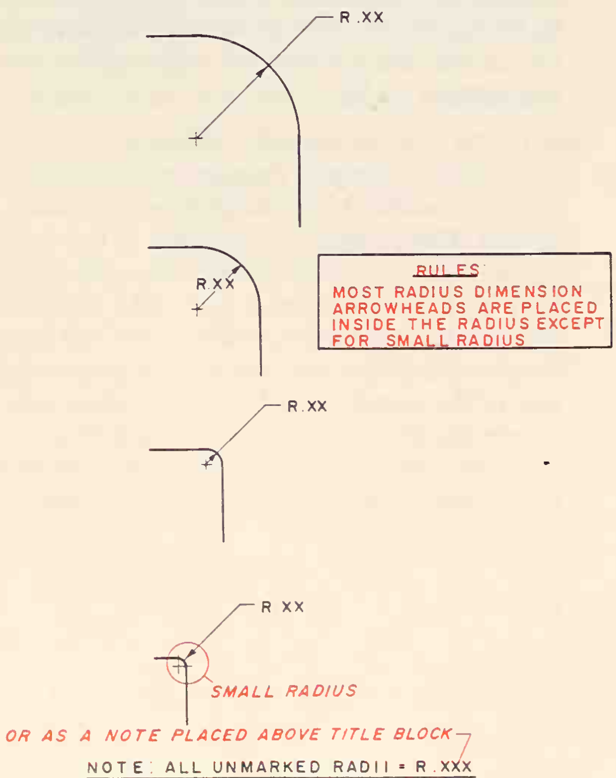


Figure 9-36 Dimensioning a radius

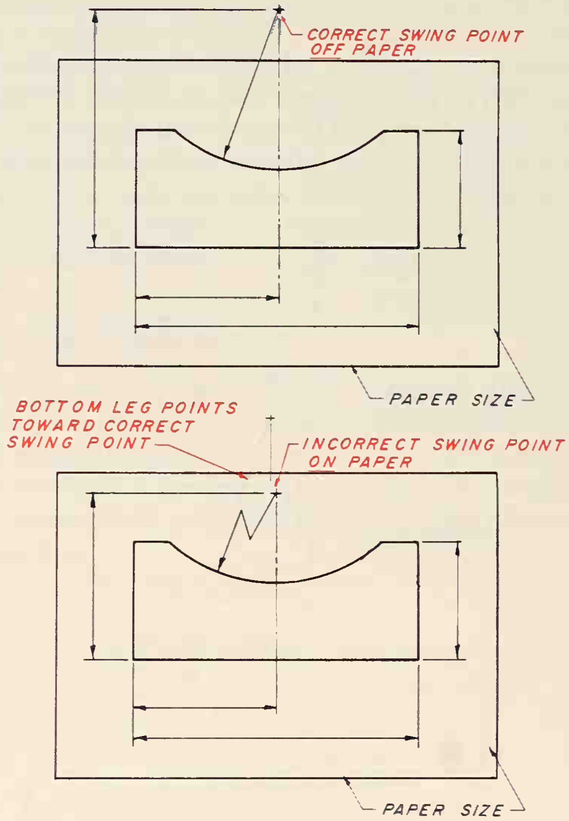


Figure 9-37 Dimensioning a foreshortening radius

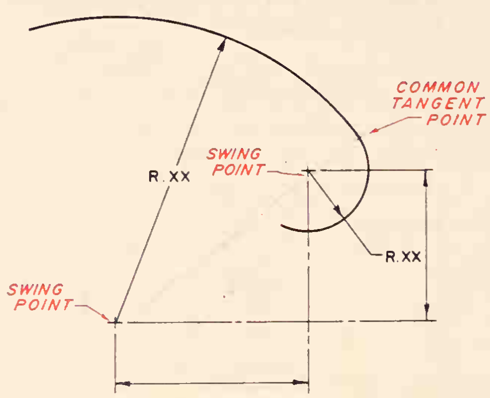


Figure 9-38 Dimensioning curved surfaces

Dimensioning Offsets

Offsets are dimensioned from the points of intersection of the tangents along one side of the object, Figure 9-39. The distance from one end of the offset to the intersection is specified with a coordinate dimension. The distance from the other end to the offset is also specified with a coordinate dimension, as shown in Figure 9-39.

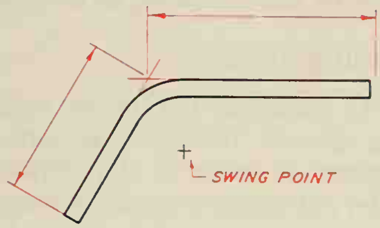


Figure 9-39 Dimensioning offsets

Dimensioning Irregular Curves

You have already seen in Figure 9-38 how to dimension curved surfaces using arc centers, radius dimensions, and tangent points. Irregular curves may also be dimensioned using coordinate dimensions from a specified datum. When this is the case the coordinate dimensions extend from a common datum to specified points along the curve, Figure 9-40.

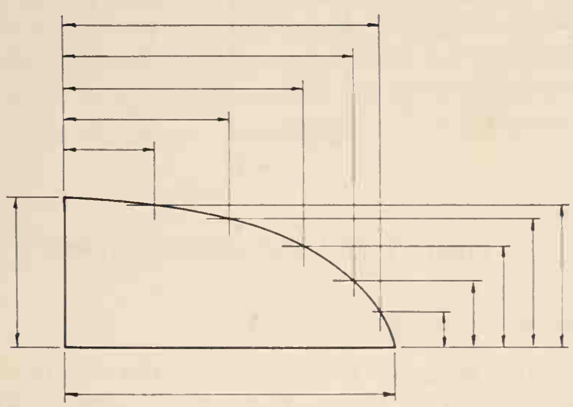
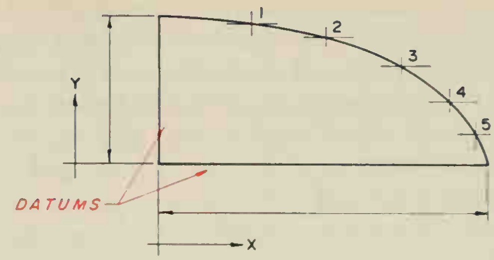


Figure 9-40 Dimensioning irregular curves

Dimensioning Contours Not Defined as Arcs

Contours not defined as arcs can be dimensioned by indicating X, Y coordinates at points along the surface of the contour. Each of these points, sometimes referred to as stations, is numbered. The X and Y coordinates for each station are tabulated and placed in table form under the drawing, Figure 9-41.



STATION	1	2	3	4	5
X	1.12	2.12	3.00	3.62	4.00
Y	1.75	1.50	1.12	.75	.31

Figure 9-41 Dimensioning contours not defined as arcs

Dimensioning Multiple Radii

When dimensioning an object that requires several radii, arcs should be dimensioned showing the radius in a view which gives the true shape of the curve. The dimension lines for a radius should be drawn as a radial line at an angle, rather than horizontally or vertically. Only one arrowhead is used. The dimensional value of the radius should be followed by a capital "R" when dimensioning in the decimal-inch system. The "R" precedes the dimensional value when dimensioning in the metric system. This method is illustrated in Figures 9-42, 9-43, and 9-44. Notice in Figure 9-44 that where a radius is dimensioned in a view that does not show the true radius, a note should be used to indicate that the true radius is not shown, and a separate note used to indicate what the true radius is.

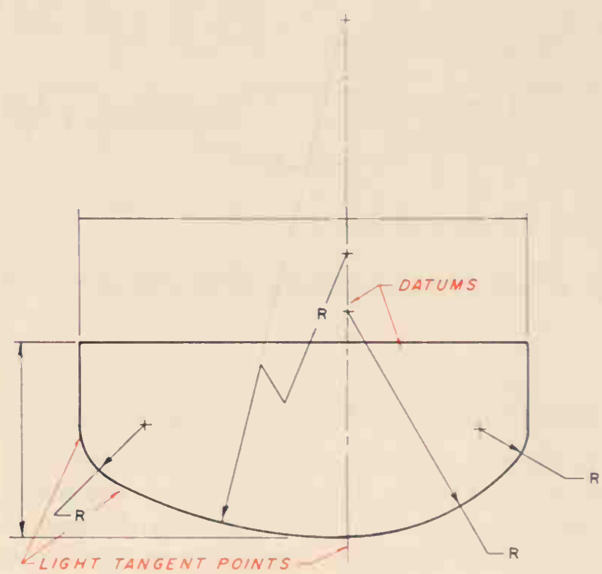


Figure 9-42 Dimensioning multiple radii

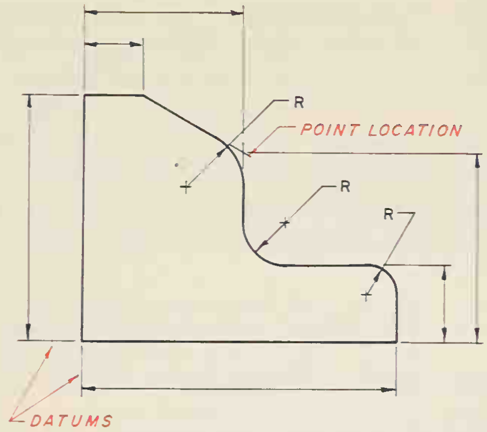


Figure 9-43 Dimensioning multiple radii

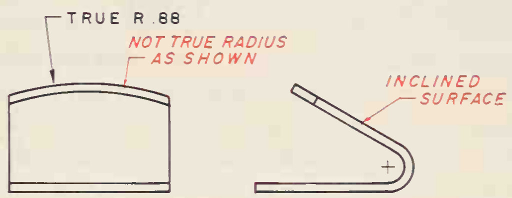


Figure 9-44 Dimensioning multiple radii

Dimensioning by Offset (Round Objects)

Another way to dimension a round object is the offset method. In this method, dimension lines are used as extension lines. Dimension lines are distributed across the object perpendicular to the center line of the object and spaced using coordinate dimensions, Figure 9-45.

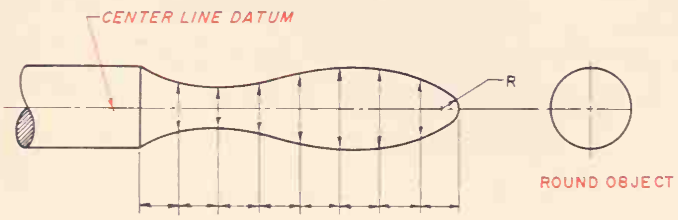


Figure 9-45 Dimensioning by offset (round object)

Dimensioning by Offset (Flat Objects)

Flat objects may also be dimensioned using the offset method. Again, dimension lines on the object become extension lines. Dimension lines are spaced across the object perpendicular to the center line of the datum and extended to become extension lines for the coordinate dimensions which space them, Figure 9-46.

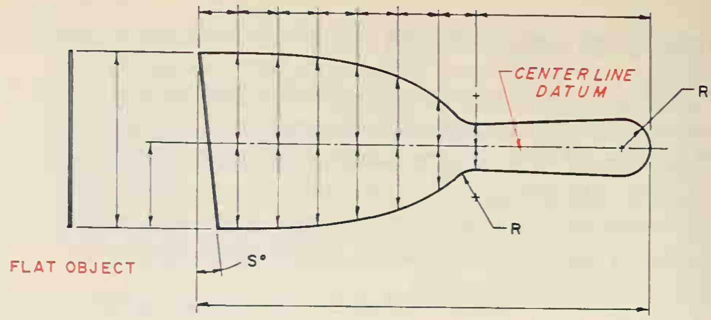


Figure 9-46 Dimensioning by offset (flat object)

Dimensioning Spheres

Figure 9-47 illustrates the proper method for dimensioning spheres. The diameter method is used when the sphere is shown in plan. When this is the case, a leader points to the center of the sphere, and the diameter note is preceded with a capital "S" to indicate that it is a spherical diameter. When the radius method is used, a dimension extends from the arc center to the arc and is extended on with a leader, and the note is preceded by a capital "SR" to indicate a spherical radius.

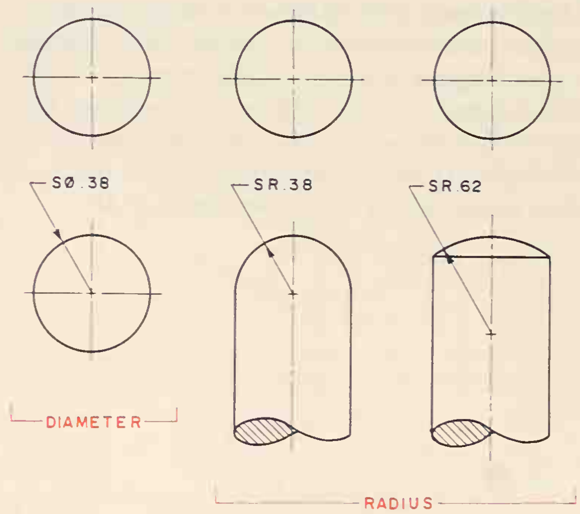


Figure 9-47 Dimensioning spheres

Dimensioning Round Holes

Round holes are dimensioned in the view in which they appear as circles, Figure 9-48. Holes may be dimensioned using a leader which points toward the center of the hole in which the note gives the diameter, or extension lines may be drawn from the circle with a dimension that also indicates the diameter. Larger circles are dimensioned with a dimension line drawn across the circle through its center at an angle with the diameter dimension shown. Except for very large holes, the arrowhead and the dimensional value are placed outside the hole. It is important when dimensioning holes to call off the diameter, not the radius.

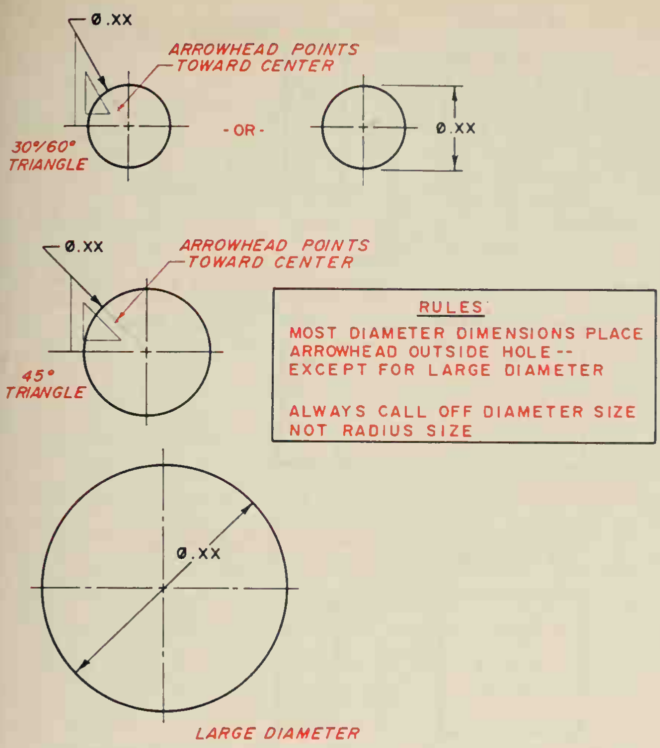


Figure 9-48 Dimensioning round holes

Simple Hole Callouts

Drafters and engineers need to know how to apply simple callouts to both through-holes and blind-holes. A through-hole is one which passes all the way through the object. A blind-hole is one which cuts into but does not pass through the object. Both types of holes, and the callout used for each, are illustrated in Figure 9-49. Machine holes are generally drilled to make the rough hole and then reamed to refine the hole. Figure 9-49 shows the difference between a drill and a ream. No hole is only reamed. A hole must be drilled before it can be reamed.

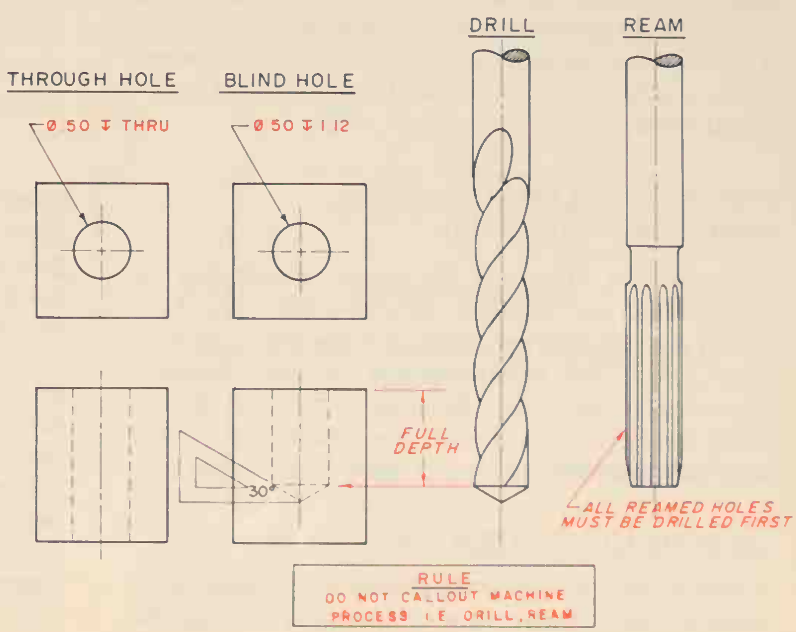
A through-hole callout has a leader line extending toward the center of the hole in the view in which the hole appears as a circle. The note attached to the leader gives the diameter of the hole, the depth symbol, and the word "thru" to indicate that the hole passes through an object. Blind-hole callouts are similar to through-hole callouts, except that the depth symbol is followed by the actual depth of the hole.

Drill Size Tolerancing

Holes are not drilled to the exact size specified on a drawing. This is because there are several factors which mitigate against a perfectly sized hole. The accuracy of the actual drill, the tolerance level of the machine, and the qualifications of the machinist all have an impact on the actual size of a hole once it's drilled. It is accepted in manufacturing that no hole, even with the added accuracy provided by computer-aided manufacturing, is going to be drilled exactly the size specified. Therefore, drafters and engineers need to know how much variation to expect in a hole so that they can decide what limits to give the hole and whether the actual drilled hole will give the fit required in a given situation.

Drill size tolerance charts have been developed to assist drafters and engineers in determining the expected upper and lower limits of a drilled hole. Such charts are contained in Appendix B as Table 16. Turn to these tables and you will notice that the standard drill size is given a number/letter, a fractional designation, a decimal designation, and a metric designation. To the right-hand side of the table

Figure 9-49 Simple hole callouts



the tolerance for each drill size is given in decimals. The left-hand column is the plus tolerance, and the right-hand column is the minus. To use these tables, apply the following steps:

1. Find the letter or number of the drill in question on the left-hand side of the table.
2. Find the corresponding size for the drill in decimal form.
3. Find the plus tolerance for that size drill and add it to the decimal drill size. This will give you the upper limit for the hole size.
4. Find the minus tolerance for that drill size and subtract it from the decimal drill size. This will give you the lower limit for the hole.
5. Write the upper and lower limits with the smaller number on top separated from the larger number by a horizontal line. For example, an H-size drill has a decimal diameter of 0.2660. To find the upper limits for a hole using this drill size, add the plus tolerance of 0.0064 to this decimal drill size to get 0.2724 as the upper limit for the hole. To find the lower limit, subtract the minus tolerance of .002 from the decimal drill size to get a lower limit of 0.2640.

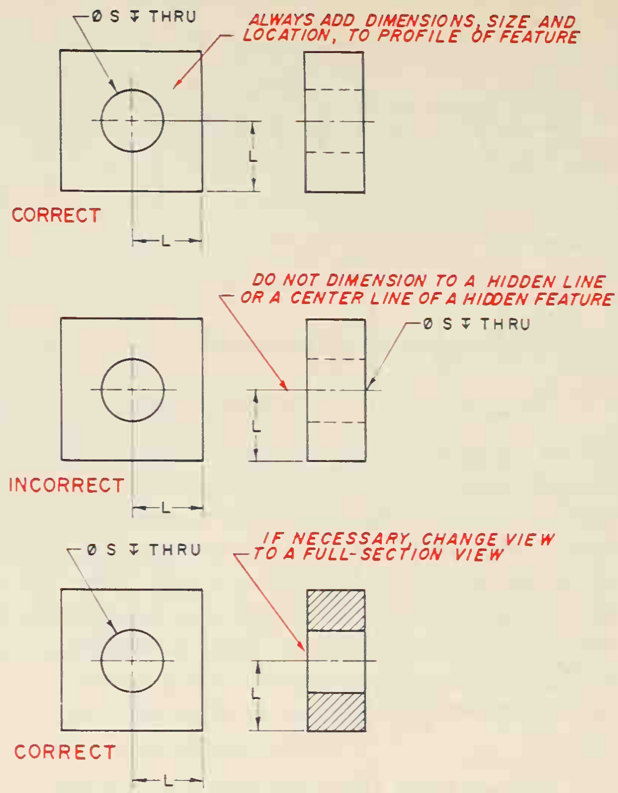


Figure 9-50 Dimensioning hole locations

Dimensioning Hole Locations

In addition to dimensioning the size of a hole, drafters and engineers must also dimension the locations of holes. Figure 9-50 illustrates the proper methods for dimensioning the location of a hole. The preferred method is to dimension the location of the hole in the view where the hole appears as a circle. It is common practice to dimension from a reference side of the object to the center line of the hole. One should never dimension to a hidden line, however. If it is necessary to show one of the locational dimensions in a hidden view, convert the view into a sectional view.

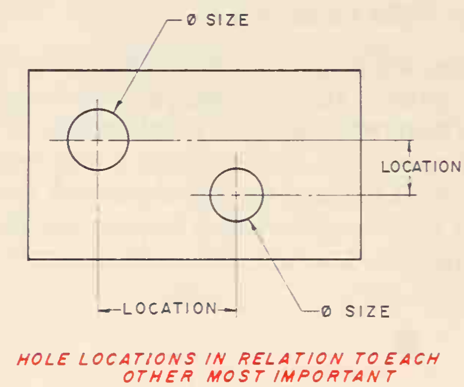


Figure 9-51 Dimensioning hole locations (more than one hole)

Dimensioning Hole Locations (More Than One Hole)

Figure 9-51 illustrates the proper method of dimensioning the locations of more than one hole within an object. When there is more than one hole in an object, what is important is the relationship of the holes to each other. Because of this, the dimensions applied show the distance horizontally and vertically between the center lines of the holes.

Locating Holes About a Bolt Center

A common dimensioning situation is to have holes spaced about a bolt center. When this is the case the holes may be dimensioned using coordinate dimensions or angular dimensions, Figure 9-52. For the greatest accuracy, coordinate dimensions can be given from the center line of the bolt's center as well as center-to-center dimensions of the holes. This method is illustrated in the top half of Figure 9-52. Notice that the diameter of the bolt center is specified as a reference dimension. Reference dimensions are given only for informational purposes. They are not intended to be measured or to be used in dictating manufacturing operations. Another method that can be used for locating holes about a bolt center is illustrated in the bottom half of Figure 9-52. With this method the diameter of the bolt circle is shown

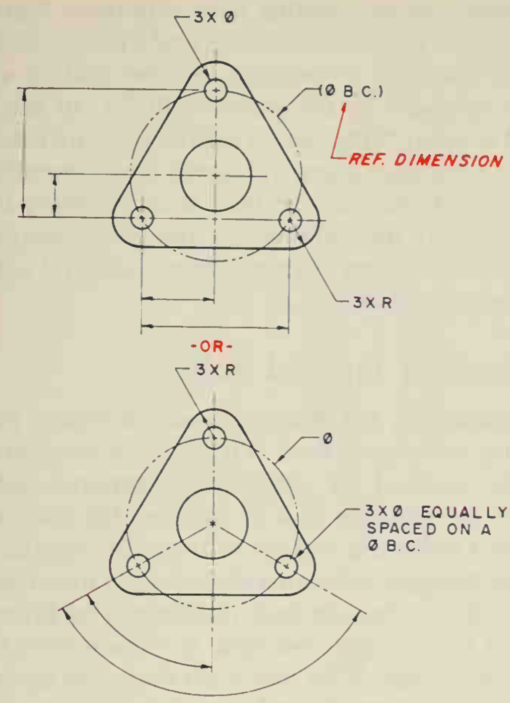


Figure 9-52 Locating holes about a bolt center

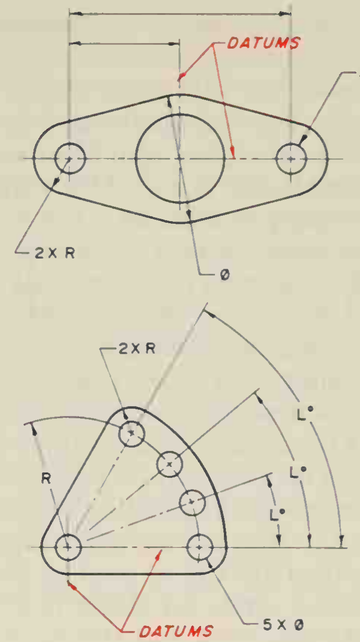


Figure 9-53 Locating holes on center lines and concentric arcs

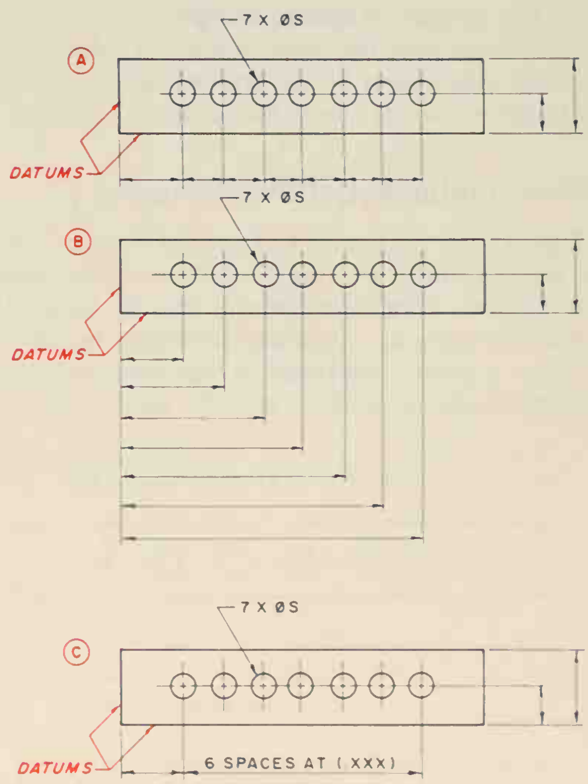


Figure 9-54 Dimensioning multiple holes

and a note specifying the number of holes, their diameters, and the indication "equally spaced" is given. If the holes are unequally spaced, the same method can be used except that the note "equally spaced" is dropped and an angular measurement with reference to one of the center lines is indicated.

Locating Holes on Center Lines and Concentric Arcs

When locating holes on common center lines, the center lines become datums from which coordinate measurements can be made, as illustrated in the top half of Figure 9-53. All three holes in the object in this figure share the same horizontal center line. Consequently, the only dimensions required are dimensions from center to center of the circles. This is accomplished by providing a coordinate dimension from the center of a large circle to the center of one of the smaller circles, and the overall coordinate dimension between the centers of the two small circles, as illustrated. When centers are located on concentric arcs, the polar system of dimensioning can be used, as illustrated in the bottom half of Figure 9-53. When this is the case the radial distances from the point of concurrency and the angular measurements between the holes are used to locate the centers of the holes. The distance from the point of concurrency to the center of each hole is indicated by the radius, as shown.

Dimensioning Multiple Holes Along the Same Center Line

Figure 9-54 shows the proper method used for dimensioning multiple holes along the same center line. The method shown at the top of Figure 9-54 is known as "chain dimensioning." The center line of the first hole is dimensioned from a reference datum which is normally one side of the object. Then each successive center line is dimensioned from the immediate preceding center line. A problem with this type of dimensioning is that if one of the features in the chain is improperly located, all successive features will be improperly located. As a result, another method of dimensioning multiple holes or features is often used in place of chain dimensioning. This dimensioning concept is known as "datum," or "baseline" dimensioning. As is shown in the middle part of Figure 9-54, each successive center line is dimensioned from a baseline or datum. In this way any one of the multiple features can be improperly located by the machinist without affecting the others. When this happens, the error can sometimes be corrected.

Another method that can be used for dimensioning multiple features within an object is illustrated at the bottom of Figure 9-54. With this method the center line of the first feature is dimensioned from a given datum, usually the edge of the object. Remaining features are dimensioned using a note which indicates the number of spaces at a given distance. This method does have the disadvantage of relying on an accurate placement of the first feature in order for each successive feature to be accurately located.

Dimensioning Repetitive Features

Figure 9-55 illustrates the proper methods used for dimensioning an object which contains repetitive features. Repetitive features may be located on a drawing using a note which specifies the number of times a given dimension is repeated, and giving one particular dimension and the total length as a

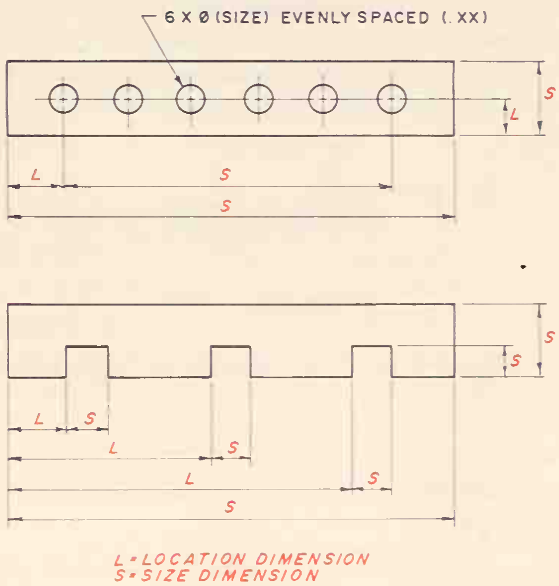


Figure 9-55 Dimensioning repetitive features

reference. When dealing with repetitive features it is necessary to use both size and locational dimensions. The size dimension for one feature can be given followed by the word "TYPICAL" or the shortened version "TYP," which means that the other successive features have the same size dimensions as the one single feature that is completely dimensioned. Note the dimensions that have been given in Figure 9-55. Some are size dimensions and some are location dimensions.

Callouts for Tapered Holes

Occasionally the design of a manufactured part will require a tapered hole. Figure 9-56 illustrates the proper method for annotating a tapered hole and shows an example of a 4° tapered bit. Callouts for tapered holes are similar to those for regular holes except that the note must also contain the taper symbol and the degree and the length of taper. The callout for the tapered hole in Figure 9-56 means that the subject hole has a .50 diameter at the top. It is drilled through and tapered at 4° for the full length of the hole.

Callouts for Countersunk Holes

Countersinking is a machining process to form a conical head so that a fastener can fit flush with the top of a part. The callout for a countersunk hole should contain the diameter of the countersink hole, which is the maximum diameter on the surface, and the angle of the countersink. The proper method for calling out a countersunk hole is illustrated in Figure 9-57. First a .50 diameter hole is drilled through the part. Then, using a countersink bit, the top of the hole is countersunk at 82° until the head of the countersink has a diameter of 1.12.

Callouts for Counterbored Holes

On occasion a hole in a part is counterbored to allow the head of a bolt or another type fastener to be recessed. The bottom of a counterbore is flat rather than angled as in a countersink. The callout for a counterbored hole shows the diameter of the drilled hole, the counterbore symbol, the diameter of the counterbore itself, and the depth of the counterbore. When a hole is to be counterbored, the hole itself is drilled first and then the counterbore is applied using a special counterbore bit, as shown in Figure 9-58.

Callouts for Spotfaces

A spotface is a machining process used to finish the surface around the top of a hole so that a bolt or other type of threaded fastener can feed properly. A

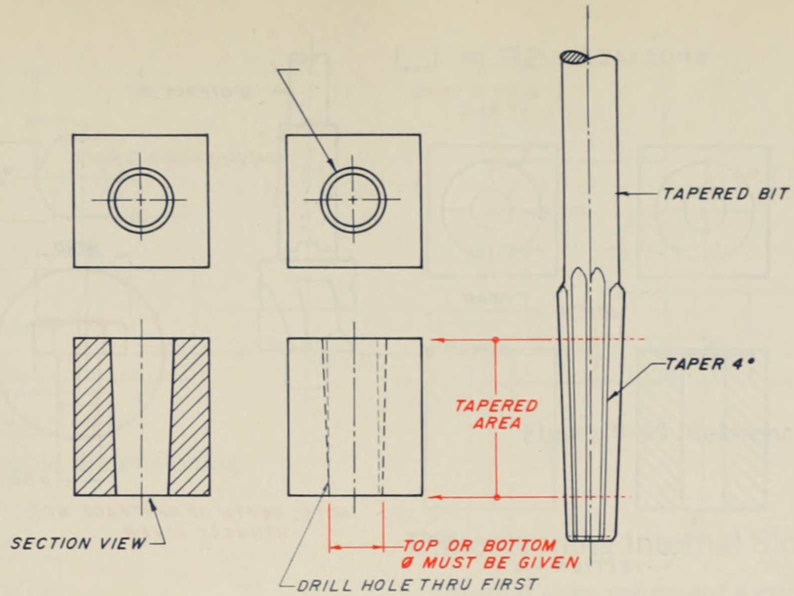


Figure 9-56 Callouts for tapered holes

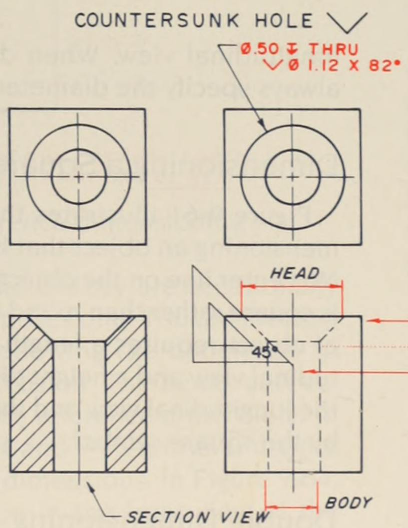


Figure 9-57 Callouts for countersunk holes

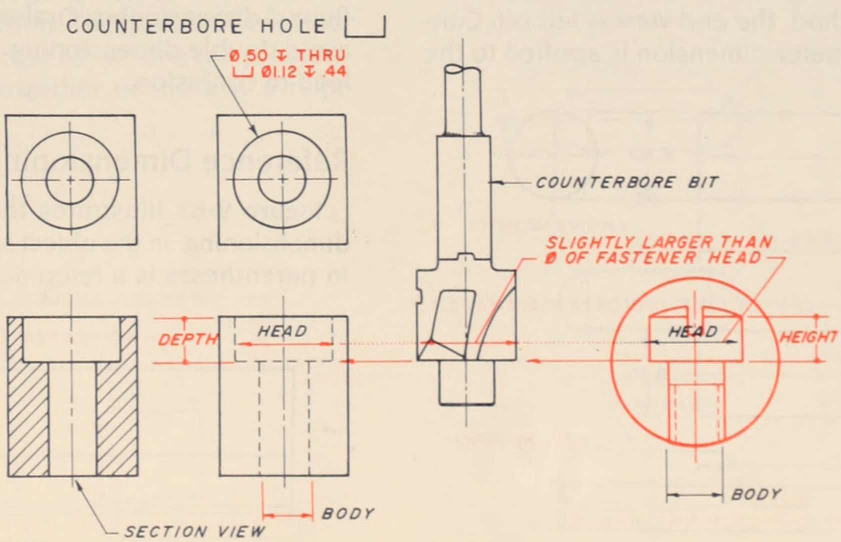


Figure 9-58 Callouts for counterbored holes

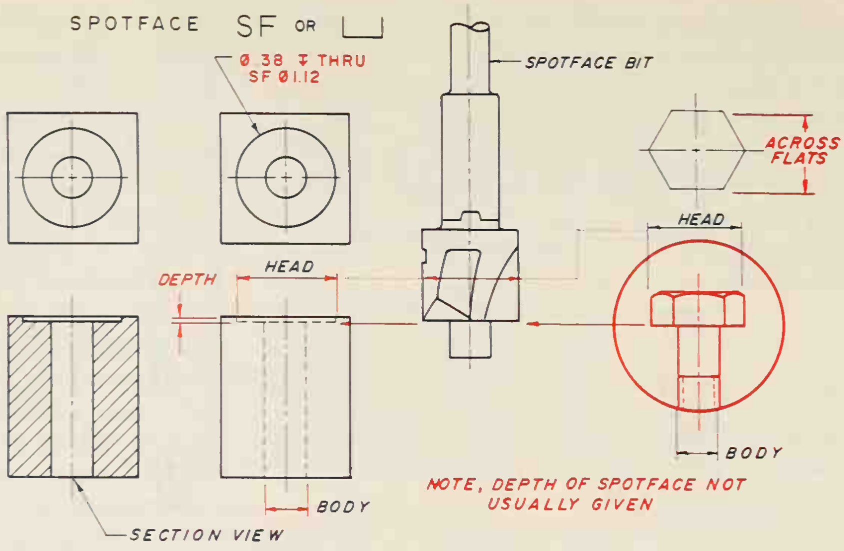


Figure 9-59 Callouts for spotfaces

spotface resembles a very shallow counterbore. The callout for a spotface contains the diameter of the actual hole, the capital letters "SF," and the diameter of the spotface. The depth of a spotface is not normally shown. When a hole is to be spotfaced, the hole itself is drilled first and then the spotface is applied with a special spotface bit, as illustrated in Figure 9-59.

Dimensioning a Cylinder

Figure 9-60 shows the proper way for dimensioning a cylinder. Notice from this figure that there are two methods which can be used. In the first method the longitudinal view and the end view of the cylinder are given. When this method is used, the length of the cylinder is shown and the diameter dimension is applied between the longitudinal view and the end view. In the second method, the end view is left off. Consequently, the diameter dimension is applied to the longitudinal view. When dimensioning a cylinder, always specify the diameter rather than the radius.

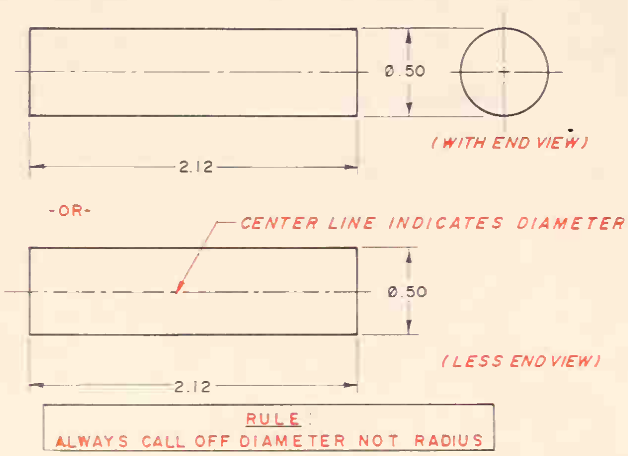


Figure 9-60 Dimensioning a cylinder

Dimensioning a Square

Figure 9-61 illustrates the proper method for dimensioning an object that is square in cross section. No center line on the object indicates that the object is square rather than round in cross section. This type of object requires a length dimension on the longitudinal view and a height dimension placed between the longitudinal view and the end view, and preceded by the square symbol.

Double Dimensioning

Figure 9-62 illustrates the concept of double dimensioning. This is sometimes referred to as "superfluous" dimensioning. Drafters and engineers should avoid double dimensioning. It is redundant and can lead to confusion.

Reference Dimensioning

Figure 9-63 illustrates the concept of reference dimensioning. In the object shown, the .62 dimension in parentheses is a reference dimension. Reference

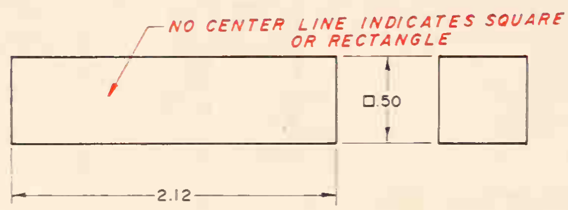


Figure 9-61 Dimensioning a square

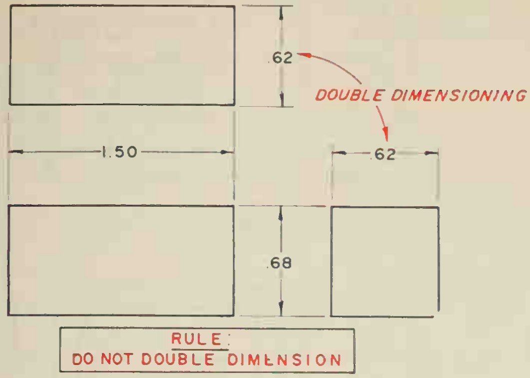


Figure 9-62 Double dimensioning

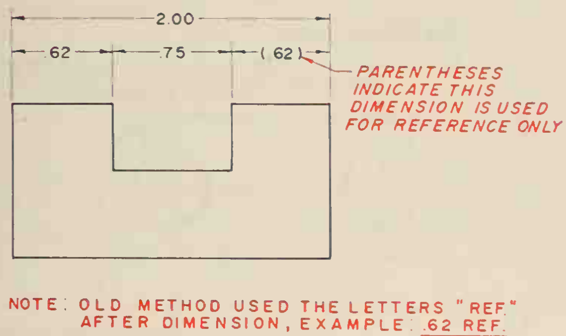


Figure 9-63 Reference dimensioning

dimensions are not required. They are occasionally given for information purposes only. The old method used the letters "REF" following the dimension to indicate a reference dimension. The newer and accepted method is to place reference dimensions in parentheses. Figures 9-64 and 9-65 further illustrate the concept of reference dimensions. In Figure 9-64, the second .25 dimension in the front view of the object is a double dimension; it is superfluous. In Figure 9-65, the problem has been solved by placing the second dimension in parentheses, thereby making it a reference dimension. The drafter or engineer had two options in this case for solving the problem: omit the dimension altogether or make it a reference dimension.

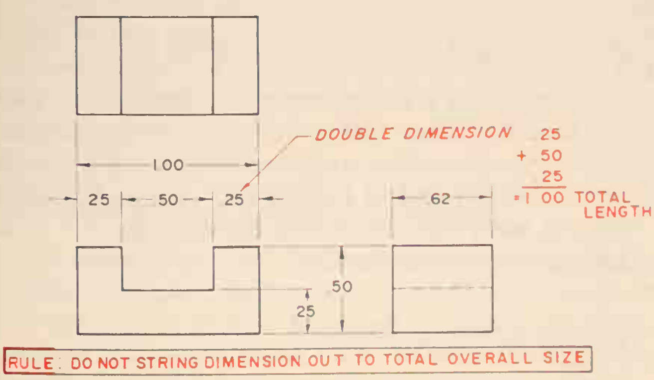


Figure 9-64 Reference dimensions

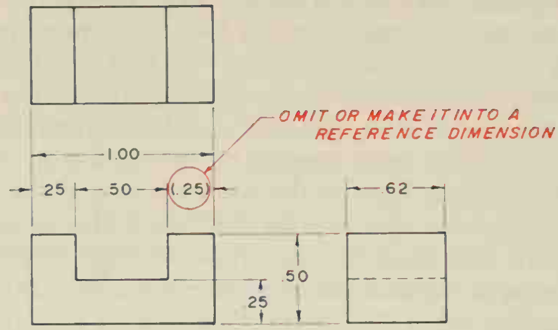


Figure 9-65 Reference dimensions

Dimensioning Internal Slots

Internal slots represent a common manufacturing situation. Drafters and engineers approach internal slots as two partial holes separated by a space. There are a variety of methods for dimensioning internal slots. The preferred methods are illustrated in Figure 9-66. Notice from these examples that when the width of the slot is dimensioned, there is no need to indicate the size of the radius. To do so would be double dimensioning. All of the methods shown in Figure 9-66 are acceptable methods and can be substituted for each other based on the needs of the individual drawing and local preferences.

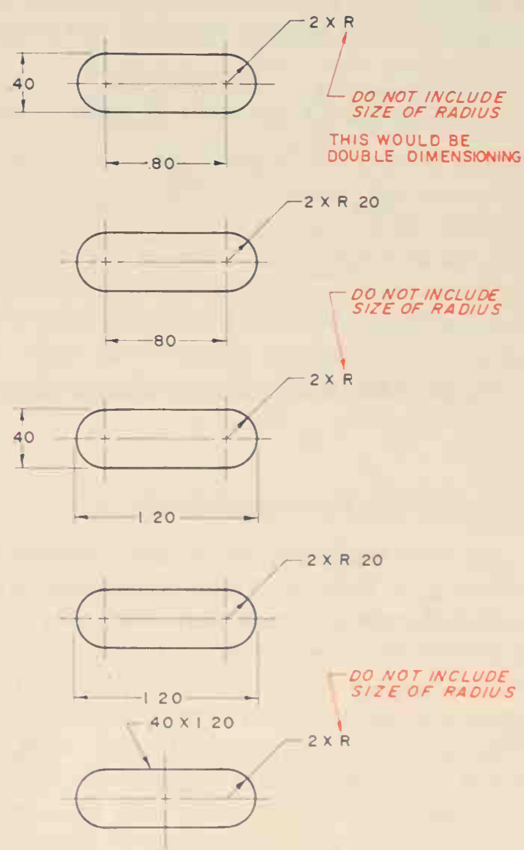


Figure 9-66 Dimensioning internal slots

Figures 9-67 and 9-68 are examples of how to dimension internal slots for two other manufacturing situations. Note in Figure 9-67 that the distance from the concurrent center point to the center line of the slot is indicated with a radius dimension. In addition, the angle formed by the extension of the 2-hole center lines to their intersection at the converging point must also be dimensioned as an angle. Figure 9-68 illustrates the proper method for dimensioning an internal slot when one of the holes is larger than the other. If a width dimension is provided, a radius value is not provided. If a width dimension is not provided, the radius dimension must be.

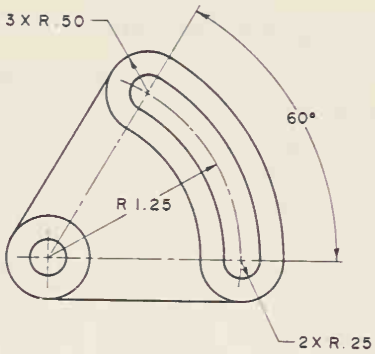


Figure 9-67 Dimensioning internal slots

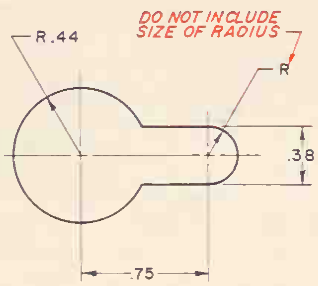


Figure 9-68 Dimensioning internal slots

Dimensioning Rounded Ends

Figure 9-69 illustrates the proper method for dimensioning the three most common situations involving external rounded ends. Parts with fully rounded ends should be dimensioned with an overall dimension and the radius should be indicated but not dimensioned, as indicated at the top of Figure 9-69. Figures with partially rounded ends, such as the example in the middle of Figure 9-69, require a radius specification. For parts with rounded ends and holes, overall dimensions can be given as reference dimensions, as shown in the bottom example of Figure 9-69.

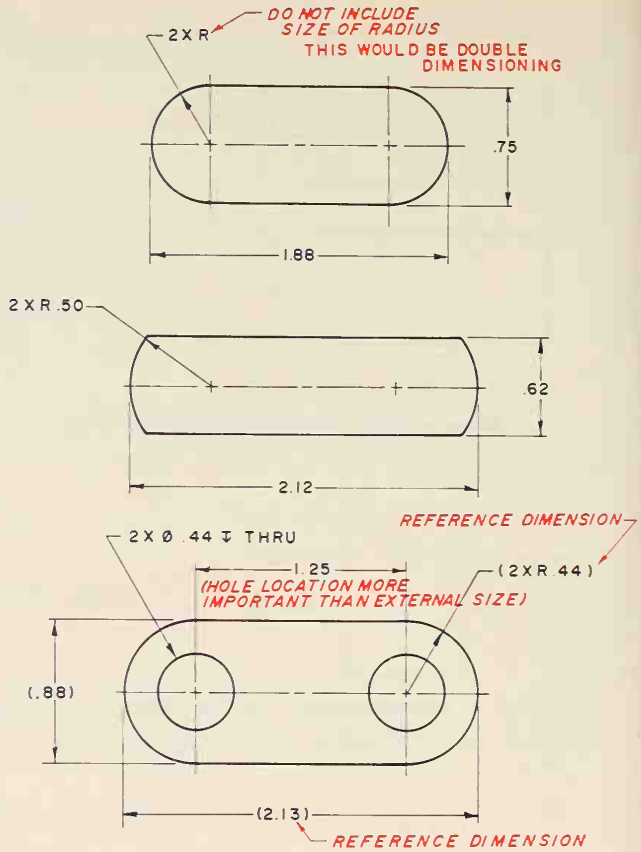


Figure 9-69 Dimensioning external rounded ends

Dimensioning and Hidden Lines

There is only one rule relative to dimensioning and hidden lines:

DO NOT DIMENSION TO HIDDEN LINES

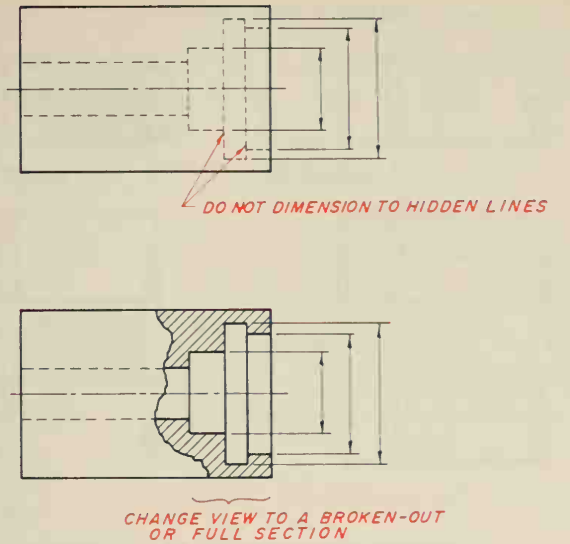
Figure 9-70 illustrates what drafters and engineers can do when faced with a situation where it is necessary to dimension hidden lines. When this is the case, and it cannot be avoided in any other way, convert the hidden-line view to a sectional view so that you are dimensioning to a solid line.

Not to Scale (NTS) Dimensions

On occasion it is necessary to enter a dimension not to scale. When this is the case, the not-to-scale dimension should be underlined with a solid straight line, as illustrated in Figure 9-71. The old method used a wavy line under the dimension. This is no longer acceptable practice.

Nominal Dimensions

A nominal dimension is one which represents a general classification size given to a part or product.



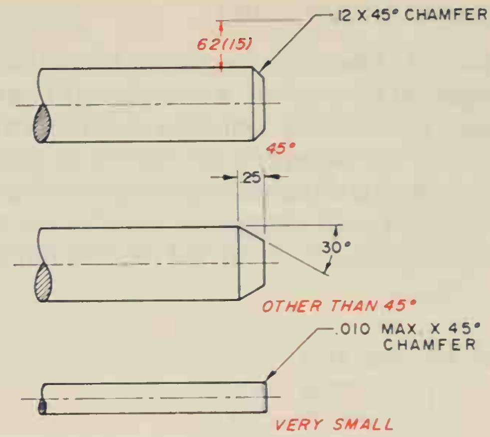


Figure 9-73 Dimensioning external chamfers

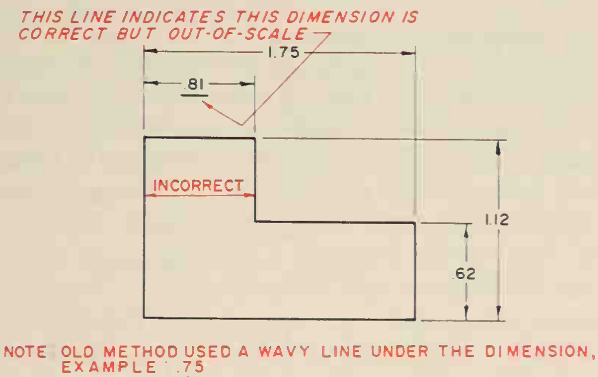


Figure 9-71 Not to scale (NTS) dimensions

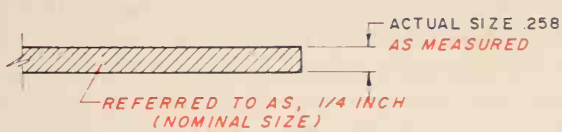


Figure 9-72 Nominal dimensions

It may not, and usually does not, express the actual size of the object dimensioned. There is usually a small amount of difference between the actual size of a part and the nominal size, as illustrated in Figure 9-72.

Dimensioning External Chamfers

A chamfer is a beveled edge normally applied to cylindrical parts and a variety of different types of fasteners. Chamfers are used to eliminate rough edges that might break off or impede the assembly of parts. Figure 9-73 illustrates three accepted procedures for dimensioning external chamfers. The illustration at the top shows how to dimension a chamfer using a leader and note. This is frequently done when the chamfer is a 45° chamfer. The middle illustration shows how to dimension larger chamfers at angles other than 45°. Notice that the length of the chamfer is dimensioned, as is the angle of the chamfer. The bottom illustration shows how to dimension a 45° chamfer that is very small. The dimension is called out and followed by the term "MAX." This tells the machinist that a 45° chamfer is to be applied but its length is to be no more than .010.

Dimensioning Internal Chamfers

Figure 9-74 illustrates two accepted methods for dimensioning internal chamfers. The example on the left illustrates how to call out a 45° chamfer. The example on the right illustrates how to call out a chamfer other than 45°. Notice that when the chamfer is other than 45° the dimension of the top of the hole after the chamfer has been applied must be given, as must the angle of the chamfer.

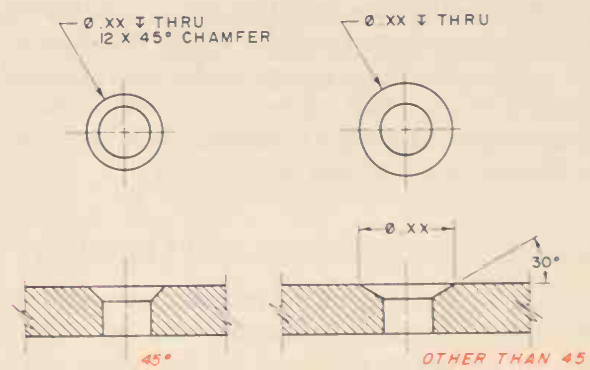


Figure 9-74 Dimensioning internal chamfers

Staggered Dimensions

Figure 9-75 illustrates the proper method for applying staggered dimensions. A succession of parallel dimensions can become confusing and difficult to read. As a result, the accepted practice is to stagger the series of parallel dimensions as shown in the bottom half of Figure 9-75. Staggered dimensions are usually easier to read than aligned parallel dimensions.

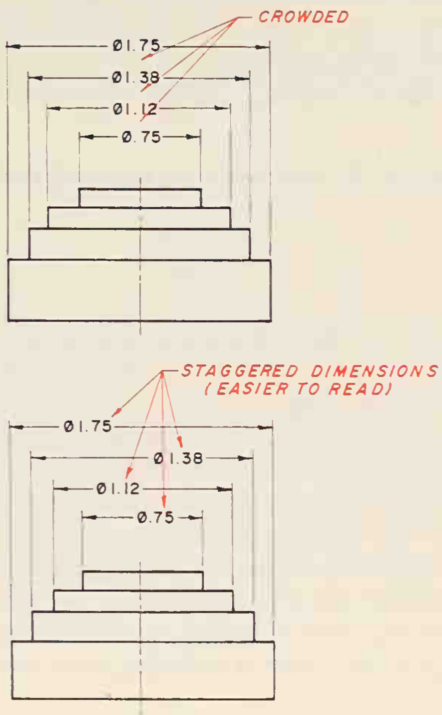


Figure 9-75 Staggered dimensions

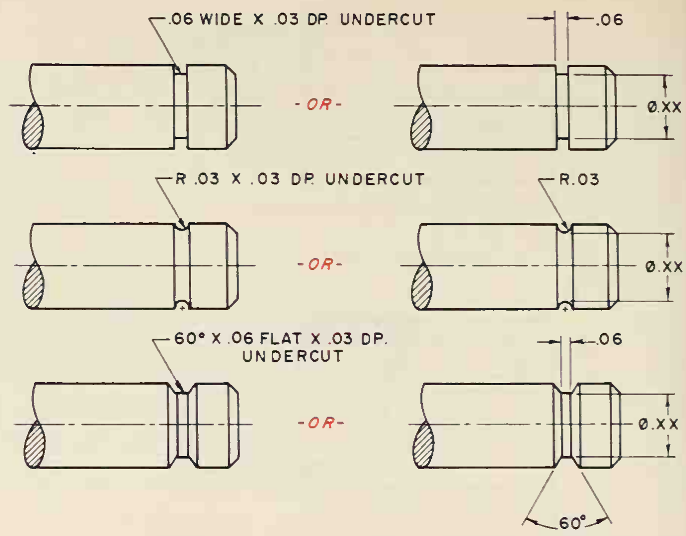


Figure 9-76 Dimensioning necks and undercuts

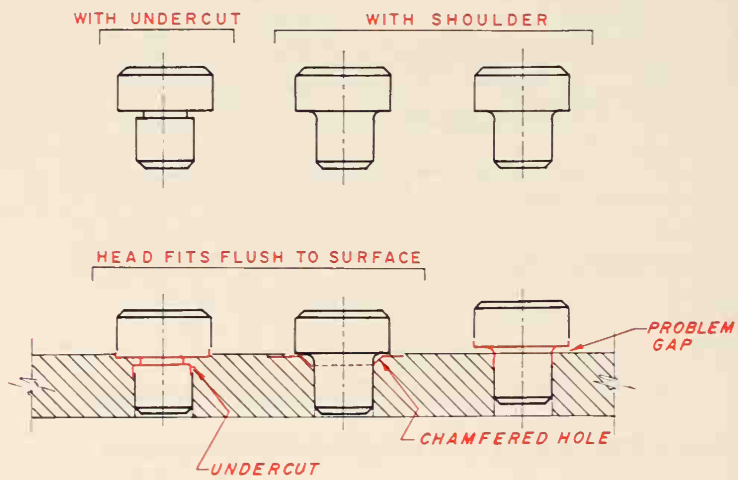


Figure 9-77 Headfits for undercuts and chamfers

Dimensioning Necks and Undercuts

Necks and undercuts are recessed cuts into cylindrical parts. They are generally used where cylinders or other geometric shapes come together. Figure 9-76 illustrates the proper method for dimensioning necks and undercuts. Notice from the three examples on the left side of Figure 9-76 that necks and undercuts may be dimensioned using a leader and accompanying note. The three examples on the right side of Figure 9-76 show that necks and undercuts may also be dimensioned using a combination of notes, angular dimensions, and size dimensions.

Head Fits for Undercuts and Chamfers

Figure 9-77 illustrates the proper method for showing head fits for parts with undercuts and shoulders. With an undercut, the head fits flush with the surface. With a shoulder, the head will only fit flush with the surface if the surface has been chamfered.

Dimensioning Knurls

Knurls are diamond-shaped or parallel patterns cut onto cylindrical surfaces to improve gripping, to improve the bonding between parts for permanent press fits, and, sometimes, for decoration. The accepted methods for dimensioning both parallel and diamond-shaped knurls are illustrated in Figure 9-78. Notice in this figure that when knurls are fully dimensioned on a drawing, there is no need to actually show them. The callouts for a knurl should include the type, pitch, and diameter. The initials "DP" in the knurl callouts stand for diametrical pitch. The most commonly used diametrical pitches for knurling are 64 DP, 96 DP, 128 DP, and 160 DP. In addition to the knurling callout, the length of the knurl and the diameter of the cylinder that will receive the knurls must be shown.

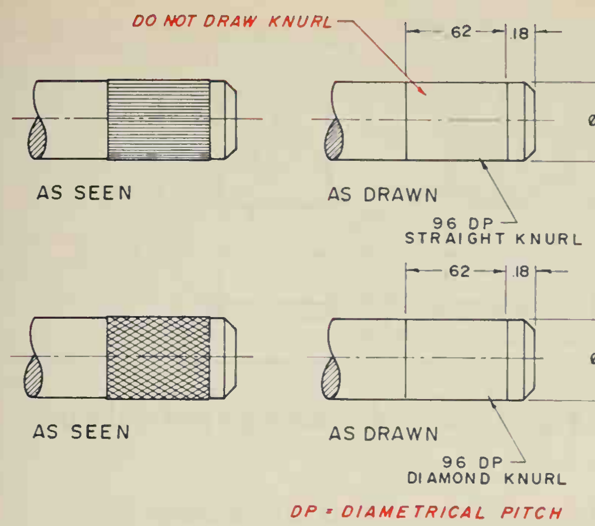


Figure 9-78 Dimensioning knurls

Dimensioning Keyways

Figure 9-79 illustrates the preferred methods for dimensioning both exterior and interior keyways. Notice that both size and location dimensions are required to completely dimension a keyway. The size dimension gives the overall width of the keyway, and the location dimension locates the keyway on the object in question from a specified datum such as the center line of the object. With an exterior keyway, the depth is shown using a dimension which runs from the bottom of the keyway to the bottom of the part in question and parallel to the center line or axis of the shaft. With an interior keyway, the depth of the keyway is specified using a dimension which runs from the top of the keyway to the bottom of the hole and parallel to the center line of the hole. Figure 9-80 illustrates the preferred method for dimensioning a woodruff keyway. A woodruff keyway requires both size and location dimensions. The size dimensions specify the width and depth of the keyway. The location dimension from a specified datum such as a center line locates the keyway in the part as shown in Figure 9-80. In addition, the location of the center of the keyway from one end of the shaft must also be shown. The diameter of the shaft and the woodruff cutter must also be dimensioned, as shown in Figure 9-80.

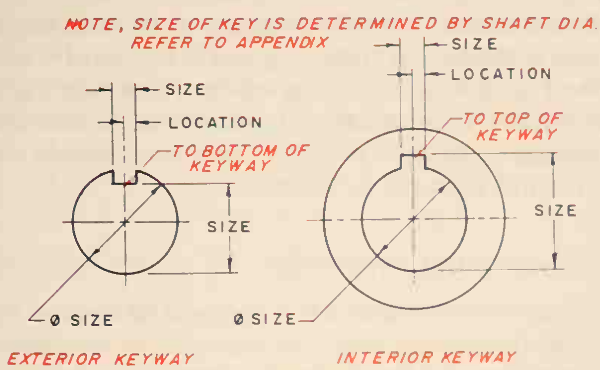


Figure 9-79 Dimensioning keyways

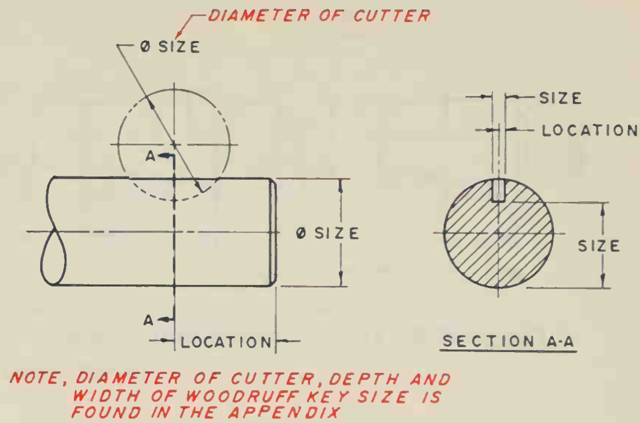


Figure 9-80 Dimensioning a woodruff keyway

Dimensioning Flat Tapers

Figure 9-81 illustrates the preferred method for dimensioning flat tapers. The method on the left uses 2-size dimensions and a leader with a taper symbol attached. In addition, the taper ratio must be shown. The 5:1 taper ratio called out for the part on the left means that the part tapers one unit in the vertical direction for every five units traveled in the horizontal. The example on the right illustrates another acceptable method for dimensioning flat tapers. In this method, 3-size dimensions provide all of the information needed to manufacture the part with the proper taper.

Dimensioning Round Tapers

Figure 9-82 illustrates two acceptable methods for dimensioning round tapers. Round tapers can be dimensioned by providing the following dimensional data: (a) the diameter or width at both ends of the taper; (b) the length of the tapered feature; and (c) the rate of taper. The example on the right shows the

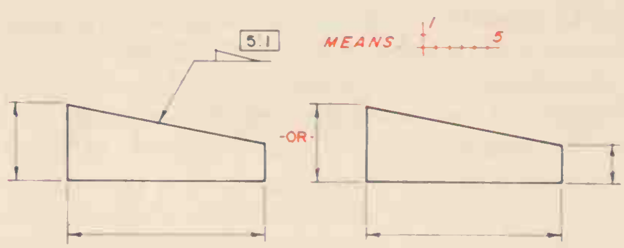


Figure 9-81 Dimensioning flat tapers

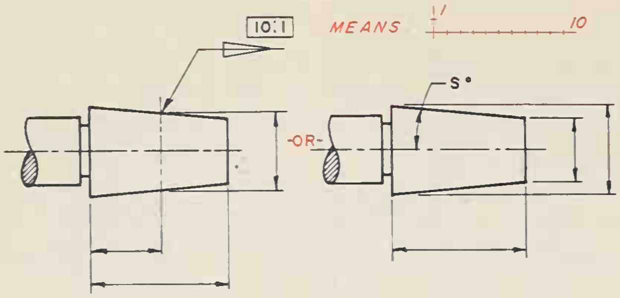


Figure 9-82 Dimensioning round tapers

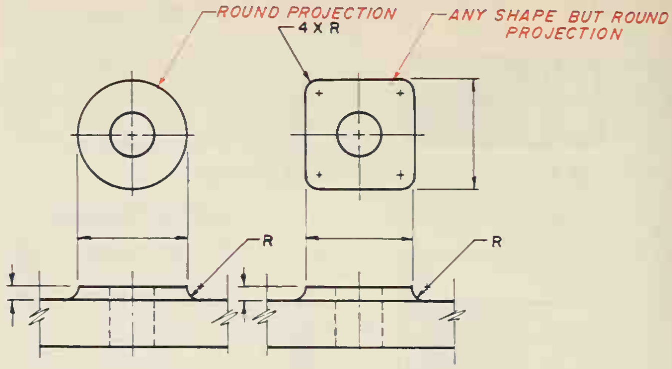


Figure 9-84 Dimensioning a pad and a boss

diameter at both ends of the taper. The example on the left shows the length of the tapered feature and is in the taper ratio of 10:1, meaning that the part is tapered one unit for every ten units parallel to the horizontal center line of the shaft.

Dimensioning Threads

Figure 9-83 shows the preferred methods for dimensioning threaded fasteners. Notice that it is not necessary to attempt to draw an actual representation of the thread. Rather, the schematic approach shown in the middle and bottom examples is preferred. The threads themselves are called out in a thread note attached to a leader. In addition, the nominal diameter of the shaft being threaded and the longitudinal distance of the threading must also be dimensioned, as shown in Figure 9-83. A chamfer call out should be shown with the leader line to indicate how the end of the threaded fastener is to be chamfered.

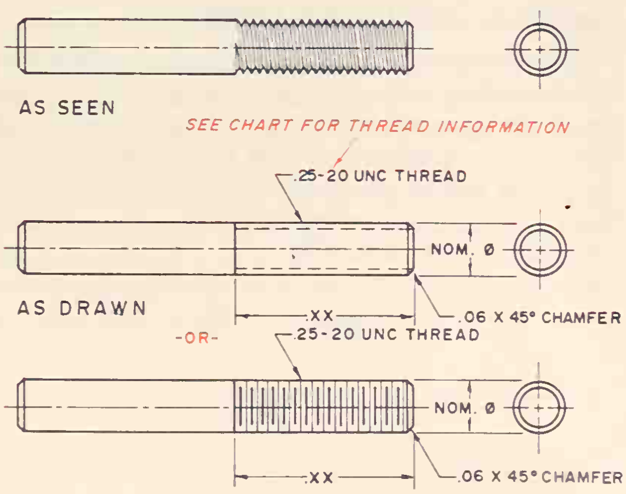


Figure 9-83 Dimensioning threads

Dimensioning a Pad and a Boss

Figure 9-84 illustrates the preferred method for dimensioning a pad and a boss. A boss is a round projection from a part. A pad is a projection of any shape other than round. Notice from Figure 9-84 that the boss requires a diameter dimension, a dimension showing how far the boss projects out from the part, and a radius indicator. The pad requires 2-size dimensions: one for length and one for width. It also requires a projection dimension and a radius indicator.

Dimensioning Sheet Metal Bends

Figure 9-85 illustrates the different methods for dimensioning sheet metal bends. When dimensioning a sheet metal object, allowances must be made for the bends. The intersection of the surfaces adjacent to a bend is called the "mold line." This is the line which is used for dimensioning purposes. Notice in Figure 9-85 that each bend has an inside mold line and an outside mold line. Dimensions begin at the intersection of the outside mold line, as shown.

Dimensioning Sectional Views

Figure 9-86 illustrates the rule for dimensioning sectional views. The dimension should, whenever possible, be placed outside the object. Placing dimensions inside an object causes them to conflict with the section lines. When there is no other way to apply a dimension than to place it inside of a sectioned area, remove enough of the section lining to permit the dimension to be easily read and the dimension lines to be easily seen, as shown in the right-hand example in Figure 9-86.

Dimensioning Pyramids

Figure 9-87 illustrates the acceptable method for dimensioning a pyramid. A pyramid is dimensioned by showing the height in the front view and the

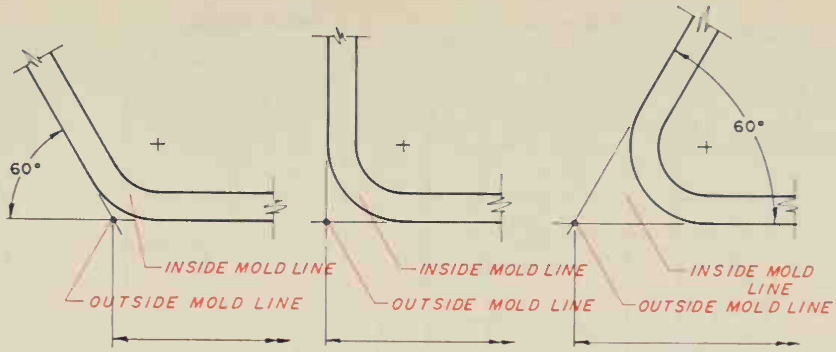


Figure 9-85 Dimensioning sheet metal bends

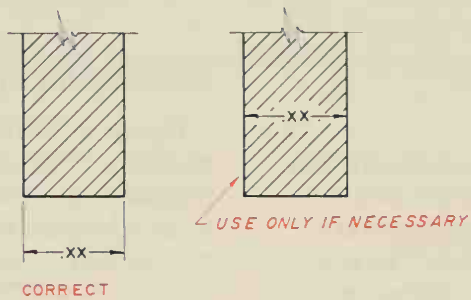


Figure 9-86 Dimensioning sectional views

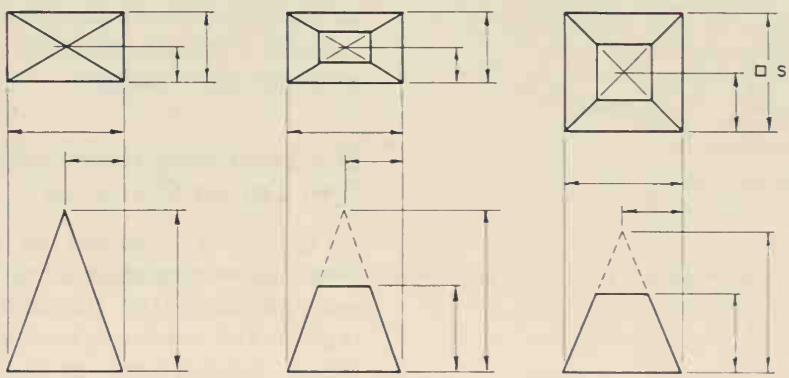


Figure 9-87 Dimensioning a pyramid

dimensions of the base and the center of the vertex in the top view. If the pyramid base is square, it is only necessary to show the base dimension on one side of the base in the top view and to indicate that the base is square by using the appropriate symbol.

Dimensioning a Cone

Figure 9-88 illustrates the preferred methods for dimensioning a cone. A cone is dimensioned by showing its altitude in the view where the cone appears as a triangle and showing the diameter of the base between the top view and front view. The frustum of a cone is dimensioned by giving the diameter between the top and front view, and both heights in the front view where the cone would appear as a triangle. The example on the right-hand side of Figure 9-88 illustrates how to dimension a cone that is cut off at an angle. The diameter of the cone's base is shown between the top and front views. The height of the cone before it is cut and the height of the cone at the center line of the cone after the cut are shown in the front view where the cone would appear as a triangle. The angle of the cut also is dimensioned in this view.

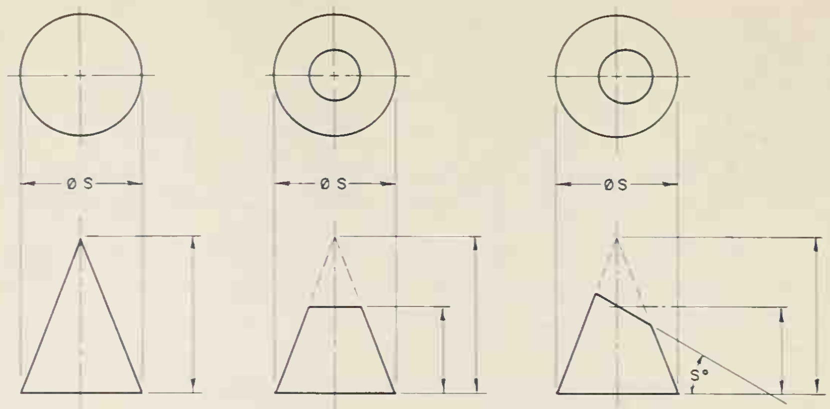


Figure 9-88 Dimensioning a cone

Dimensioning Concentric and Nonconcentric Shafts

Figure 9-89 illustrates the various methods that can be used for dimensioning concentric and nonconcentric shafts and cylinders. The example at the top uses the chain dimensioning concept. The example in the center uses the datum or baseline dimensioning concept. The example at the bottom uses the datum dimensioning concept combined with a reference dimension.

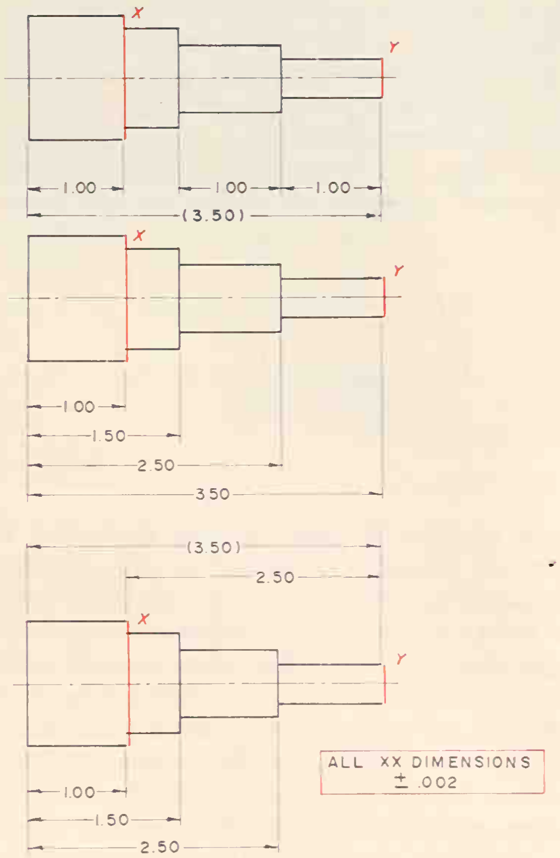


Figure 9-89 Dimensioning concentric and nonconcentric shafts

Rectangular Coordinate Dimensioning

Figure 9-90 illustrates the proper methods for applying rectangular coordinate dimensioning. Rectangular coordinate dimensioning is a system which locates features of the drawing relative to each other, individually or as a group, from a datum or series of datums. Round holes and other similar features are located by dimensioning distances to their center points. Linear dimensions in the rectangular coordinate dimension system specify distances from two or three mutually perpendicular planes which are used as datums. Coordinate dimensions should clearly indicate what features of the part being dimensioned establish these datums.

Dimensioning Holes on a Bolt Center Diameter

Figure 9-91 illustrates the proper methods used in dimensioning holes on a bolt center diameter. In the example on the left, the diameter of the bolt's circle is given and one angle is shown to indicate the number of degrees between the center lines of the six circles. This is sufficient information for the machinist to properly drill the holes. In the example on the right, a note is used to accomplish the same thing. Notice that the note specifies the number and size of the holes. It explains that the holes are drilled through the object and equally spaced on a bolt center. Either of these methods may be used for dimensioning holes around a center. Figure 9-92 shows two other methods which are used for dimensioning holes around a center. These methods are used when the holes around the bolt center are not equally spaced. The example on the left gives a dimension for the bolt center, a note containing the number of holes and their size, and angles turned off of a reference center line for locating the center lines of the other three holes. The example on the right substitutes linear dimensions for angular dimensions.

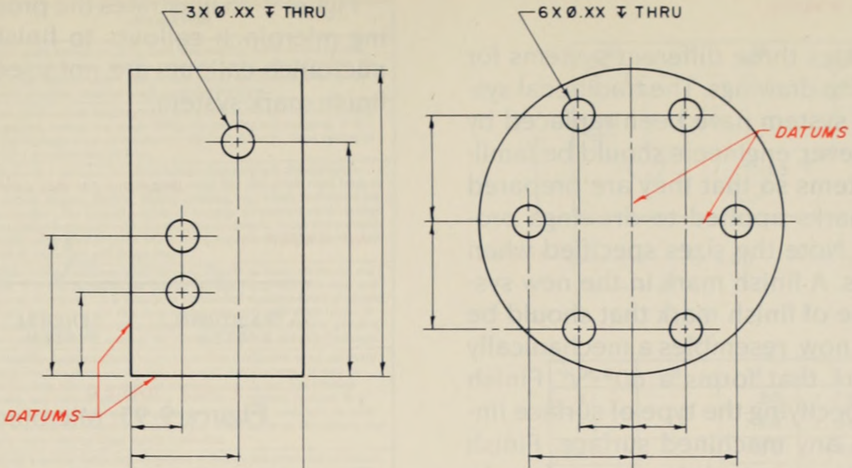


Figure 9-90 Rectangular coordinate dimensioning

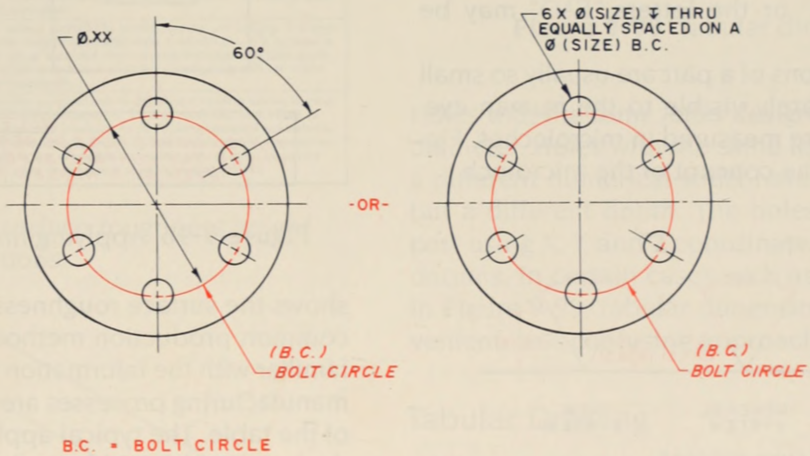


Figure 9-91 Dimensioning holes on a bolt center diameter

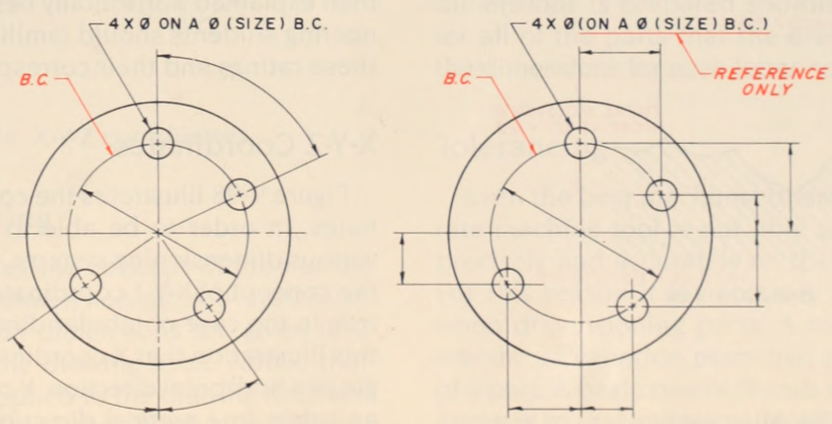


Figure 9-92 Dimensioning holes around a center

Finish Marks

Figure 9-93 illustrates three different systems for applying finish marks to drawings. The traditional system and the general system have been replaced by the new system. However, engineers should be familiar with all three systems so that they are prepared to interpret finish marks applied to drawings produced in years past. Note the sizes specified when applying finish marks. A finish mark in the new system, which is the type of finish mark that should be used on all drawings now, resembles a mechanically produced check mark that forms a 60° "v." Finish marks are used for specifying the type of surface finish to be applied to any machined surface. Finish marks should always appear where the surface in question appears as an edge view. Finish marks are not used when dimensioning notes are given for such machining processes as drilling and boring, as they would be redundant. Finish marks are also omitted when the part in question is made of machined stock. When all surfaces on a part are finished, a note stating "Finish all over" or the letters "FAO" may be substituted.

Surface imperfections of a part are usually so small that they may be barely visible to the human eye. Consequently, they are measured in microinches. Figure 9-94 illustrates the concept of the microinch.

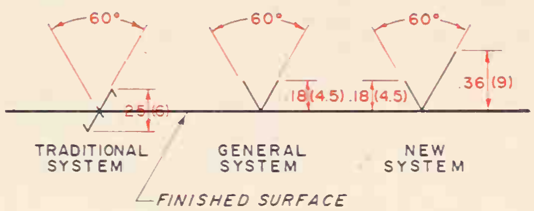


Figure 9-93 Finish marks

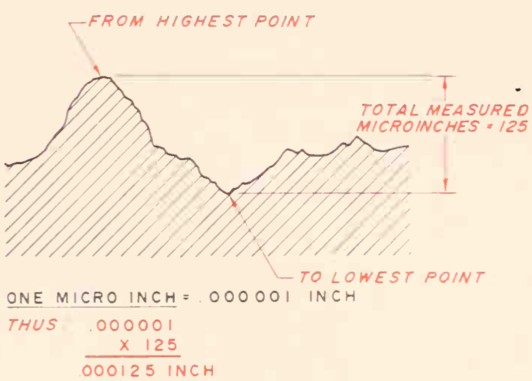


Figure 9-94 Microinches

Figure 9-95 illustrates the proper method for applying microinch callouts to finish marks. Notice that microinch callouts are not used with the traditional finish mark system.

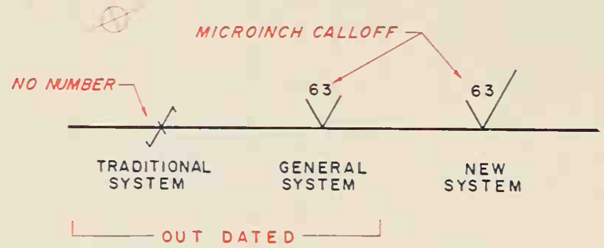


Figure 9-95 Microinch callouts

Figure 9-96 illustrates the rule for applying finish marks to drawings. Note that finish marks are to be repeated in every view where the surface in question appears as an edge. Table 46 in the Appendix shows the surface roughness textures obtainable by common production methods. Engineers should be familiar with the information in this table. The various manufacturing processes are listed along the left side of the table. The typical applications are listed along the bottom of the table, and the corresponding roughness height rating for each process/application is listed horizontally in a bar-graph format. Figure 9-97 is a table of typical surface roughness height applications. Microinch ratings are listed in the left-most column of the table. The corresponding micrometer ratings are listed in the next column. Applications are then explained horizontally beside each rating. Engineering students should familiarize themselves with these ratings and their corresponding applications.

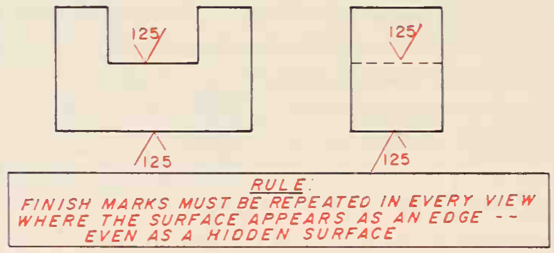


Figure 9-96 Applying finish marks to drawings

X-Y-Z Coordinates

Figure 9-98 illustrates the concept of X-Y-Z coordinates. In order to be able to fully understand the various dimensioning systems, one must understand the concept of X-Y-Z coordinates. This is particularly true in the case of tabular dimensioning. Note from this illustration that X coordinates move from an origin in a horizontal direction, Y coordinates move from an origin in a vertical direction, and Z coordinates move from an origin in a direction indicating depth.

MICROMETRES AA RATING	MICROINCHES AA RATING	APPLICATION
25.2	1000	Rough, low grade surface resulting from sand casting, torch or saw cutting, chipping, or rough forging. Machine operations are not required because appearance is not objectionable. This surface, rarely specified, is suitable for unmachined clearance areas on rough construction items.
12.5	500	Rough, low grade surface resulting from heavy cuts and coarse feeds in milling turning, shaping, boring, and rough filing, disc grinding and snagging. It is suitable for clearance areas on machinery, jigs, and fixtures. Sand casting or rough forging produces this surface.
6.3	250	Coarse production surfaces, for unimportant clearance and cleanup operations, resulting from coarse surface grind, rough file, disc grind, rapid feeds in turning, milling, shaping, drilling, boring, grinding, etc., where tool marks are not objectionable. The natural surfaces of forgings, permanent mold castings, extrusions, and rolled surfaces also produce this roughness. It can be produced economically and is used on parts where stress requirements, appearance, and conditions of operations and design permit.
3.2	125	The roughest surface recommended for parts subject to loads, vibration, and high stress. It is also permitted for bearing surfaces when motion is slow and loads light or infrequent. It is a medium commercial machine finish produced by relatively high speeds and fine feeds taking light cuts with sharp tools. It may be economically produced on lathes, milling machines, shapers, grinders, etc., or on permanent mold castings, die castings, extrusion, and rolled surfaces.
1.6	63	A good machine finish produced under controlled conditions using relatively high speeds and fine feeds to take light cuts with sharp cutters. It may be specified for close fits and used for all stressed parts, except fast rotating shafts, axles, and parts subject to severe vibration or extreme tension. It is satisfactory for bearing surfaces when motion is slow and loads light or infrequent. It may also be obtained on extrusions, rolled surfaces, die castings and permanent mold castings when rigidly controlled.
0.8	32	A high-grade machine finish requiring close control when produced by lathes, shapers, milling machines, etc., but relatively easy to produce by centerless, cylindrical, or surface grinders. Also, extruding, rolling or die casting may produce a comparable surface when rigidly controlled. This surface may be specified in parts where stress concentration is present. It is used for bearings when motion is not continuous and loads are light. When finer finishes are specified, production costs rise rapidly, therefore, such finishes must be analyzed carefully.
0.4	16	A high quality surface produced by fine cylindrical grinding, emery buffing, coarse honing, or lapping. it is specified where smoothness is of primary importance, such as rapidly rotating shaft bearings, heavily loaded bearing and extreme tension members.
0.2	8	A fine surface produced by honing, lapping, or buffing. It is specified where packings and rings must slide across the direction of the surface grain, maintaining or withstanding pressures, or for interior honed surfaces of hydraulic cylinders. It may also be required in precision gauges and instrument work, or sensitive value surfaces, or on rapidly rotating shafts and on bearings where lubrication is not dependable.
0.1	4	A costly refined surface produced by honing, lapping, and buffing. It is specified only when the design requirements make it mandatory. It is required in instrument work, gauge work, and where packing and rings must slide across the direction of surface grain such as on chrome plated piston rods, etc. where lubrication is not dependable.
0.05 0.025	2 1	Costly refined surfaces produced only by the finest of modern honing, lapping, buffing, and superfinishing equipment. These surfaces may have a satin or highly polished appearance depending on the finishing operation and material. These surfaces are specified only when design requirements make it mandatory. They are specified on fine or sensitive instrument parts or other laboratory items, and certain gauge surfaces, such as precision gauge blocks.

Figure 9-97 Typical surface roughness height applications

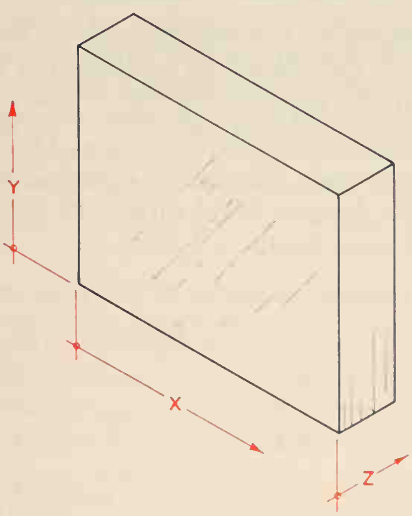
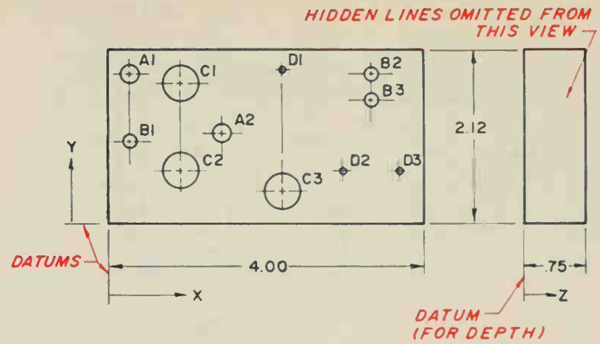


Figure 9-98 X-Y-Z coordinates

Tabular Dimensioning

Figure 9-99 illustrates the concept of tabular dimensioning. Tabular dimensioning is a system in which size and location dimensions are given in a table rather than on the drawing itself. Notice that the only dimensions applied to the drawing itself are the overall length, width, and depth dimensions. Each hole is given an alphanumeric designation.



HOLE	Ø	X	Y	Z	NOTE
A1	.25	.30	1.75	THRU	–
A2		1.38	1.06	.38	–
B1	.18	.30	.94	THRU	–
B2		3.25	1.75	THRU	–
B3		3.25	1.50	THRU	–
C1	.38	.88	1.68	.38	–
C2		.88	.62	.25	–
C3		1.12	.38	.38	–
D1	.08	2.12	1.81	THRU	–
D2		3.00	.62	.38	–
D3		3.62	.62	.38	–

Figure 9-99 Tabular dimensioning

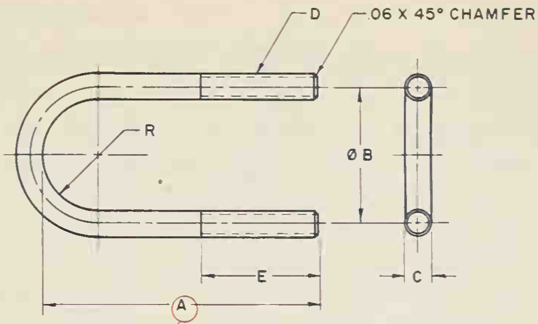
Holes with the same letter designation have the same diameter. Holes with the same letter designation but a different numerical suffix have the same diameter but a different depth. The holes are located in the part using X, Y, and Z coordinates from the specified datums. In certain cases such as the one illustrated in Figure 9-99, tabular dimensioning is a more convenient, less confusing approach.

Tabular Drawing

When parts have similar features but different dimensions, the dimensions can be given in tabular form to decrease the amount of drawing that must be done. With a tabular drawing, one drawing of the part is made with all appropriate dimension lines applied. However, instead of dimension notations, numerical notations are substituted. Then a table of dimensions is prepared showing the part numbers for all of the parts that the drawing applies to and the dimensions for each letter notation, Figure 9-100.

Tolerancing

Even the best machinist operating the most accurate machine tool is not able to produce a part as precisely and accurately as specified on a drawing. For this reason it is necessary to apply tolerances when dimensioning parts. A tolerance is the total amount of variation permitted from the design size of a part. A basic rule of thumb when applying tolerances is to make them as large as possible and still be able to produce a usable part. Tolerances may be



A85254-3	4.50	1.62	Ø.38	3/8-16 UNC-2A	1.50
A85254-2	4.88	2.50	Ø.38	3/8-16 UNC-2A	2.00
A85254-1	2.50	1.50	Ø.25	1/4-20UNC-2A	.88
PART NUMBER	A	B	C	D	E

REGULAR DRAWING NUMBER

PLAN NO 85254

Figure 9-100 Tabular drawing

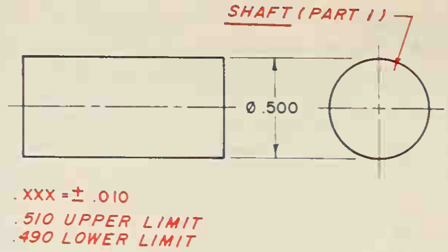


Figure 9-101 Shaft limits

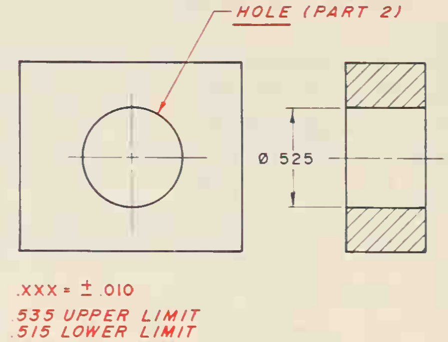


Figure 9-102 Hole limits

expressed as limits, as shown in Figures 9-101 and 9-102 or as the design size followed by the tolerance (12.382 ± 0.003). The design size of a part is also known as the nominal size. This is the dimension from which the limits are calculated. To calculate the upper limit of a toleranced dimension, add the allowable tolerance to the nominal size. To calculate the lower limits for such dimensions, subtract the allowable tolerance from the nominal size, Figure 9-101 and 9-102. There are several definitions with which drafters and engineers should be familiar before applying tolerances on drawings. The most important of these are:

Actual Size. Also called the produced size, this is the actual size of the part after it is produced.

Allowance. The amount of room between two main parts, usually considered the tightest possible fit between the two parts.

Bilateral Tolerance. A bilateral tolerance is one in which variation from the nominal dimension is allowed in both the plus and the minus direction (.500 ± .002).

Datum. A theoretically perfect surface, plane, axis, center plane, or point from which dimensions for related features are established.

Least Material Condition (LMC). The condition which exists when the least material is available for the features being dimensioned. LMC is the lower limit for an external feature and the upper limit for an internal feature.

Limits. The largest and smallest possible size in which a part may be produced and still be usable. The limits are calculated by applying the specified tolerance to the nominal dimension.

Maximum Material Condition (MMC). The condition of a part in which the most material is present. MMC is the upper limit for an external feature and the lower limit for an internal feature.

Nominal Dimension. This is the dimension from which the limits are calculated. By applying the specified tolerance to the nominal dimension one can calculate the upper and lower limits.

Tolerance. The total permissible variation in size for a part. The tolerance is the difference between the upper and lower limits for a part.

Unilateral Tolerance. A tolerance that may vary in only one direction; either in the plus or minus direction but not both:

$$.500 \begin{smallmatrix}+.000\\-.002\end{smallmatrix} \qquad .250 \begin{smallmatrix}+.002\\-.000\end{smallmatrix}$$

In addition to these tolerance-related definitions, drafters and engineers should also be familiar with the types of fits that are used with mating parts. The following definitions relate specifically to fits between mating parts.

Fit. Fit refers to the amount of tightness or looseness between mating parts. There are three types of fits: clearance, interference, and transition.

Clearance Fit. A clearance fit is one in which there is space remaining after mating parts have been assembled.

Interference Fit. The type of fit which occurs when there is a negative allowance, or in other words, when the shaft is larger than the collar with which it must mate.

Transition Fit. The type of fit in which there may be either a clearance or an interference fit after mating parts have been assembled. This occurs when the smallest shaft size within the allowable tolerance will fit within the largest hole size, resulting in a clearance fit, and when the largest shaft size within the allowable tolerance will interfere with the smallest hole within an allowable tolerance, creating an interference fit.

Shaft Limits

Figure 9-101 illustrates the concept of shaft limits. In this figure the shaft has a nominal dimension of .500. The tolerance specified is ±.010. To determine the upper limit for the shaft, the tolerance of .010 is added to the nominal dimension of .500, resulting in an upper limit of .510. To determine the lower limit of the shaft, the tolerance of .010 is subtracted from the nominal dimension of .500, resulting in a lower limit of .490.

Hole Limits

Figure 9-102 illustrates the concept of hole limits. The hole through the part shown has a nominal diameter of .525. The specified tolerance is ±.010. To determine the upper limit for the hole, the tolerance of .010 is added to the nominal dimension of .525, resulting in an upper limit of .535. The lower limit is determined by subtracting the tolerance of .010 from the nominal dimension of .525, resulting in a lower limit of .515.

Allowance

Figure 9-103 illustrates the concept of allowance or the tightest fit between mating parts. Part 1 is a shaft that, when assembled, will mate with Part 2. To determine the allowance between Part 1 and Part 2, the maximum material condition of the shaft (the largest allowable size) is subtracted from the maximum material condition of the hole (the smallest size hole). The maximum material condition of the shaft is .510. The maximum material condition of the hole is .515. Therefore, the allowance between Part 1 and Part 2 is .005.

Clearance

Figure 9-104 illustrates the concept of clearance. The shaft, Part 1, is to mate with the collar, Part 2, during assembly. To determine the clearance between

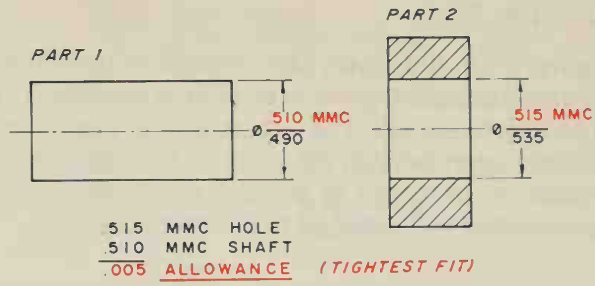


Figure 9-103 Allowance

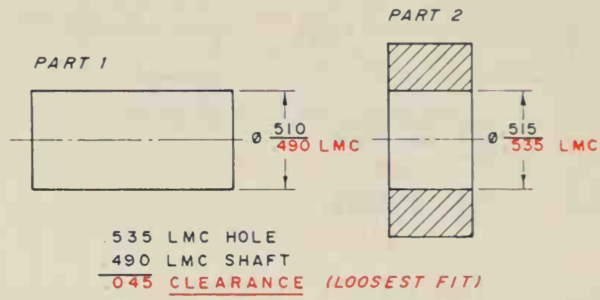


Figure 9-104 Clearance

Part 1 and Part 2, the least material condition of the shaft is subtracted from the least material condition of the hole. The least material condition of the shaft is .490. The least material condition of the hole is .535. Therefore, the clearance between Part 1 and Part 2 is .045.

Interference Fit

Figure 9-105 illustrates the concept of interference fit. The smallest shaft in this example is larger than the largest corresponding hole. To determine the amount of interference, you can calculate the allowance and the clearance. The allowance, in the case of an interference fit, represents the maximum amount of interference. The clearance, in an interference fit, represents the smallest amount of interference. You can see from the calculations in Figure 9-105 that the maximum amount of interference during assembly will be .007, or the allowance. The minimum amount of interference will be .004, or the clearance.

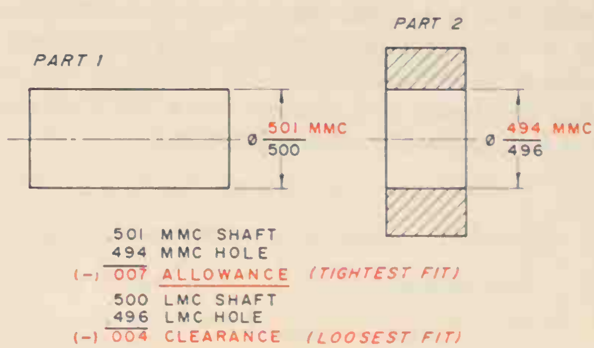


Figure 9-105 Interference fit

Transition Fit

Figure 9-106 illustrates the concept of transition fit. In this example there can be both a clearance fit and an interference fit. The largest shaft in this example would interfere with the smallest hole. However, the smallest shaft will fit through the largest hole. This condition is illustrated in the calculations.

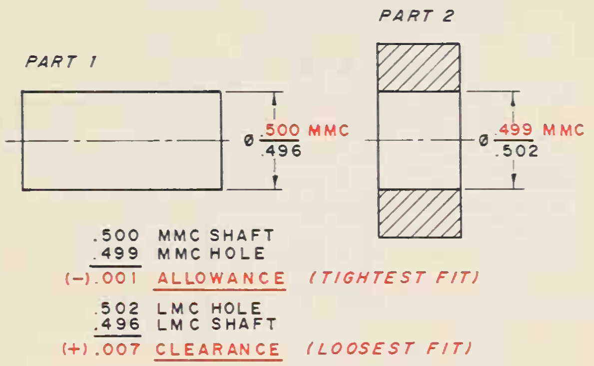


Figure 9-106 Transition fit

Size Limits

Figure 9-107 illustrates the concept of size limits. The cylindrical part shown in this figure will be usable if produced at any size between the upper and lower length limits, and at any diameter between the upper and lower diameter limits, inclusive. Applying size limits such as those illustrated in Figure 9-107 cuts down on waste, requires less time to produce the part, and, therefore, cuts the cost of production and the corresponding costs of the part.

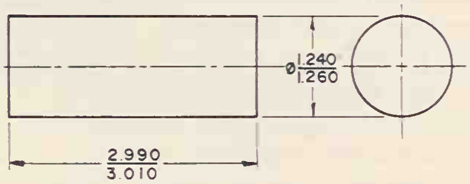


Figure 9-107 Size limits

Design Size

Figure 9-108 illustrates the concept of design size. Design size is another way of stating nominal size. The design size represents the ideal the drafter or engineer is seeking. Ideally, the produced size will match the design size. However, since this is not practical, tolerances are normally applied.

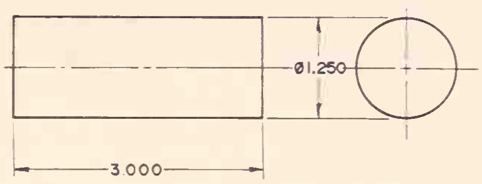


Figure 9-108 Design size

Maximum and Minimum Sizes

Figure 9-109 illustrates the concept of maximum and minimum sizes. These are the sizes between which the actual length and diameter of the produced part must fall. After all machining processes have been completed, the inspection department will check the part. If the actual produced size falls within the established maximum and minimum sizes (inclusive), the part will be passed as usable. If it is smaller in any dimension than the minimum size, the part will be scrapped as waste. If it is larger in any dimension than the maximum size, it might be salvaged through additional machining.

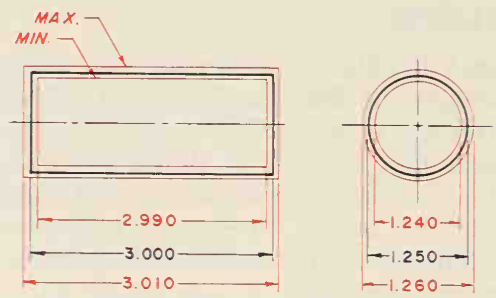


Figure 9-109 Maximum and minimum sizes

Location Limits

Just as limits are applied to size dimensions, they are also applied to location dimensions, and for the same reasons. Machinists are not able to locate features on a part precisely to the design dimension. Consequently, limits must be applied to location dimensions.

Figure 9-110 illustrates how limits are applied to location dimensions. The part shown in Figure 9-110 will be accepted if the central line of the hole falls within the limits shown.

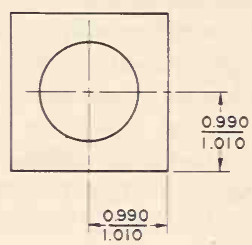


Figure 9-110 Location limits

Design Location

Figure 9-111 illustrates the concept of design location. The design location is the location the drafter or engineer actually wants. It is the theoretically ideal location of the feature. The dimensions shown on this figure are the design dimensions, sometimes referred to as nominal dimensions. The specified tolerance is applied to these nominal dimensions to determine the upper and lower limits for locating the feature.

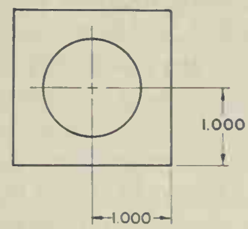


Figure 9-111 Design location

Maximum and Minimum Locations

Figure 9-112 illustrates the concept of maximum and minimum locations. By applying the specified tolerance to the nominal dimensions, the maximum and minimum locations of the center line of the feature in this figure can be determined. The tolerances applied to the nominal dimension give the machinist latitude in both the X and Y directions. This establishes a square tolerance zone within which the actual center point must fall. So long as the center of the feature falls anywhere within the prescribed tolerance zone, the parts will be accepted as usable.

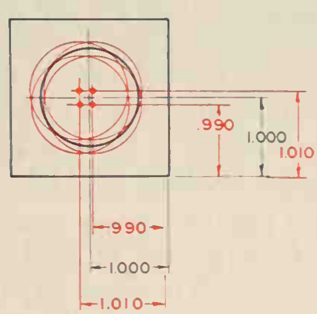


Figure 9-112 Maximum and minimum locations

Calculating Fits

Figure 9-113 illustrates the mathematics involved in calculating fits. Take special note of the rule that states "All dimensions should be given as large as possible without interfering with the function of the part in order to keep costs down—close dimensions are expensive." The tighter the fit, the more difficult the part is to manufacture. The more difficult the part is to manufacture, the more it costs to manufacture. Therefore, an engineer and a drafter should never assign a tighter fit than is absolutely necessary for the part to properly function.

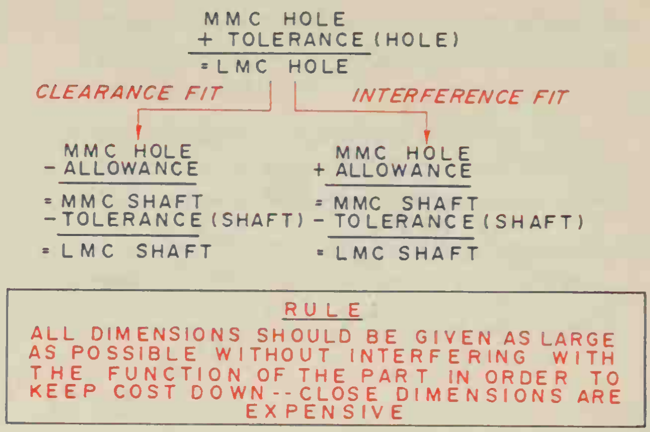


Figure 9-113 Calculating fits

Matching Parts

Figure 9-114 illustrates the concept of matching parts. During assembly, Part A must fit over Part B. You can see from this drawing that the hole in Part A must be large enough to accommodate the size and location tolerances of the pins in Part B. The parts must be able to fit if the holes in Part A are bored and located on the low side of the tolerance, and the pins in Part B are made and located on the high side of the tolerance. Obviously, determining the dimensions to be used for matching parts takes a good deal of careful planning. It is critical that features on mating parts be located from the same datum as shown in this figure. Some additional factors to consider when planning the dimensions for matching parts are:

1. The length of time the parts are to be engaged
2. The speed at which mating parts will move after assembly
3. The load of the parts after assembly
4. The type of lubrication used if lubrication is necessary
5. The average temperature at which parts will operate
6. The level of humidity during operation
7. The materials of which parts are made
8. The required functional lifespan of the part
9. The capabilities of machine tools and the people that operate them in the manufacturing plant
10. Overall costs of the part

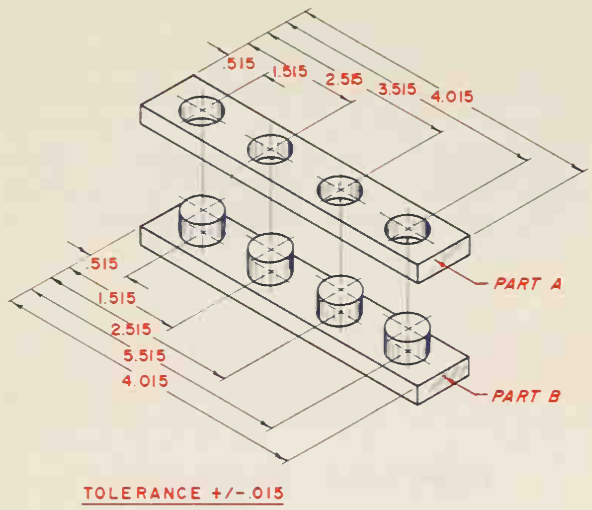


Figure 9-114 Matching parts

Standard Fits

Figure 9-115 shows the different types of standard fits. The American National Standards Institute document governing fits is ANSI B4.1-1967, R1979. This standard covers the five types of fits listed in Figure 9-115. Each of these fits is explained below.

STANDARD FITS	
RC	RUNNING AND SLIDING FITS
LC	CLEARANCE LOCATIONAL FITS
LT	TRANSITION LOCATIONAL FITS
LN	INTERFERENCE LOCATIONAL FITS
FN	FORCE AND SHRINK FITS

Figure 9-115 Standard fits

Running or Sliding Clearance Fits (RC). Running or sliding fits are used to provide a similar running or sliding performance, with an allowance for suitable lubrication, for all sizes within the specified range. Figure 9-116 is a table of American National Standard Running and Sliding Fits (ANSI B4.1-1967, R1979). From this table you can see that there are nine classes of running and sliding fits: Classes RC1, RC2, RC3, RC4, RC5, RC6, RC7, RC8, and RC9.

Class RC1 is used with close sliding fits for accurately locating parts that must fit together without any play. Class RC2 is used for sliding fits where accurate location is important, but where greater maximum clearance than is provided by class RC1 fits is necessary. Parts manufactured to this fit do not run freely, but they do move and turn easily. Class RC3 is used for precision running fits. This class ensures the closest possible fit that can be expected to run freely. This fit is used for precision work that will operate at slow speeds under light pressures, but is not suitable where significant temperature differences are likely to occur.

Class RC4 is used for close running fits on accurate machinery with medium surface speeds and pressure when accurate location and very little play is desired. Classes RC5 and RC6 are used for medium running fits on accurate machinery with higher running speeds and/or heavier pressures. Class RC7 is used for free running fits where accuracy is less important and/or where significant temperature variations are likely. Classes RC8 and RC9 are used for loose running fits when large tolerances are necessary, together with an allowance on the external parts.

Clearance Locational Fits (LC). Clearance locational fits are used with parts that are stationary but must be able to be freely assembled or disassembled. Figure 9-117 is a table of American National Standard Clearance Locational Fits from ANSI 4.1-1967, R1979.

Transition Locational Fits (LT). Transition locational fits fall on a continuum between clearance and interference fits, and are used in applications where locational accuracy is important but a small amount of clearance or interference is allowable. Figure 9-118 is a table of American National Standard Transition Locational Fits from ANSI B4.1-1978, R1979.

Interference Locational Fits (LN). Interference locational fits are used when locational accuracy is very important and for parts requiring rigidity and alignment but no special requirements for bore pressure. Interference locational fits are not used for parts which are designed to transmit frictional loads to other parts through the tightness of the fits. These types of applications are covered by force fits. Figure 9-119 is a table of American National Standard Interference Locational Fits from ANSI B4.1-1967, R1979.

Force and Shrink Fits (FN). Force or shrink fits are a special type of interference fit used when maintenance of constant bore pressure for all sizes within the specified range is important. The amount of interference varies with the diameter, and the difference between minimum and maximum values is small to ensure maintenance of the resulting pressures within reasonable limits. Figure 9-120 is a table of American National Standard Force and Shrink Fits from ANSI B4.1-1967, R1979.

Using Fit Tables

Figures 9-116 through 9-120 are fit tables taken from ANSI B4.1-1967, R1979. It is important for engineers and drafters to know how to use tables such as these. Look at the table in Figure 9-116. The nine classes explained earlier are arranged across the top of the table. Under each class column there are three other columns: one giving the clearance, one giving the standard tolerance limits for the hole, and one giving the standard tolerance limits for the shaft. On the extreme left-hand side of the chart the nominal size range in inches is given. To use this table, as well as the others contained in this chapter, select the appropriate class across the top of the table and locate the nominal size at the extreme left-hand side of the table. Moving across the row that contains the appropriate nominal size range to the class column you have selected, you will find the tolerance limits you need. These tolerance limits are added to or subtracted from the basic size to obtain maximum and minimum sizes of mating parts. Each tolerance is preceded by either a plus or a minus to indicate whether it is added to or subtracted from the basic size.

Manufacturing Precision

Figure 9-121 is a table showing the levels of tolerances engineers and drafters can expect from various common manufacturing processes. It is important for engineers and drafters to know what to expect from the manufacturing processes that will be used in converting their design into an actual working part. It will serve no purpose to specify a tolerance greater than that which can be expected of a given manufacturing process.

Summary of Dimensioning Rules

This section summarizes most of the dimensioning rules with which engineers and drafters should be familiar. This section can be used as a checklist for ensuring that drawings you do throughout this book are properly dimensioned. Use this summary as a checklist until you are so familiar with these rules that the checklist is no longer necessary.

1. Give all dimensions necessary to accurately communicate the design to manufacturing personnel, but only those dimensions necessary.
2. Apply dimensions in such a way that they cannot be misinterpreted.
3. Show dimensions between surfaces or points that have a functional relationship.
4. Do not dimension to or from rough surfaces. Always attempt to dimension from a finished surface.
5. Give complete dimensions, so that manufacturing personnel do not have to interrupt their work to calculate or otherwise determine a dimension they need.
6. Apply dimensions in the views where the shape of the part is shown most accurately.
7. Apply dimensions in those views where the part being dimensioned appears true size and true shape.
8. Do not dimension to hidden lines. If it becomes necessary to dimension to hidden lines, change the view to a sectional view.
9. Attempt to place dimensions which apply to two adjacent views between the views.
10. Avoid crossing extension lines with dimension lines.
11. Clearly dimension and annotate all features. Never expect manufacturing personnel to assume anything.
12. Do not apply a complete chain of detail dimensions. Omit the last one or indicate that the last dimension in the chain is a reference dimension.
13. Avoid placing dimensions on the part itself.
14. Always place dimension lines uniformly throughout the drawing.
15. Never use a line that constitutes a portion of the drawing of a part as a dimension line.
16. Avoid crossing dimension lines wherever possible.
17. Extension lines that cross other extension lines or object lines should not be broken.
18. A center line may be used as an extension line.
19. Center lines should not extend from view to view.
20. Leader lines should point to the center of a hole or circular feature.
21. Leader lines should be straight and broken at precise angles. They should never curve.
22. Leader lines should begin approximately at the center of a note height and extend either from the beginning or end of the note.
23. If it becomes necessary to letter within a section-lined area, erase enough of the section lines to leave a clear space so that the dimension can be easily read.
24. Fraction bars should be horizontal rather than angled.
25. The numerator and denominator of a fraction should not touch the horizontal fraction bar.
26. Finish marks should be applied on views in which the surface appears as an edge.

27. Finish marks are not necessary on parts made from rolled stock.

28. If a part is finished all over, finish marks are not used. Substitute the letters FAO or apply a note that says "Finish All Over."

29. Dimension a cylinder by showing the diameter and length on the rectangular view or by showing the diameter as a diagonal dimension in the circular view.

30. Always specify drill sizes in decimals.

31. A metric diameter dimension should be preceded by the diameter symbol.

32. A metric radius dimension should be preceded by a capital "R."

33. Dimensions that are not to scale should be underlined with a straight line.

34. Decimal dimensioning is preferred for mechanical and manufacturing related drawings.

American National Standard Running and Sliding Fits (ANSI B4.1-1967, R1979)

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or − sign) to obtain maximum and minimum sizes of mating parts.

Nominal Size Range, Inches	Class RC 1			Class RC 2			Class RC 3			Class RC 4		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Clearance*	Hole H5	Shaft g4	Clearance*	Hole H6	Shaft g5	Clearance*	Hole H7	Shaft f6	Clearance*	Hole H8	Shaft f7
Over To	Values shown below are in thousandths of an inch											
0– 0.12	0.1 0.45	+0.2 0	−0.1 −0.25	0.1 0.55	+0.25 0	−0.1 −0.3	0.3 0.95	+0.4 0	−0.3 −0.55	0.3 1.3	+0.6 0	−0.3 −0.7
0.12– 0.24	0.15 0.5	+0.2 0	−0.15 −0.3	0.15 0.65	+0.3 0	−0.15 −0.35	0.4 1.12	+0.5 0	−0.4 −0.7	0.4 1.6	+0.7 0	−0.4 −0.9
0.24– 0.40	0.2 0.6	+0.25 0	−0.2 −0.35	0.2 0.85	+0.4 0	−0.2 −0.45	0.5 1.5	+0.6 0	−0.5 −0.9	0.5 2.0	+0.9 0	−0.5 −1.1
0.40– 0.71	0.25 0.75	+0.3 0	−0.25 −0.45	0.25 0.95	+0.4 0	−0.25 −0.55	0.6 1.7	+0.7 0	−0.6 −1.0	0.6 2.3	+1.0 0	−0.6 −1.3
0.71– 1.19	0.3 0.95	+0.4 0	−0.3 −0.55	0.3 1.2	+0.5 0	−0.3 −0.7	0.8 2.1	+0.8 0	−0.8 −1.3	0.8 2.8	+1.2 0	−0.8 −1.6
1.19– 1.97	0.4 1.1	+0.4 0	−0.4 −0.7	0.4 1.4	+0.6 0	−0.4 −0.8	1.0 2.6	+1.0 0	−1.0 −1.6	1.0 3.6	+1.6 0	−1.0 −2.0
1.97– 3.15	0.4 1.2	+0.5 0	−0.4 −0.7	0.4 1.6	+0.7 0	−0.4 −0.9	1.2 3.1	+1.2 0	−1.2 −1.9	1.2 4.2	+1.8 0	−1.2 −2.4
3.15– 4.73	0.5 1.5	+0.6 0	−0.5 −0.9	0.5 2.0	+0.9 0	−0.5 −1.1	1.4 3.7	+1.4 0	−1.4 −2.3	1.4 5.0	+2.2 0	−1.4 −2.8
4.73– 7.09	0.6 1.8	+0.7 0	−0.6 −1.1	0.6 2.3	+1.0 0	−0.6 −1.3	1.6 4.2	+1.6 0	−1.6 −2.6	1.6 5.7	+2.5 0	−1.6 −3.2
7.09– 9.85	0.6 2.0	+0.8 0	−0.6 −1.2	0.6 2.6	+1.2 0	−0.6 −1.4	2.0 5.0	+1.8 0	−2.0 −3.2	2.0 6.6	+2.8 0	−2.0 −3.8
9.85–12.41	0.8 2.3	+0.9 0	−0.8 −1.4	0.8 2.9	+1.2 0	−0.8 −1.7	2.5 5.7	+2.0 0	−2.5 −3.7	2.5 7.5	+3.0 0	−2.5 −4.5
12.41–15.75	1.0 2.7	+1.0 0	−1.0 −1.7	1.0 3.4	+1.4 0	−1.0 −2.0	3.0 6.6	+2.2 0	−3.0 −4.4	3.0 8.7	+3.5 0	−3.0 −5.2
15.75–19.69	1.2 3.0	+1.0 0	−1.2 −2.0	1.2 3.8	+1.6 0	−1.2 −2.2	4.0 8.1	+2.5 0	−4.0 −5.6	4.0 10.5	+4.0 0	−4.0 −6.5

See footnotes at end of table.

Nominal Size Range, Inches	Class RC 5			Class RC 6			Class RC 7			Class RC 8			Class RC 9		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Clearance*	Hole H8	Shaft e7	Clearance*	Hole H9	Shaft e8	Clearance*	Hole H9	Shaft d8	Clearance*	Hole H10	Shaft c9	Clearance*	Hole H11	Shaft
Over To	Values shown below are in thousandths of an inch														
0– 0.12	0.6 1.6	+0.6 0	−0.6 −1.0	0.6 2.2	+1.0 0	−0.6 −1.2	1.0 2.6	+1.0 0	−1.0 −1.6	2.5 5.1	+1.6 0	−2.5 −3.5	4.0 8.1	+2.5 0	−4.0 −5.6
0.12– 0.24	0.8 2.0	+0.7 0	−0.8 −1.3	0.8 2.7	+1.2 0	−0.8 −1.5	1.2 3.1	+1.2 0	−1.2 −1.9	2.8 5.8	+1.8 0	−2.8 −4.0	4.5 9.0	+3.0 0	−4.5 −6.0
0.24– 0.40	1.0 2.5	+0.9 0	−1.0 −1.6	1.0 3.3	+1.4 0	−1.0 −1.9	1.6 3.9	+1.4 0	−1.6 −2.5	3.0 6.6	+2.2 0	−3.0 −4.4	5.0 10.7	+3.5 0	−5.0 −7.2
0.40– 0.71	1.2 2.9	+1.0 0	−1.2 −1.9	1.2 3.8	+1.6 0	−1.2 −2.2	2.0 4.6	+1.6 0	−2.0 −3.0	3.5 7.9	+2.8 0	−3.5 −5.1	6.0 12.8	+4.0 0	−6.0 −8.8
0.71– 1.19	1.6 3.6	+1.2 0	−1.6 −2.4	1.6 4.8	+2.0 0	−1.6 −2.8	2.5 5.7	+2.0 0	−2.5 −3.7	4.5 10.0	+3.5 0	−4.5 −6.5	7.0 15.5	+5.0 0	−7.0 −10.5
1.19– 1.97	2.0 4.6	+1.6 0	−2.0 −3.0	2.0 6.1	+2.5 0	−2.0 −3.6	3.0 7.1	+2.5 0	−3.0 −4.6	5.0 11.5	+4.0 0	−5.0 −7.5	8.0 18.0	+6.0 0	−8.0 −12.0
1.97– 3.15	2.5 5.5	+1.8 0	−2.5 −3.7	2.5 7.3	+3.0 0	−2.5 −4.3	4.0 8.8	+3.0 0	−4.0 −5.8	6.0 13.5	+4.5 0	−6.0 −9.0	9.0 20.5	+7.0 0	−9.0 −13.5
3.15– 4.73	3.0 6.6	+2.2 0	−3.0 −4.4	3.0 8.7	+3.5 0	−3.0 −5.2	5.0 10.7	+3.5 0	−5.0 −7.2	7.0 15.5	+5.0 0	−7.0 −10.5	10.0 24.0	+9.0 0	−10.0 −15.0
4.73– 7.09	3.5 7.6	+2.5 0	−3.5 −5.1	3.5 10.0	+4.0 0	−3.5 −6.0	6.0 12.5	+4.0 0	−6.0 −8.5	8.0 18.0	+6.0 0	−8.0 −12.0	12.0 28.0	+10.0 0	−12.0 −18.0
7.09– 9.85	4.0 8.6	+2.8 0	−4.0 −5.8	4.0 11.3	+4.5 0	−4.0 −6.8	7.0 14.3	+4.5 0	−7.0 −9.8	10.0 21.5	+7.0 0	−10.0 −14.5	15.0 34.0	+12.0 0	−15.0 −22.0
9.85–12.41	5.0 10.0	+3.0 0	−5.0 −7.0	5.0 13.0	+5.0 0	−5.0 −8.0	8.0 16.0	+5.0 0	−8.0 −11.0	12.0 25.0	+8.0 0	−12.0 −17.0	18.0 38.0	+12.0 0	−18.0 −26.0
12.41–15.75	6.0 11.7	+3.5 0	−6.0 −8.2	6.0 15.5	+6.0 0	−6.0 −9.5	10.0 19.5	+6.0 0	−10.0 −13.5	14.0 29.0	+9.0 0	−14.0 −20.0	22.0 45.0	+14.0 0	−22.0 −31.0
15.75–19.69	8.0 14.5	+4.0 0	−8.0 −10.5	8.0 18.0	+6.0 0	−8.0 −12.0	12.0 22.0	+6.0 0	−12.0 −16.0	16.0 32.0	+10.0 0	−16.0 −22.0	25.0 51.0	+16.0 0	−25.0 −35.0

All data above heavy lines are in accord with ABC agreements. Symbols H5, g4, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are also given in the ANSI Standard.

* Pairs of values shown represent minimum and maximum amounts of clearance resulting from application of standard tolerance limits.

Figure 9-116 ANSI Standard Running and Sliding Fits (*Courtesy of* ASME)

American National Standard Clearance Locational Fits (ANSI B4.1-1967, R1979)

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or − sign) to obtain maximum and minimum sizes of mating parts.

Nominal Size Range, Inches	Class LC 1			Class LC 2			Class LC 3			Class LC 4			Class LC 5		
	Clearance*	Standard Tolerance Limits		Clearance*	Standard Tolerance Limits		Clearance*	Standard Tolerance Limits		Clearance*	Standard Tolerance Limits		Clearance*	Standard Tolerance Limits	
Over To		Hole H6	Shaft h5		Hole H7	Shaft h6		Hole H8	Shaft h7		Hole H10	Shaft h9		Hole H7	Shaft g6
	Values shown below are in thousandths of an inch														
0– 0.12	0 0.45	+0.25 0	0 −0.2	0 0.65	+0.4 0	0 −0.25	0 1	+0.6 0	0 −0.4	0 2.6	+1.6 0	0 −1.0	0.1 0.75	+0.4 0	−0.1 −0.35
0.12– 0.24	0 0.5	+0.3 0	0 −0.2	0 0.8	+0.5 0	0 −0.3	0 1.2	+0.7 0	0 −0.5	0 3.0	+1.8 0	0 −1.2	0.15 0.95	+0.5 0	−0.15 −0.45
0.24– 0.40	0 0.65	+0.4 0	0 −0.25	0 1.0	+0.6 0	0 −0.4	0 1.5	+0.9 0	0 −0.6	0 3.6	+2.2 0	0 −1.4	0.2 1.2	+0.6 0	−0.2 −0.6
0.40– 0.71	0 0.7	+0.4 0	0 −0.3	0 1.1	+0.7 0	0 −0.4	0 1.7	+1.0 0	0 −0.7	0 4.4	+2.8 0	0 −1.6	0.25 1.35	+0.7 0	−0.25 −0.65
0.71– 1.19	0 0.9	+0.5 0	0 −0.4	0 1.3	+0.8 0	0 −0.5	0 2	+1.2 0	0 −0.8	0 5.5	+3.5 0	0 −2.0	0.3 1.6	+0.8 0	−0.3 −0.8
1.19– 1.97	0 1.0	+0.6 0	0 −0.4	0 1.6	+1.0 0	0 −0.6	0 2.6	+1.6 0	0 −1	0 6.5	+4.0 0	0 −2.5	0.4 2.0	+1.0 0	−0.4 −1.0
1.97– 3.15	0 1.2	+0.7 0	0 −0.5	0 1.9	+1.2 0	0 −0.7	0 3	+1.8 0	0 −1.2	0 7.5	+4.5 0	0 −3	0.4 2.3	+1.2 0	−0.4 −1.1
3.15– 4.73	0 1.5	+0.9 0	0 −0.6	0 2.3	+1.4 0	0 −0.9	0 3.6	+2.2 0	0 −1.4	0 8.5	+5.0 0	0 −3.5	0.5 2.8	+1.4 0	−0.5 −1.4
4.73– 7.09	0 1.7	+1.0 0	0 −0.7	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 10.0	+6.0 0	0 −4	0.6 3.2	+1.6 0	−0.6 −1.6
7.09– 9.85	0 2.0	+1.2 0	0 −0.8	0 3.0	+1.8 0	0 −1.2	0 4.6	+2.8 0	0 −1.8	0 11.5	+7.0 0	0 −4.5	0.6 3.6	+1.8 0	−0.6 −1.8
9.85–12.41	0 2.1	+1.2 0	0 −0.9	0 3.2	+2.0 0	0 −1.2	0 5	+3.0 0	0 −2.0	0 13.0	+8.0 0	0 −5	0.7 3.9	+2.0 0	−0.7 −1.9
12.41–15.75	0 2.4	+1.4 0	0 −1.0	0 3.6	+2.2 0	0 −1.4	0 5.7	+3.5 0	0 −2.2	0 15.0	+9.0 0	0 −6	0.7 4.3	+2.2 0	−0.7 −2.1
15.75–19.69	0 2.6	+1.6 0	0 −1.0	0 4.1	+2.5 0	0 −1.6	0 6.5	+4 0	0 −2.5	0 16.0	+10.0 0	0 −6	0.8 4.9	+2.5 0	−0.8 −2.4

See footnotes at end of table.

Nominal Size Range, Inches	Class LC 6			Class LC 7			Class LC 8			Class LC 9			Class LC 10			Class LC 11		
	Clearance*	Std. Tolerance Limits		Clearance*	Std. Tolerance Limits		Clearance*	Std. Tolerance Limits		Clearance*	Std. Tolerance Limits		Clearance*	Std. Tolerance Limits		Clearance*	Std. Tolerance Limits	
Over To		Hole H9	Shaft f8		Hole H10	Shaft e9		Hole H10	Shaft d9		Hole H11	Shaft c10		Hole H12	Shaft		Hole H13	Shaft
	Values shown below are in thousandths of an inch																	
0– 0.12	0.3 1.9	+1.0 0	−0.3 −0.9	0.6 3.2	+1.6 0	−0.6 −1.6	1.0 2.0	+1.6 0	−1.0 −2.0	2.5 6.6	+2.5 0	−2.5 −4.1	4 12	+4 0	−4 −8	5 17	+6 0	−5 −11
0.12– 0.24	0.4 2.3	+1.2 0	−0.4 −1.1	0.8 3.8	+1.8 0	−0.8 −2.0	1.2 4.2	+1.8 0	−1.2 −2.4	2.8 7.6	+3.0 0	−2.8 −4.6	4.5 14.5	+5 0	−4.5 −9.5	6 20	+7 0	−6 −13
0.24– 0.40	0.5 2.8	+1.4 0	−0.5 −1.4	1.0 4.6	+2.2 0	−1.0 −2.4	1.6 5.2	+2.2 0	−1.6 −3.0	3.0 8.7	+3.5 0	−3.0 −5.2	5 17	+6 0	−5 −11	7 25	+9 0	−7 −16
0.40– 0.71	0.6 3.2	+1.6 0	−0.6 −1.6	1.2 5.6	+2.8 0	−1.2 −2.8	2.0 6.4	+2.8 0	−2.0 −3.6	3.5 10.3	+4.0 0	−3.5 −6.3	6 20	+7 0	−6 −13	8 28	+10 0	−8 −18
0.71– 1.19	0.8 4.0	+2.0 0	−0.8 −2.0	1.6 7.1	+3.5 0	−1.6 −3.6	2.5 8.0	+3.5 0	−2.5 −4.5	4.5 13.0	+5.0 0	−4.5 −8.0	7 23	+8 0	−7 −15	10 34	+12 0	−10 −22
1.19– 1.97	1.0 5.1	+2.5 0	−1.0 −2.6	2.0 8.5	+4.0 0	−2.0 −4.5	3.6 9.5	+4.0 0	−3.0 −5.5	5.0 15.0	+6 0	−5.0 −9.0	8 28	+10 0	−8 −18	12 44	+16 0	−12 −28
1.97– 3.15	1.2 6.0	+3.0 0	−1.0 −3.0	2.5 10.0	+4.5 0	−2.5 −5.5	4.0 11.5	+4.5 0	−4.0 −7.0	6.0 17.5	+7 0	−6.0 −10.5	10 34	+12 0	−10 −22	14 50	+18 0	−14 −32
3.15– 4.73	1.4 7.1	+3.5 0	−1.4 −3.6	3.0 11.5	+5.0 0	−3.0 −6.5	5.0 13.5	+5.0 0	−5.0 −8.5	7 21	+9 0	−7 −12	11 39	+14 0	−11 −25	16 60	+22 0	−16 −38
4.73– 7.09	1.6 8.1	+4.0 0	−1.6 −4.1	3.5 13.5	+6.0 0	−3.5 −7.5	6 16	+6 0	−6 −10	8 24	+10 0	−8 −14	12 44	+16 0	−12 −28	18 68	+25 0	−18 −43
7.09– 9.85	2.0 9.3	+4.5 0	−2.0 −4.8	4.0 15.5	+7.0 0	−4.0 −8.5	7 18.5	+7 0	−7 −11.5	10 29	+12 0	−10 −17	16 52	+18 0	−16 −34	22 78	+28 0	−22 −50
9.85–12.41	2.2 10.2	+5.0 0	−2.2 −5.2	4.5 17.5	+8.0 0	−4.5 −9.5	7 20	+8 0	−7 −12	12 32	+12 0	−12 −20	20 60	+20 0	−20 −40	28 88	+30 0	−28 −58
12.41–15.75	2.5 12.0	+6.0 0	−2.5 −6.0	5.0 20.0	+9.0 0	−5 −11	8 23	+9 0	−8 −14	14 37	+14 0	−14 −23	22 66	+22 0	−22 −44	30 100	+35 0	−30 −65
15.75–19.69	2.8 12.8	+6.0 0	−2.8 −6.8	5.0 21.0	+10.0 0	−5 −11	9 25	+10 0	−9 −15	16 42	+16 0	−16 −26	25 75	+25 0	−25 −50	35 115	+40 0	−35 −75

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

* Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Figure 9-117 ANSI Standard Clearance Locational Fits (*Courtesy of* ASME)

ANSI Standard Transition Locational Fits (ANSI B4.1-1967, R1979)

Nominal Size Range, Inches	Class LT 1			Class LT 2			Class LT 3			Class LT 4			Class LT 5			Class LT 6		
		Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits			Std. Tolerance Limits	
	Fit*	Hole H7	Shaft js6	Fit*	Hole H8	Shaft js7	Fit*	Hole H7	Shaft k6	Fit*	Hole H8	Shaft k7	Fit*	Hole H7	Shaft n6	Fit*	Hole H7	Shaft n7
Over To	Values shown below are in thousandths of an inch																	
0– 0.12	-0.12 +0.52	+0.4 0	+0.12 -0.12	-0.2 +0.8	+0.6 0	+0.2 -0.2							-0.5 +0.15	+0.4 0	+0.5 +0.25	-0.65 +0.15	+0.4 0	+0.65 +0.25
0.12– 0.24	-0.15 +0.65	+0.5 0	+0.15 -0.15	-0.25 +0.95	+0.7 0	+0.25 -0.25							-0.6 +0.2	+0.5 0	+0.6 +0.3	-0.8 +0.2	+0.5 0	+0.8 +0.3
0.24– 0.40	-0.2 +0.8	+0.6 0	+0.2 -0.2	-0.3 +1.2	+0.9 0	+0.3 -0.3	-0.5 +0.5	+0.6 0	+0.5 +0.1	-0.7 +0.8	+0.9 0	+0.7 +0.1	-0.8 +0.2	+0.6 0	+0.8 +0.4	-1.0 +0.2	+0.6 0	+1.0 +0.4
0.40– 0.71	-0.2 +0.9	+0.7 0	+0.2 -0.2	-0.35 +1.35	+1.0 0	+0.35 -0.35	-0.5 +0.6	+0.7 0	+0.5 +0.1	-0.8 +0.9	+1.0 0	+0.8 +0.1	-0.9 +0.2	+0.7 0	+0.9 +0.5	-1.2 +0.2	+0.7 0	+1.2 +0.5
0.71– 1.19	-0.25 +1.05	+0.8 0	+0.25 -0.25	-0.4 +1.6	+1.2 0	+0.4 -0.4	-0.6 +0.7	+0.8 0	+0.6 +0.1	-0.9 +1.1	+1.2 0	+0.9 +0.1	-1.1 +0.2	+0.8 0	+1.1 +0.6	-1.4 +0.2	+0.8 0	+1.4 +0.6
1.19– 1.97	-0.3 +1.3	+1.0 0	+0.3 -0.3	-0.5 +2.1	+1.6 0	+0.5 -0.5	-0.7 +0.9	+1.0 0	+0.7 +0.1	-1.1 +1.5	+1.6 0	+1.1 +0.1	-1.3 +0.3	+1.0 0	+1.3 +0.7	-1.7 +0.3	+1.0 0	+1.7 +0.7
1.97– 3.15	-0.3 +1.5	+1.2 0	+0.3 -0.3	-0.6 +2.4	+1.8 0	+0.6 -0.6	-0.8 +1.1	+1.2 0	+0.8 +0.1	-1.3 +1.7	+1.8 0	+1.3 +0.1	-1.5 +0.4	+1.2 0	+1.5 +0.8	-2.0 +0.4	+1.2 0	+2.0 +0.8
3.15– 4.73	-0.4 +1.8	+1.4 0	+0.4 -0.4	-0.7 +2.9	+2.2 0	+0.7 -0.7	-1.0 +1.3	+1.4 0	+1.0 +0.1	-1.5 +2.1	+2.2 0	+1.5 +0.1	-1.9 +0.4	+1.4 0	+1.9 +1.0	-2.4 +0.4	+1.4 0	+2.4 +1.0
4.73– 7.09	-0.5 +2.1	+1.6 0	+0.5 -0.5	-0.8 +3.3	+2.5 0	+0.8 -0.8	-1.1 +1.5	+1.6 0	+1.1 +0.1	-1.7 +2.4	+2.5 0	+1.7 +0.1	-2.2 +0.4	+1.6 0	+2.2 +1.2	-2.8 +0.4	+1.6 0	+2.8 +1.2
7.09– 9.85	-0.6 +2.4	+1.8 0	+0.6 -0.6	-0.9 +3.7	+2.8 0	+0.9 -0.9	-1.4 +1.6	+1.8 0	+1.4 +0.2	-2.0 +2.6	+2.8 0	+2.0 +0.2	-2.6 +0.4	+1.8 0	+2.6 +1.4	-3.2 +0.4	+1.8 0	+3.2 +1.4
9.85–12.41	-0.6 +2.6	+2.0 0	+0.6 -0.6	-1.0 +4.0	+3.0 0	+1.0 -1.0	-1.4 +1.8	+2.0 0	+1.4 +0.2	-2.2 +2.8	+3.0 0	+2.2 +0.2	-2.6 +0.6	+2.0 0	+2.6 +1.4	-3.4 +0.6	+2.0 0	+3.4 +1.4
12.41–15.75	-0.7 +2.9	+2.2 0	+0.7 -0.7	-1.0 +4.5	+3.5 0	+1.0 -1.0	-1.6 +2.0	+2.2 0	+1.6 +0.2	-2.4 +3.3	+3.5 0	+2.4 +0.2	-3.0 +0.6	+2.2 0	+3.0 +1.6	-3.8 +0.6	+2.2 0	+3.8 +1.6
15.75–19.69	-0.8 +3.3	+2.5 0	+0.8 -0.8	-1.2 +5.2	+4.0 0	+1.2 -1.2	-1.8 +2.3	+2.5 0	+1.8 +0.2	-2.7 +3.8	+4.0 0	+2.7 +0.2	-3.4 +0.7	+2.5 0	+3.4 +1.8	-4.3 +0.7	+2.5 0	+4.3 +1.8

All data above heavy lines are in accord with ABC agreements. Symbols H7, js6, etc. are hole and shaft designations in ABC system.

* Pairs of values shown represent maximum amount of interference (−) and maximum amount of clearance (+) resulting from application of standard tolerance limits.

Figure 9-118 ANSI Standard Transition Locational Fits (*Courtesy of* ASME)

ANSI Standard Interference Locational Fits (ANSI B4.1-1967, R1979)

Tolerance limits given in body of table are added or subtracted to basic size (as indicated by + or − sign) to obtain maximum and minimum sizes of mating parts.

Nominal Size Range, Inches	Class LN 1			Class LN 2			Class LN 3		
	Limits of Interference	Standard Limits		Limits of Interference	Standard Limits		Limits of Interference	Standard Limits	
		Hole H6	Shaft n5		Hole H7	Shaft p6		Hole H7	Shaft r6
Over To	Values shown below are given in thousandths of an inch								
0– 0.12	0 0.45	+0.25 0	+0.45 +0.25	0 0.65	+0.4 0	+0.65 +0.4	0.1 0.75	+0.4 0	+0.75 +0.5
0.12– 0.24	0 0.5	+0.3 0	+0.5 +0.3	0 0.8	+0.5 0	+0.8 +0.5	0.1 0.9	+0.5 0	+0.9 +0.6
0.24– 0.40	0 0.65	+0.4 0	+0.65 +0.4	0 1.0	+0.6 0	+1.0 +0.6	0.2 1.2	+0.6 0	+1.2 +0.8
0.40– 0.71	0 0.8	+0.4 0	+0.8 +0.4	0 1.1	+0.7 0	+1.1 +0.7	0.3 1.4	+0.7 0	+1.4 +1.0
0.71– 1.19	0 1.0	+0.5 0	+1.0 +0.5	0 1.3	+0.8 0	+1.3 +0.8	0.4 1.7	+0.8 0	+1.7 +1.2
1.19– 1.97	0 1.1	+0.6 0	+1.1 +0.6	0 1.6	+1.0 0	+1.6 +1.0	0.4 2.0	+1.0 0	+2.0 +1.4
1.97– 3.15	0.1 1.3	+0.7 0	+1.3 +0.8	0.2 2.1	+1.2 0	+2.1 +1.4	0.4 2.3	+1.2 0	+2.3 +1.6
3.15– 4.73	0.1 1.6	+0.9 0	+1.6 +1.0	0.2 2.5	+1.4 0	+2.5 +1.6	0.6 2.9	+1.4 0	+2.9 +2.0
4.73– 7.09	0.2 1.9	+1.0 0	+1.9 +1.2	0.2 2.8	+1.6 0	+2.8 +1.8	0.9 3.5	+1.6 0	+3.5 +2.5
7.09– 9.85	0.2 2.2	+1.2 0	+2.2 +1.4	0.2 3.2	+1.8 0	+3.2 +2.0	1.2 4.2	+1.8 0	+4.2 +3.0
9.85–12.41	0.2 2.3	+1.2 0	+2.3 +1.4	0.2 3.4	+2.0 0	+3.4 +2.2	1.5 4.7	+2.0 0	+4.7 +3.5
12.41–15.75	0.2 2.6	+1.4 0	+2.6 +1.6	0.3 3.9	+2.2 0	+3.9 +2.5	2.3 5.9	+2.2 0	+5.9 +4.5
15.75–19.69	0.2 2.8	+1.6 0	+2.8 +1.8	0.3 4.4	+2.5 0	+4.4 +2.8	2.5 6.6	+2.5 0	+6.6 +5.0

All data in this table are in accordance with American-British-Canadian (ABC) agreements.

Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI Standard.

Symbols H7, p6, etc. are hole and shaft designations in ABC system.

* Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Figure 9-119 ANSI Standard Interference Locational Fits (*Courtesy of* ASME)

ANSI Standard Force and Shrink Fits (ANSI B4.1-1967. R1979)

Nominal Size Range, Inches	Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Interference*	Hole H6	Shaft	Interference*	Hole H7	Shaft s6	Interference*	Hole H7	Shaft t6	Interference*	Hole H7	Shaft u6	Interference*	Hole H8	Shaft x7
Over To	Values shown below are in thousandths of an inch														
0–0.12	0.05 0.5	+0.25 0	+0.5 +0.3	0.2 0.85	+0.4 0	+0.85 +0.6				0.3 0.95	+0.4 0	+0.95 +0.7	0.3 1.3	+0.6 0	+1.3 +0.9
0.12–0.24	0.1 0.6	+0.3 0	+0.6 +0.4	0.2 1.0	+0.5 0	+1.0 +0.7				0.4 1.2	+0.5 0	+1.2 +0.9	0.5 1.7	+0.7 0	+1.7 +1.2
0.24–0.40	0.1 0.75	+0.4 0	+0.75 +0.5	0.4 1.4	+0.6 0	+1.4 +1.0				0.6 1.6	+0.6 0	+1.6 +1.2	0.5 2.0	+0.9 0	+2.0 +1.4
0.40–0.56	0.1 0.8	+0.4 0	+0.8 +0.5	0.5 1.6	+0.7 0	+1.6 +1.2				0.7 1.8	+0.7 0	+1.8 +1.4	0.6 2.3	+1.0 0	+2.3 +1.6
0.56–0.71	0.2 0.9	+0.4 0	+0.9 +0.6	0.5 1.6	+0.7 0	+1.6 +1.2				0.7 1.8	+0.7 0	+1.8 +1.4	0.8 2.5	+1.0 0	+2.5 +1.8
0.71–0.95	0.2 1.1	+0.5 0	+1.1 +0.7	0.6 1.9	+0.8 0	+1.9 +1.4				0.8 2.1	+0.8 0	+2.1 +1.6	1.0 3.0	+1.2 0	+3.0 +2.2
0.95–1.19	0.3 1.2	+0.5 0	+1.2 +0.8	0.6 1.9	+0.8 0	+1.9 +1.4	0.8 2.1	+0.8 0	+2.1 +1.6	1.0 2.3	+0.8 0	+2.3 +1.8	1.3 3.3	+1.2 0	+3.3 +2.5
1.19–1.58	0.3 1.3	+0.6 0	+1.3 +0.9	0.8 2.4	+1.0 0	+2.4 +1.8	1.0 2.6	+1.0 0	+2.6 +2.0	1.5 3.1	+1.0 0	+3.1 +2.5	1.4 4.0	+1.6 0	+4.0 +3.0
1.58–1.97	0.4 1.4	+0.6 0	+1.4 +1.0	0.8 2.4	+1.0 0	+2.4 +1.8	1.2 2.8	+1.0 0	+2.8 +2.2	1.8 3.4	+1.0 0	+3.4 +2.8	2.4 5.0	+1.6 0	+5.0 +4.0
1.97–2.56	0.6 1.8	+0.7 0	+1.8 +1.3	0.8 2.7	+1.2 0	+2.7 +2.0	1.3 3.2	+1.2 0	+3.2 +2.5	2.3 4.2	+1.2 0	+4.2 +3.5	3.2 6.2	+1.8 0	+6.2 +5.0
2.56–3.15	0.7 1.9	+0.7 0	+1.9 +1.4	1.0 2.9	+1.2 0	+2.9 +2.2	1.8 3.7	+1.2 0	+3.7 +3.0	2.8 4.7	+1.2 0	+4.7 +4.0	4.2 7.2	+1.8 0	+7.2 +6.0
3.15–3.94	0.9 2.4	+0.9 0	+2.4 +1.8	1.4 3.7	+1.4 0	+3.7 +2.8	2.1 4.4	+1.4 0	+4.4 +3.5	3.6 5.9	+1.4 0	+5.9 +5.0	4.8 8.4	+2.2 0	+8.4 +7.0
3.94–4.73	1.1 2.6	+0.9 0	+2.6 +2.0	1.6 3.9	+1.4 0	+3.9 +3.0	2.6 4.9	+1.4 0	+4.9 +4.0	4.6 6.9	+1.4 0	+6.9 +6.0	5.8 9.4	+2.2 0	+9.4 +8.0

See footnotes at end of table.

Nominal Size Range, Inches	Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
		Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits			Standard Tolerance Limits	
	Interference*	Hole H6	Shaft	Interference*	Hole H7	Shaft s6	Interference*	Hole H7	Shaft t6	Interference*	Hole H7	Shaft u6	Interference*	Hole H8	Shaft x7
Over To	Values shown below are in thousandths of an inch														
4.73– 5.52	1.2 2.9	+1.0 0	+2.9 +2.2	1.9 4.5	+1.6 0	+4.5 +3.5	3.4 6.0	+1.6 0	+6.0 +5.0	5.4 8.0	+1.6 0	+8.0 +7.0	7.5 11.6	+2.5 0	+11.6 +10.0
5.52– 6.30	1.5 3.2	+1.0 0	+3.2 +2.5	2.4 5.0	+1.6 0	+5.0 +4.0	3.4 6.0	+1.6 0	+6.0 +5.0	5.4 8.0	+1.6 0	+8.0 +7.0	9.5 13.6	+2.5 0	+13.6 +12.0
6.30– 7.09	1.8 3.5	+1.0 0	+3.5 +2.8	2.9 5.5	+1.6 0	+5.5 +4.5	4.4 7.0	+1.6 0	+7.0 +6.0	6.4 9.0	+1.6 0	+9.0 +8.0	9.5 13.6	+2.5 0	+13.6 +12.0
7.09– 7.88	1.8 3.8	+1.2 0	+3.8 +3.0	3.2 6.2	+1.8 0	+6.2 +5.0	5.2 8.2	+1.8 0	+8.2 +7.0	7.2 10.2	+1.8 0	+10.2 +9.0	11.2 15.8	+2.8 0	+15.8 +14.0
7.88– 8.86	2.3 4.3	+1.2 0	+4.3 +3.5	3.2 6.2	+1.8 0	+6.2 +5.0	5.2 8.2	+1.8 0	+8.2 +7.0	8.2 11.2	+1.8 0	+11.2 +10.0	13.2 17.8	+2.8 0	+17.8 +16.0
8.86– 9.85	2.3 4.3	+1.2 0	+4.3 +3.5	4.2 7.2	+1.8 0	+7.2 +6.0	6.2 9.2	+1.8 0	+9.2 +8.0	10.2 13.2	+1.8 0	+13.2 +12.0	13.2 17.8	+2.8 0	+17.8 +16.0
9.85–11.03	2.8 4.9	+1.2 0	+4.9 +4.0	4.0 7.2	+2.0 0	+7.2 +6.0	7.0 10.2	+2.0 0	+10.2 +9.0	10.0 13.2	+2.0 0	+13.2 +12.0	15.0 20.0	+3.0 0	+20.0 +18.0
11.03–12.41	2.8 4.9	+1.2 0	+4.9 +4.0	5.0 8.2	+2.0 0	+8.2 +7.0	7.0 10.2	+2.0 0	+10.2 +9.0	12.0 15.2	+2.0 0	+15.2 +14.0	17.0 22.0	+3.0 0	+22.0 +20.0
12.41–13.98	3.1 5.5	+1.4 0	+5.5 +4.5	5.8 9.4	+2.2 0	+9.4 +8.0	7.8 11.4	+2.2 0	+11.4 +10.0	13.8 17.4	+2.2 0	+17.4 +16.0	18.5 24.2	+3.5 0	+24.2 +22.0
13.98–15.75	3.6 6.1	+1.4 0	+6.1 +5.0	5.8 9.4	+2.2 0	+9.4 +8.0	9.8 13.4	+2.2 0	+13.4 +12.0	15.8 19.4	+2.2 0	+19.4 +18.0	21.5 27.2	+3.5 0	+27.2 +25.0
15.75–17.72	4.4 7.0	+1.6 0	+7.0 +6.0	6.5 10.6	+2.5 0	+10.6 +9.0	9.5 13.6	+2.5 0	+13.6 +12.0	17.5 21.6	+2.5 0	+21.6 +20.0	24.0 30.5	+4.0 0	+30.5 +28.0
17.72–19.69	4.4 7.0	+1.6 0	+7.0 +6.0	7.5 11.6	+2.5 0	+11.6 +10.0	11.5 15.6	+2.5 0	+15.6 +14.0	19.5 23.6	+2.5 0	+23.6 +22.0	26.0 32.5	+4.0 0	+32.5 +30.0

All data above heavy lines are in accordance with American-British-Canadian (ABC) agreements. Symbols H6, H7, s6, etc. are hole and shaft designations in ABC system. Limits for sizes above 19.69 inches are not covered by ABC agreements but are given in the ANSI standard.

* Pairs of values shown represent minimum and maximum amounts of interference resulting from application of standard tolerance limits.

Figure 9-120 ANSI Standard Force and Shrink Fits (*Courtesy of* ASME)

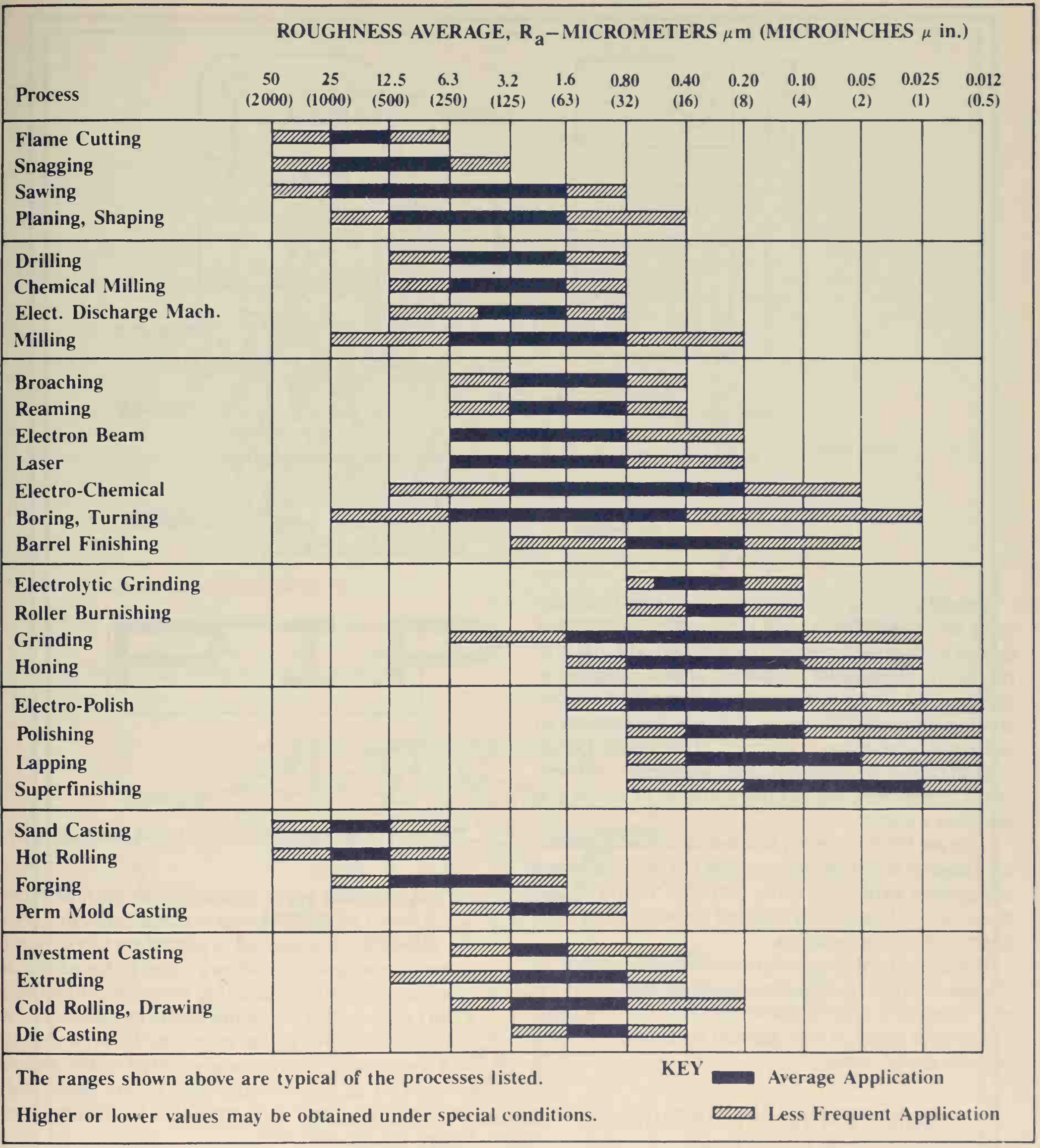


Figure 9-121 Manufacturing precision (*From Machinery's Handbook, 23rd Edition.* © 1988 *by Industrial Press Inc. Used with permission.*)

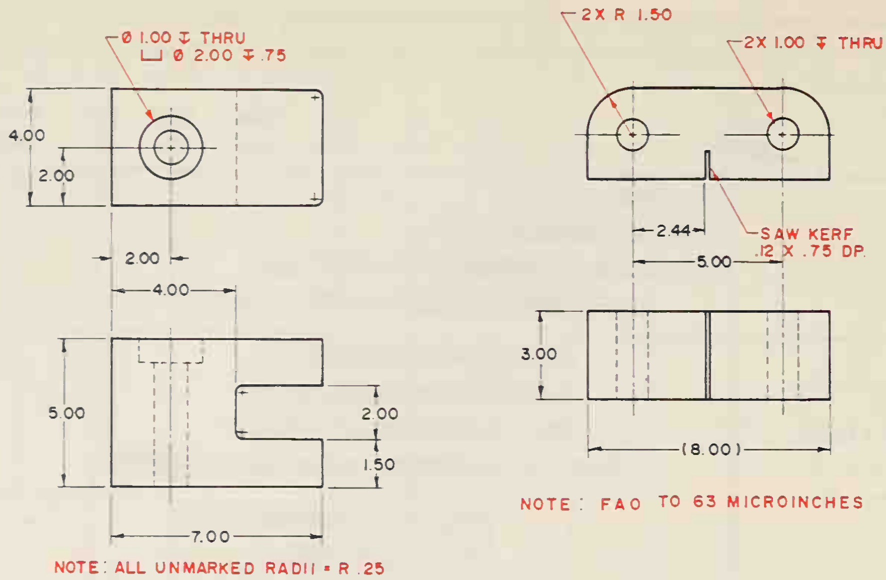


Figure 9-122 Notes on drawings improve communication

Notation

A good drawing may be defined as one that contains all of the information required by the various design and manufacturing people who will use it in producing the subject part. Most of this information can be conveyed graphically, using standard dimensioning practices. However, it is not uncommon to encounter a situation in which all of the needed information cannot be communicated graphically. In these cases, notes are used to communicate or clarify the designer's intent.

Notes are brief, carefully worded statements placed on drawings to convey information not covered or not adequately explained using graphics, Figure 9-122. Notes should be clearly worded so as to allow only one correct interpretation.

There are no ANSI standards specifically governing the use of notes on technical drawings. However, several rules of a general nature should be observed. These rules apply to both general notes and the more specific detail notes.

Rules for Applying Notes on Drawings

Notes may be lettered freehand, entered using a keyboard in a computer-aided drafting (CAD) system, or through any one of several mechanical lettering processes. Sample notes are included on the drawings in Figures 9-123 and 9-124. In any case, regardless of how they are put on the drawing, notes should be oriented horizontally on the drafting sheet, Figure 9-125. General notes should be located directly above the title block, Figure 9-126. When using manual processes to apply general notes such as those in Figure 9-126, the first note is placed directly above the title block, the second is placed on top of it and so on up the line. This allows notes to be added as needed without renumbering. However, when using a CAD system, this is not necessary since one of the advantages of CAD is that notes can be renumbered and rearranged automatically. Detail notes should be located as close as possible to the detail they are describing, and connected to it by a leader line, Figure 9-127 (page 368).

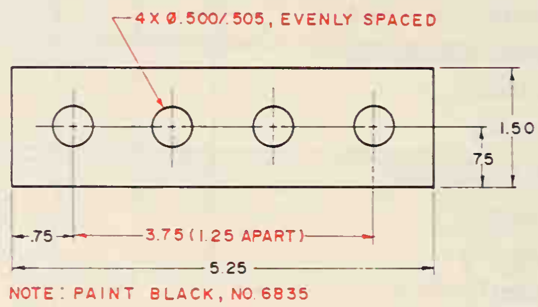


Figure 9-123 Sample note lettered mechanically

Notes should be applied to drawings after all graphics have been completed. This prevents notes and graphics from overlapping, and minimizes other technique problems such as smudging the worksheet and frequent erasing of notes as changes are required on a drawing.

Two basic types of notes are used on technical drawings: general notes and detail notes. They serve different purposes and, therefore, must be examined separately.

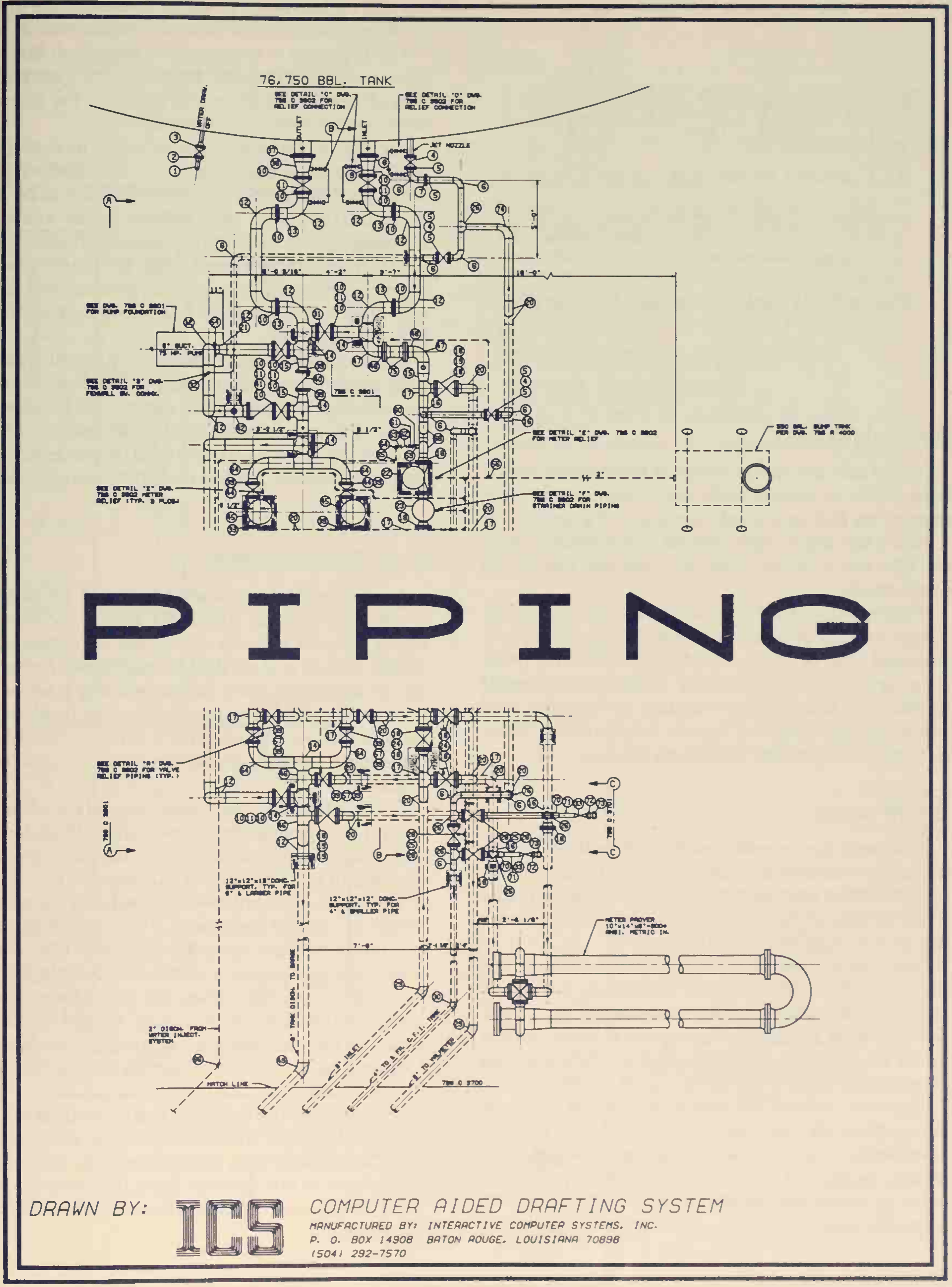


Figure 9-124 Notes lettered on a CAD system (*Courtesy Interactive Computer Systems, Inc.*)

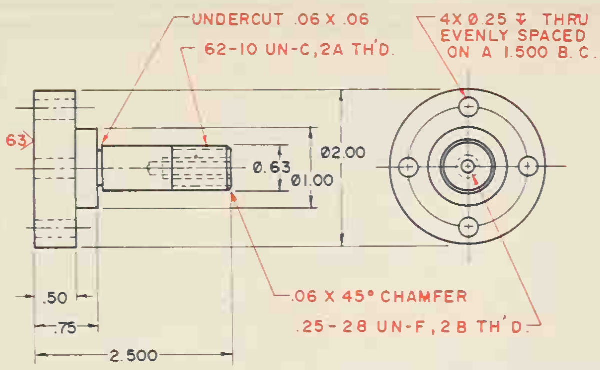


Figure 9-125 Notes are placed horizontally

General Notes

General notes are broad items of information which have a job- or project-wide application rather than relating to just one single element of a project or a part. They are usually placed immediately above the title block on the drawing sheet and numbered sequentially.

Information placed in general notes includes such characteristics of a product as finish specifications; standard sizes of fillets, rounds, and radii; heat treatment specifications; cleaning instructions; general tolerancing data; hardness testing instructions; and stamping specifications. Figures 9-128 and 9-129 are examples of drawings containing general notes.

Detail Notes

Detail notes are specific notes that pertain to one particular element or characteristic of a part. They are placed as near as possible to the characteristic to which they apply, and are connected using a leader line, Figure 9-130 (page 371).

Detail notes should not be placed on views, Figure 9-131. The only exception to this rule is in cases where a great deal of open space exists on a view, but very little around it, Figure 9-132. Notes should never be superimposed over other data such as dimensions, lines or symbols, Figure 9-133.

Common sense is the best rule to follow in applying detail notes. Since detail notes are used to more completely communicate or to clarify intent, they should be placed as close as possible to the element to which they pertain and in such a way as to be easily read.

Writing Notes

The written word lends itself to interpretations that may vary. Thus, notes used on drawings must convey the exact intent of the designer. Consequently, drafters must be especially careful in the preparation of notes.

The first step is to place in a legend all abbreviations used in the notes, Figure 9-134. This ensures that all readers of the notes interpret the abbreviations consistently and correctly.

Another technique which will limit misinterpretation of notes is punctuation or indentation. Notes containing more than one sentence should be properly punctuated so that readers know where one sentence leaves off and the next one begins, Figure 9-135. Indentation is used when the length of a note requires more than one line. The second line is indented so that readers know it is part of the first line, Figure 9-136.

Another technique is particularly useful for beginning drafters. It is called *verification*. Notes to be placed on drawings are first jotted down, legibly, on a print of the drawing. Another drafter, preferably one with experience, is then asked to read the notes to ensure that they are not open to multiple interpretations.

Note Specifications

A number of specifications should be observed when writing notes. The most widely accepted lettering style for notes is uppercase (all capital) block Gothic letters in a vertical format. Some companies accept uppercase block Gothic lettering in an inclined or slanted format. The proper lettering height is one-quarter inch for titles such as GENERAL NOTES, and one-eighth to three-sixteenths inch for actual notes, Figure 9-137.

Spacing between successive lines of the same note should be approximately one-sixteenth inch. Spacing between separate notes should be approximately one-eighth inch, Figure 9-138 (page 372).

There are no hard and fast rules governing the length of a line of notation, but from four to six words per line is widely accepted, Figure 9-139. When a note string will contain more than six words, it should be divided into more than one line. The number of words in the multiple line note should be divided so as to balance the finished note. One long line followed by a drastically shorter line is bad form, Figure 9-140.

On occasion, the last word in a note string will have to be hyphenated. There are rules governing the dividing of words according to syllables. If the proper point of division is not obvious from the makeup of the word, consult a dictionary. Do not hyphenate abbreviated words.

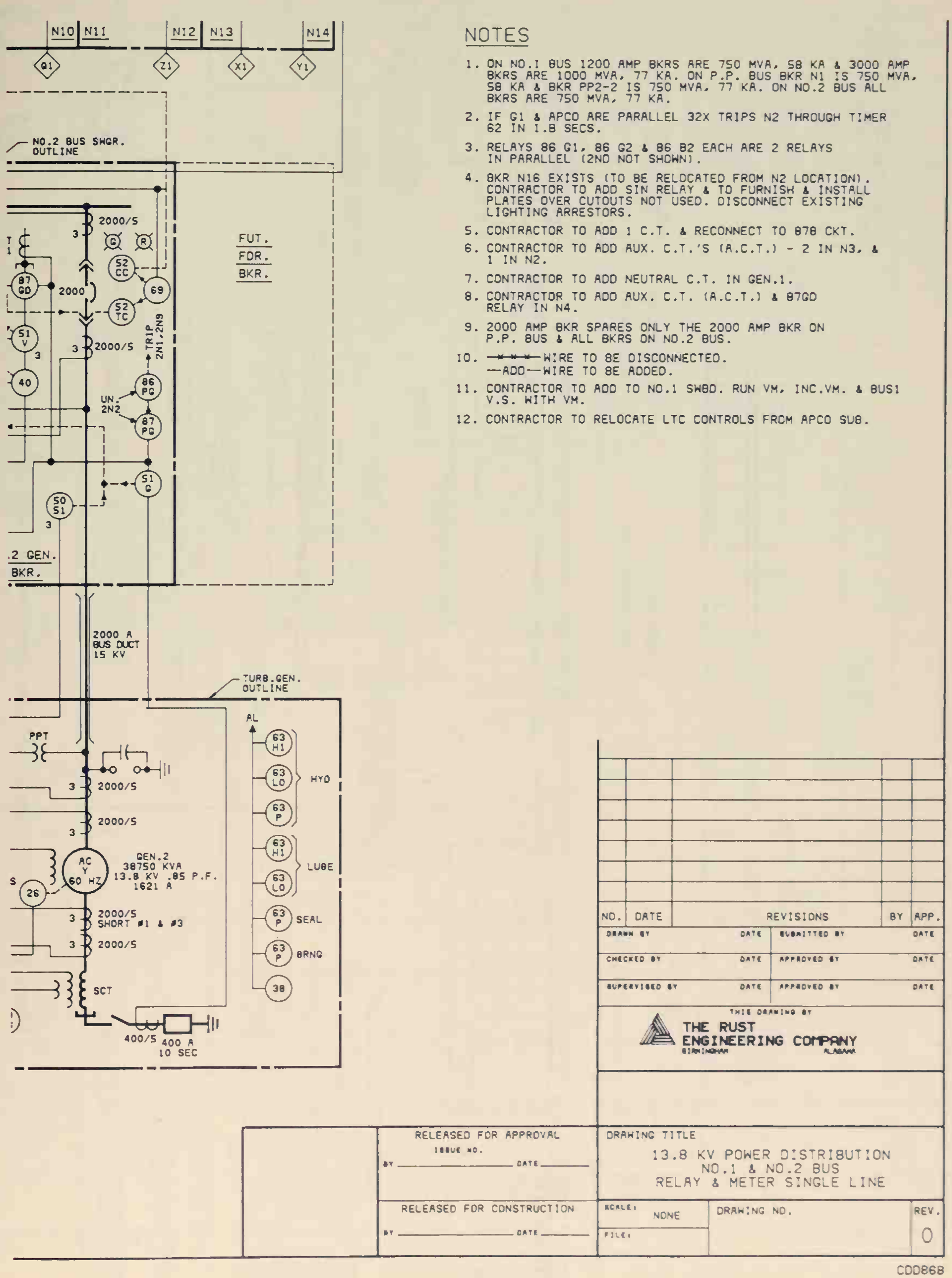


Figure 9-126 General notes are located over the titleblock (*Courtesy The Rust Engineering Co.*)

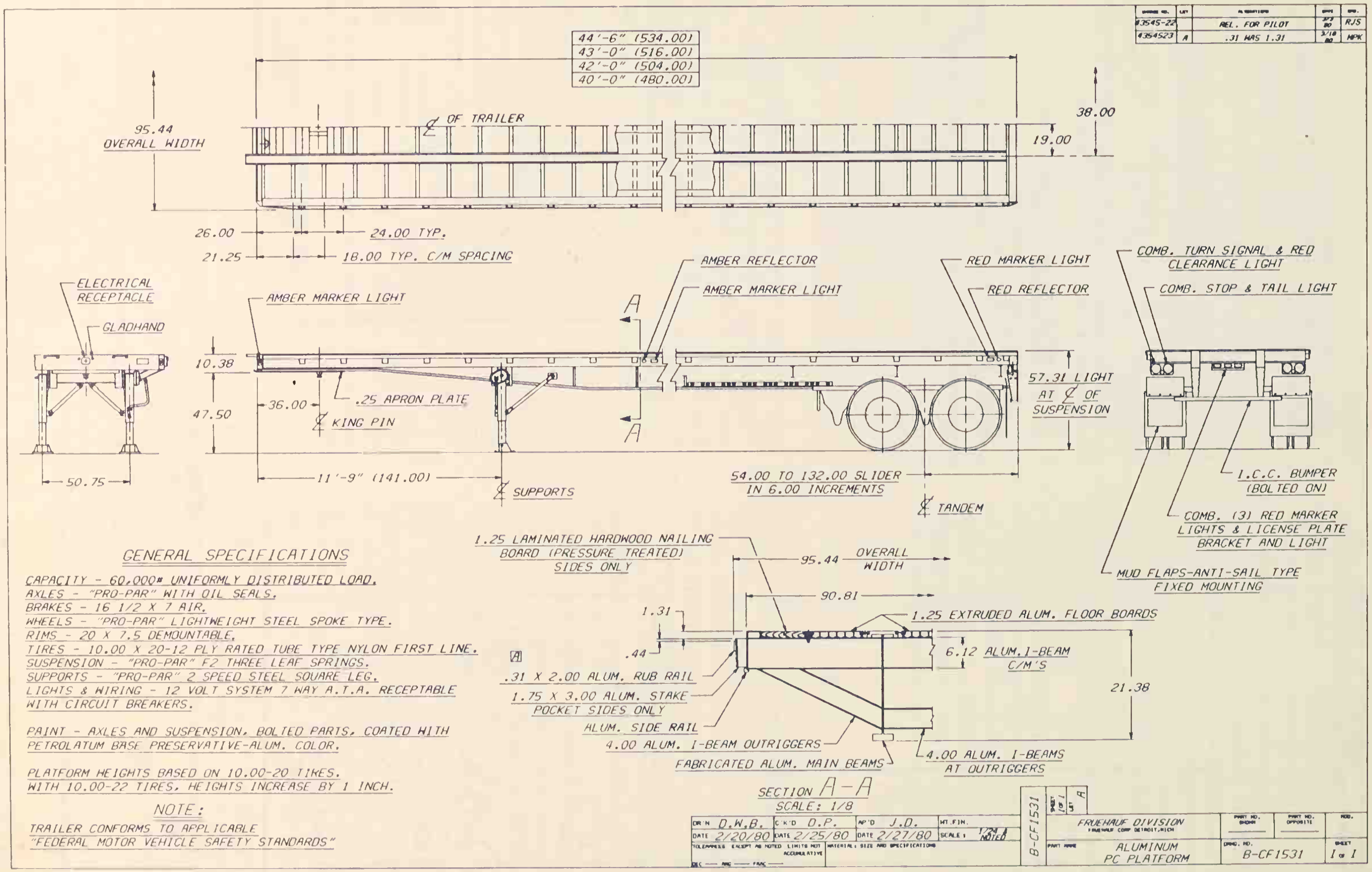


Figure 9-127 Detail notes using leader lines (*Courtesy Fruehauf Division, Fruehauf Corp.*)

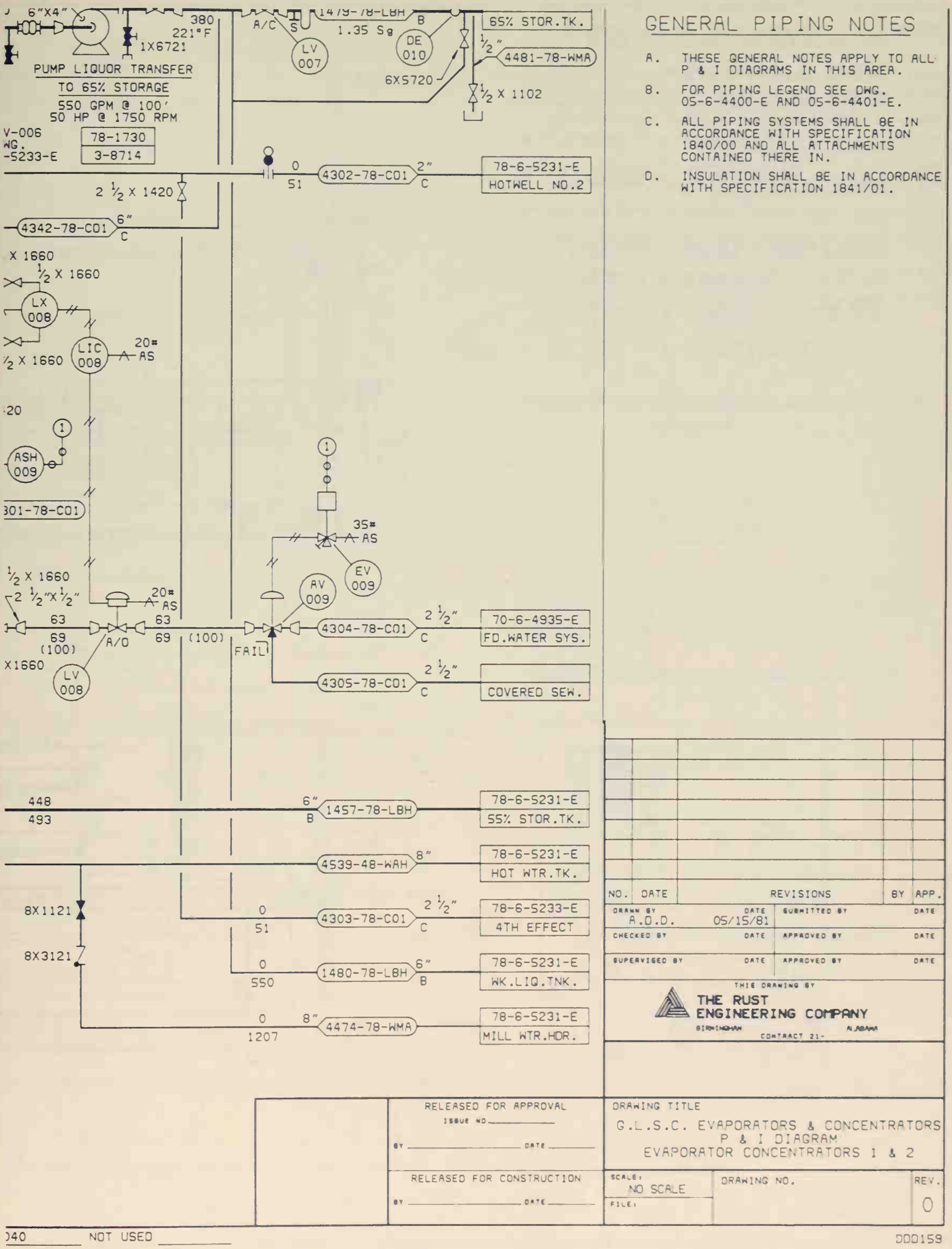


Figure 9-128 General notes on drawings (*Courtesy The Rust Engineering Co.*)

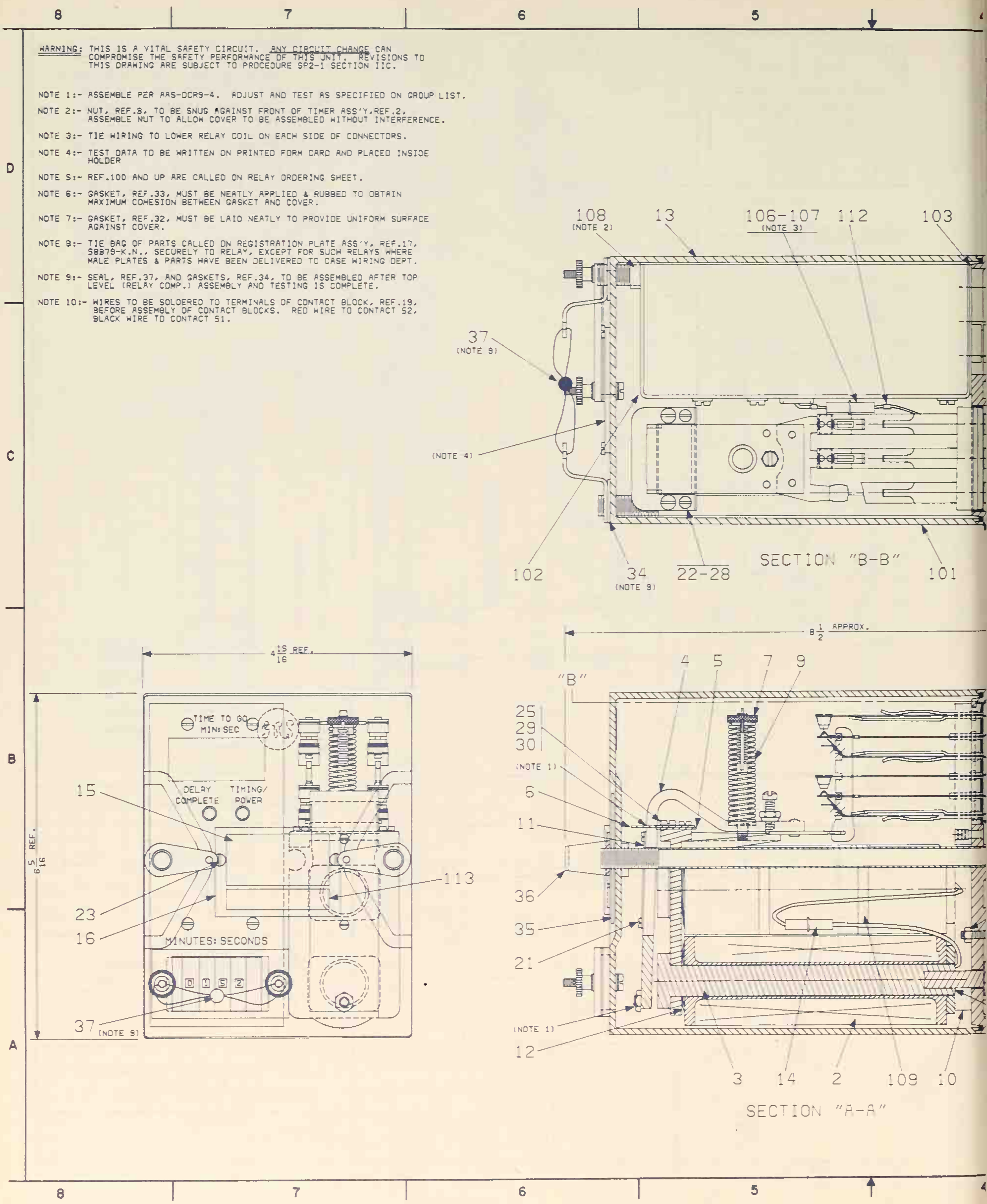


Figure 9-129 General notes on drawings (*Courtesy General Railway Signal Corp.*)

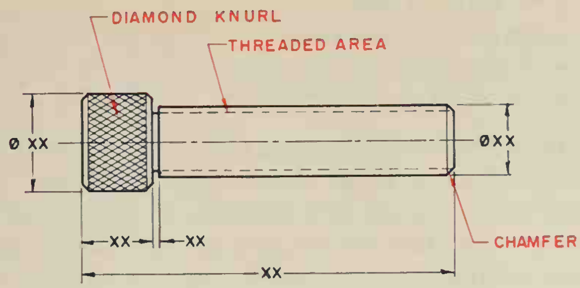


Figure 9-130 Detail note connected with a leader line

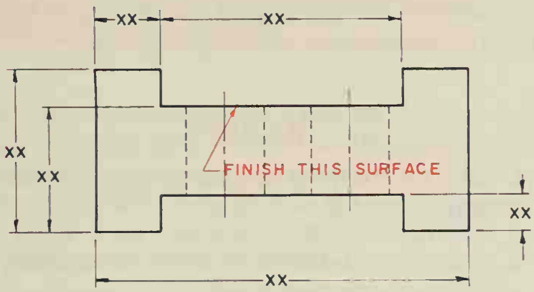


Figure 9-131 Poor placement of a detail note

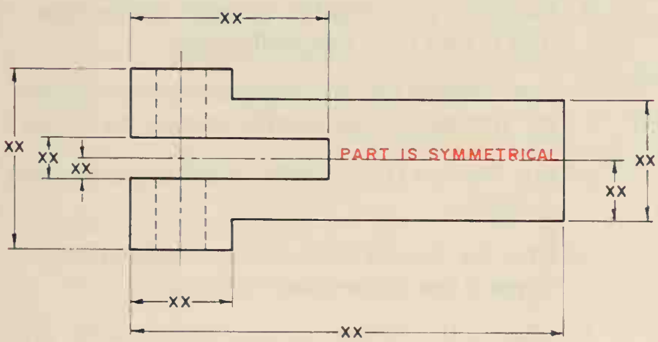


Figure 9-132 Acceptable placement of a detail note when there is space

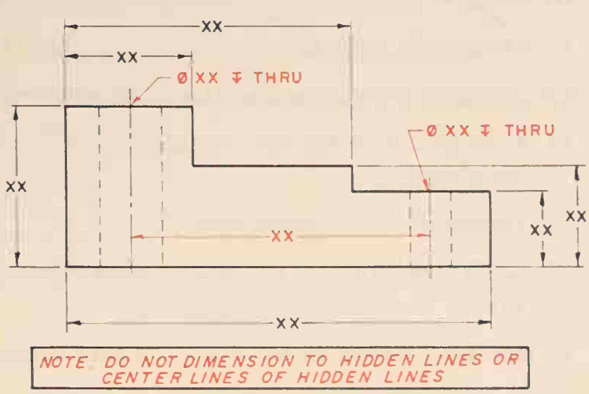


Figure 9-133 Superimposing a note is poor practice

LEGEND

1. ASSY = ASSEMBLY
2. FAO = FINISH ALL OVER
3. MS = MACHINE STEEL
4. FAB = FABRICATE
5. CARB = CARBURIZE
6. DVTL = DOVETAIL
7. HT TR = HEAT TREAT
8. KST = KEYSEAT
9. TPR = TAPER
10. SF = SPOTFACED

Figure 9-134 Abbreviations are explained in a legend

NOTE

POWER BRUSH ALL SURFACES. APPLY THREE COATS PAINT. STAMP PART WITH NUMBER 01929612.

Figure 9-135 Proper punctuation of notes is important

NOTE

ALL DIMENSIONS AND CONDITIONS
SHALL BE FIELD CHECKED AND
VERIFIED BY PROPER TRADES

Figure 9-136 Indenting for clarity

GENERAL NOTES ← LETTERS .25 HIGH

ALL FILLETS AND ROUNDS .125 DIA.
ALL SURFACES MUST BE FREE OF BURRS.
LETTERS .125-.1875 HIGH

Figure 9-137 Proper lettering height is important

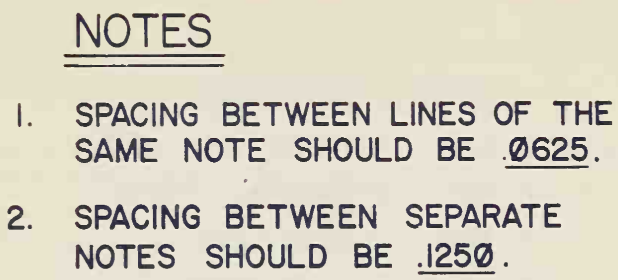


Figure 9-138 Spacing of notes

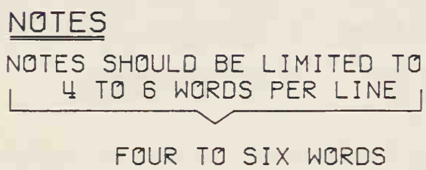


Figure 9-139 Number of words per line limitations are important

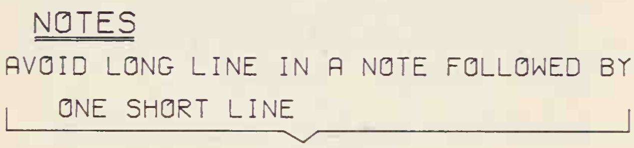


Figure 9-140 Lines in notes should be approximately equal

Sample Notes

The following is a list of sample notes of the types frequently used on technical drawings:

- All fillets and rounds R1/8
- 45 degree chamfer all edges
- Surfaces A & B parallel
- Stock .125 thick
- Heat treat
- All internal radii R.0625
- FAO
- Ream for 1/4 dowels
- All bends R5/32
- CBORE from bottom
- Identical bolts—both sides
- 3/32 × 1/16 oil groove
- 87 CSK 3/4 dia—4 holes
- Rounds .125 R unless otherwise specified
- 4 holes equally spaced
- 1/32 × 45 chamfer
- #7 Drill .75 deep
- Machine steel—4 reqd.
- Power brush all ext surfaces
- Sandblast before painting

Notice that these sample notes are very brief, concise, and to the point. Words such as "a," "an," "the," and "are" are used only sparingly. The notes are not always complete sentences in terms of proper grammar, but they are complete thoughts in terms of communication. Notice also the use of abbreviations such as FAO (finish all over), CBORE (counterbore), and CSK (countersink). Abbreviations can be used frequently to cut down on the length of notes and the time required to letter them. However, when used, abbreviations should always be placed in a legend to ensure consistency of interpretation.

Review

1. What is the most frequently used dimensioning standard?
2. How does a drafter indicate on a drawing that a dimension is NTS?
3. Of the three dimensioning systems used, which is most frequently used on mechanical technical drawings?
4. Illustrate how to label a metric dimension that is less than one millimeter.
5. How should the line separating the numerator and denominator of a fraction be drawn?
6. List the five components of all dimensioning systems.
7. How far should an extension line extend beyond the dimension line?
8. What is the recommended length/width ratio of arrowheads?
9. What is the keyword to remember in making arrowheads, regardless of the size?
10. What is unidirectional dimensioning?
11. Define the term *notes*.
12. Describe the proper location of general notes.
13. How should notes be oriented on the drafting sheet?
14. Define the term *general notes*.
15. What is the proper height for lettering note titles?
16. Define the term *verification* as it relates to notes.
17. Explain the significance of balance in terms of notation.

Chapter Nine Problems

The following problems are intended to give beginning drafters and engineers practice in applying the various dimensioning techniques required on technical drawings in industry. Students should follow the general instructions which apply to all problems, and any additional instructions provided for special problems. All problems should be dimensioned in strict accordance with the rules set forth in this chapter.

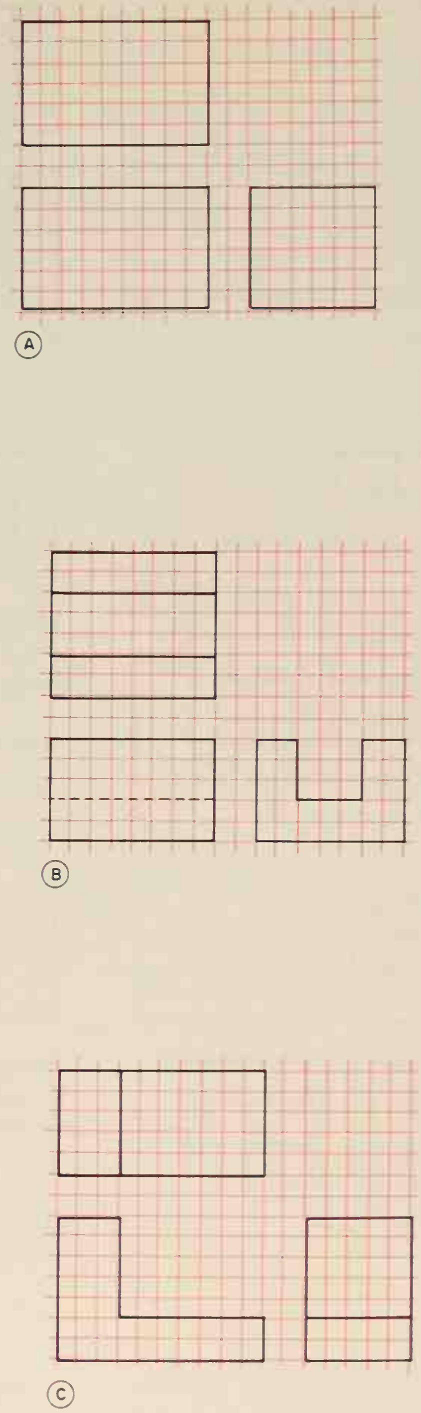
General Instructions

1. Study each problem carefully.
2. Make a complete sketch of the problem, applying all dimensions on the sketch. Note on the sketch the proper spacing between views, between the object and first dimension lines, and between successive dimension lines.
3. Compare your fully dimensioned sketch against all applicable sections of this chapter and "The Summary of Dimensioning Rules."

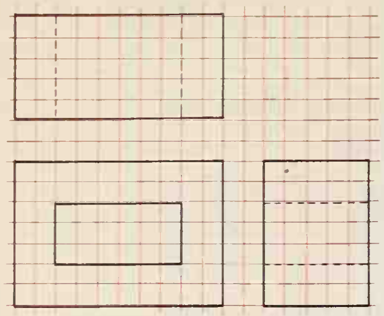
Note: These instructions do not apply to Problems 9-47 through 9-50.

Problems 9-1 through 9-24

1. Use the grid to determine all dimensions.
2. Redraw the views shown, and fully dimension your drawing.



Problem 9-1



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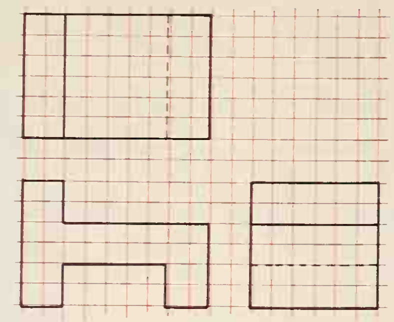

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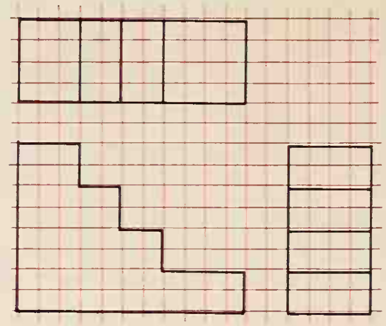

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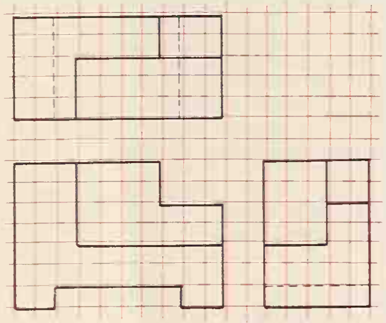

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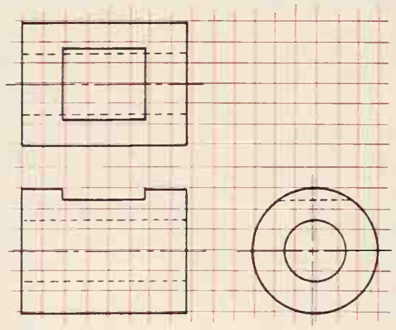

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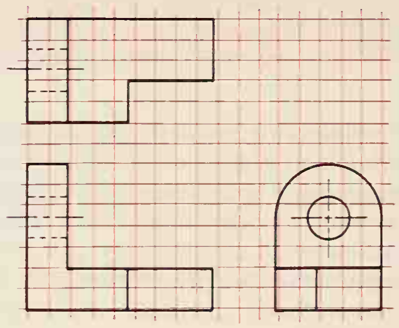
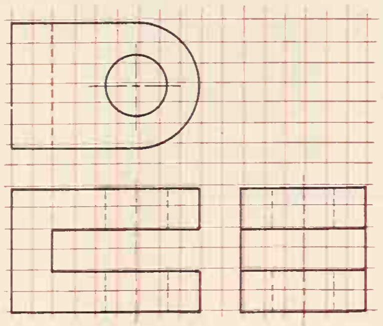


I



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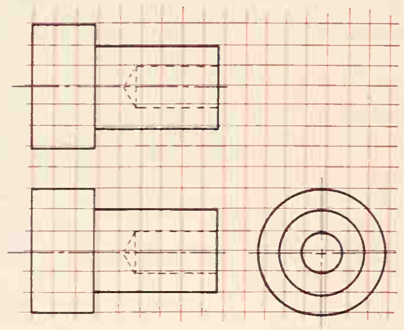
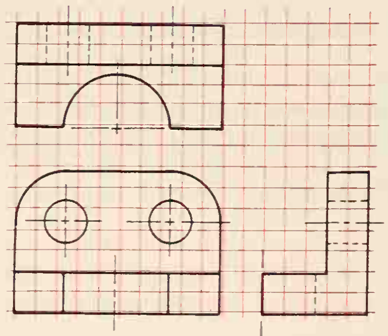
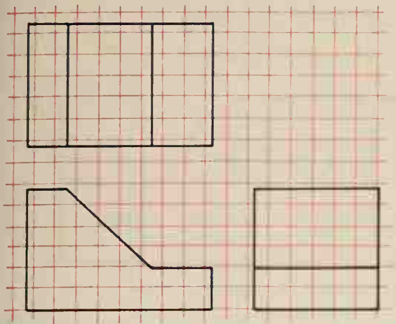


K

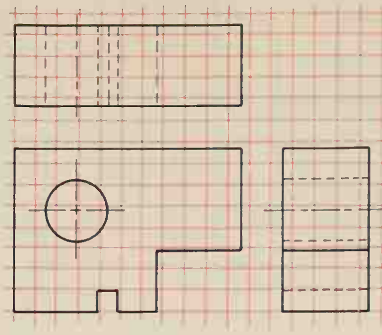


L

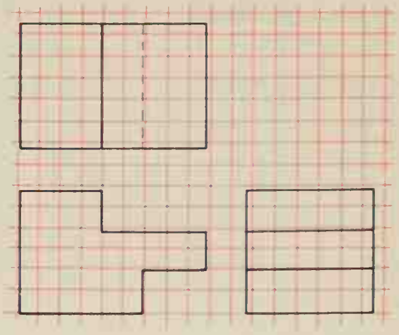
Problem 9-1 Cont'd.



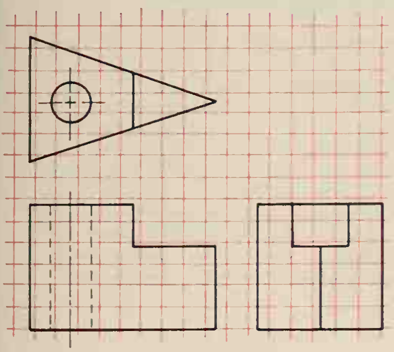
(A)



(B)



(C)



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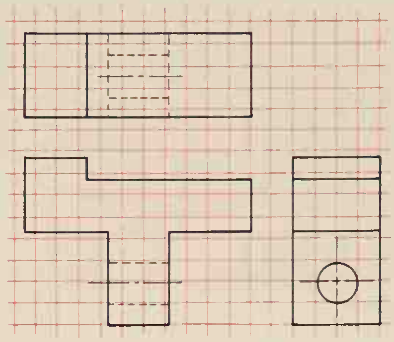

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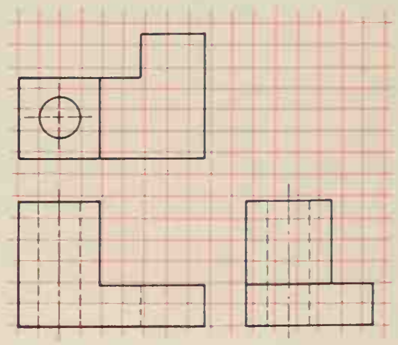

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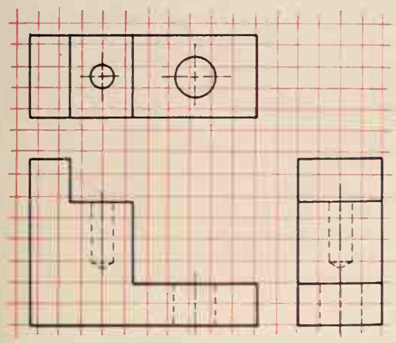

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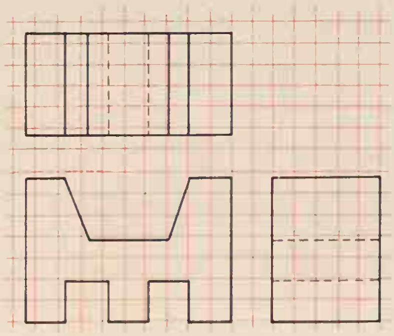

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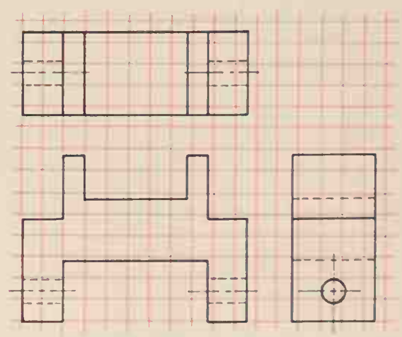

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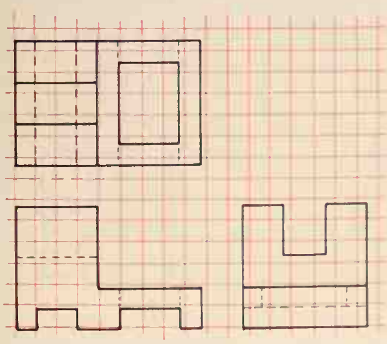
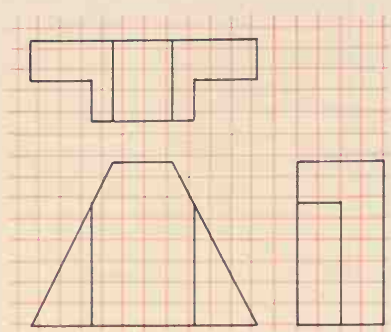
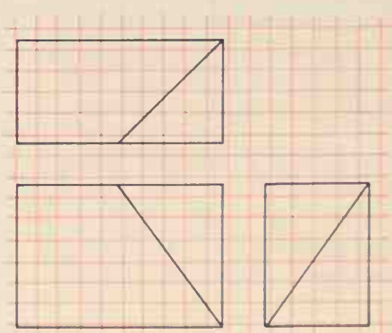


(J)

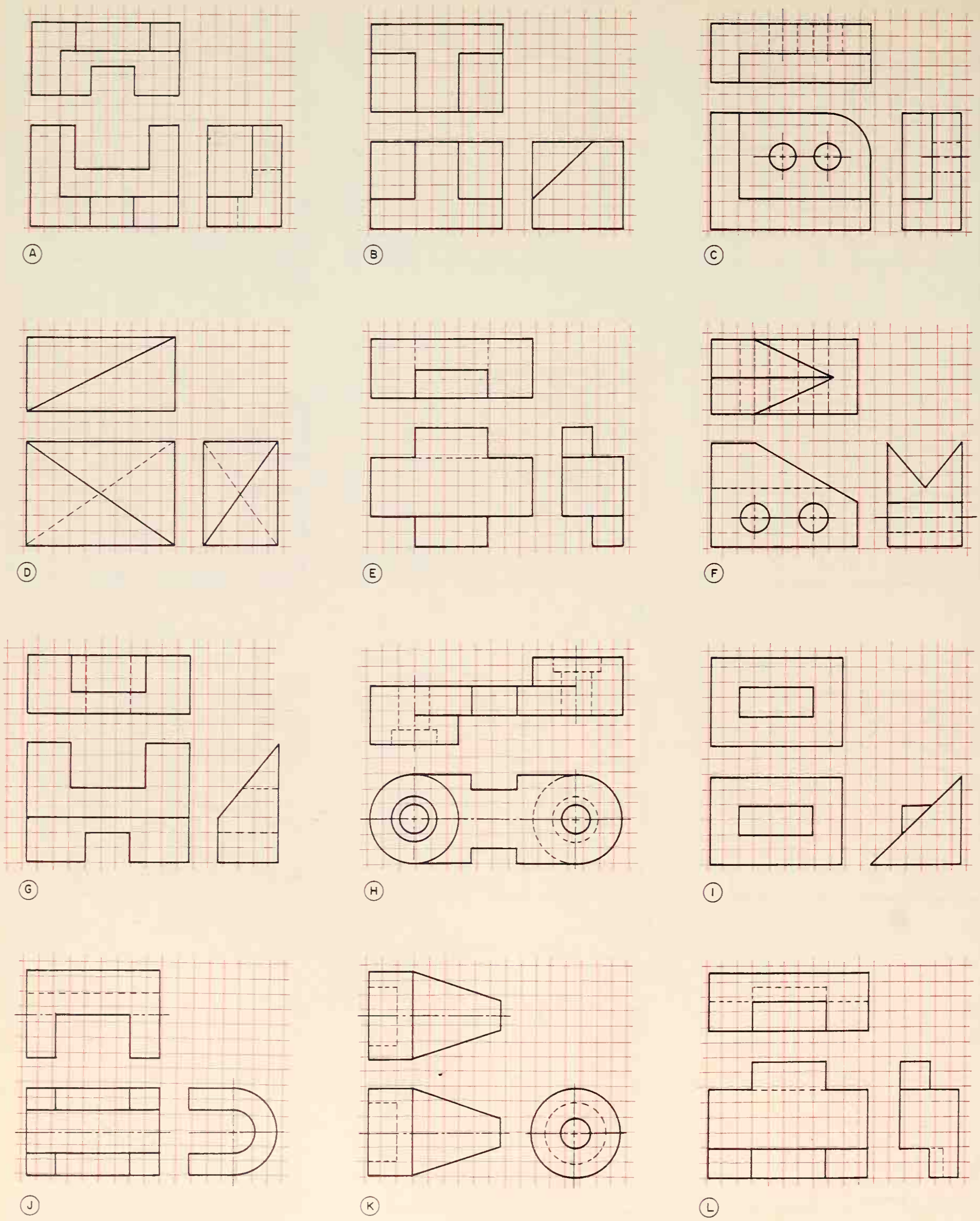


(K)

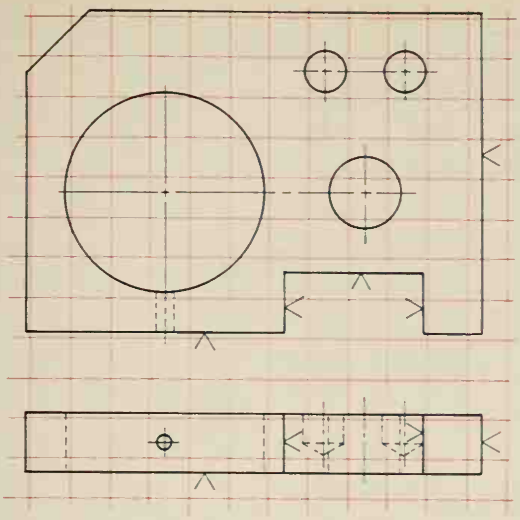


(L)

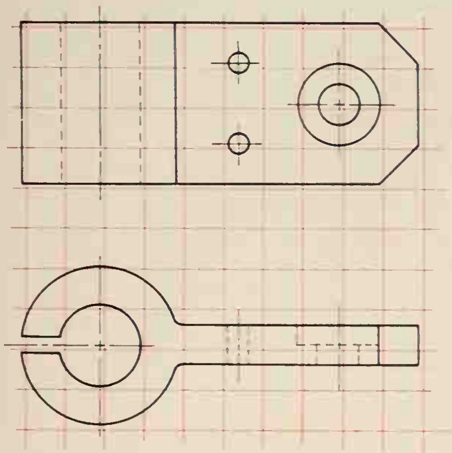
Problem 9-2



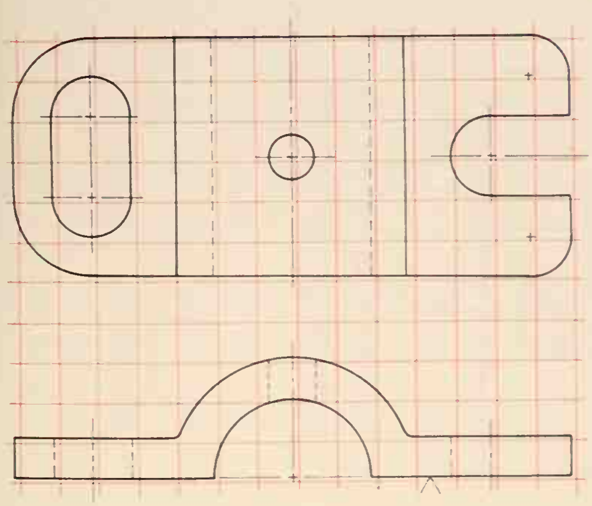
Problem 9-3



Problem 9-4



Problem 9-5



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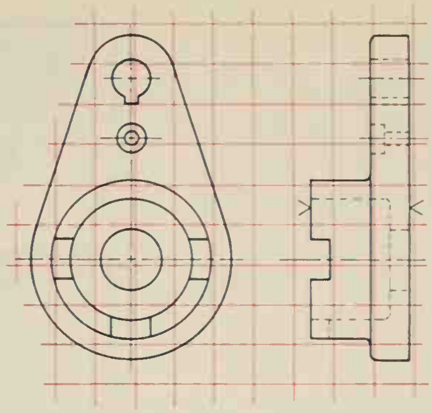

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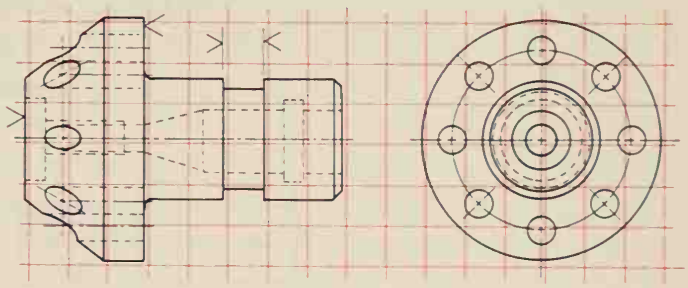

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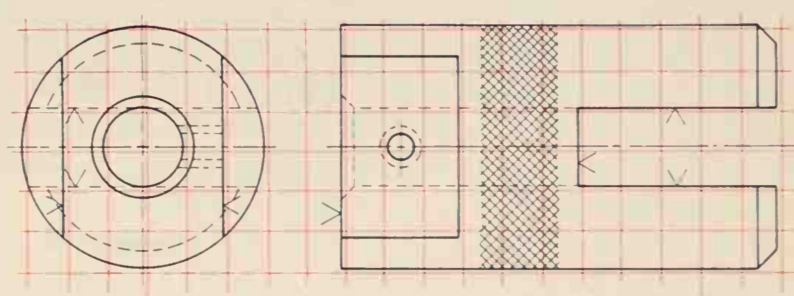
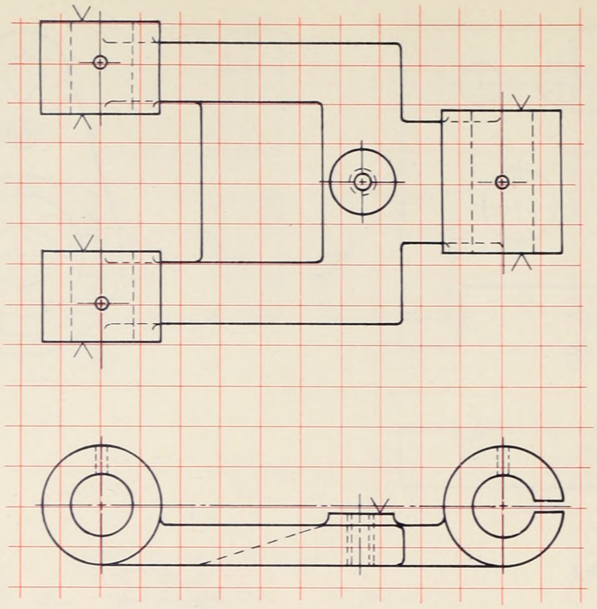
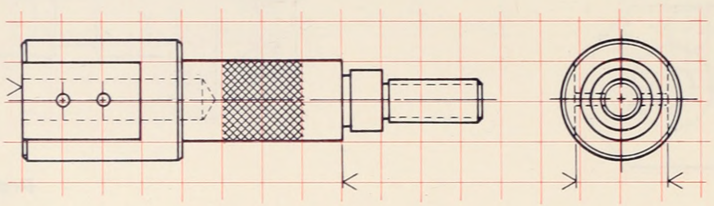


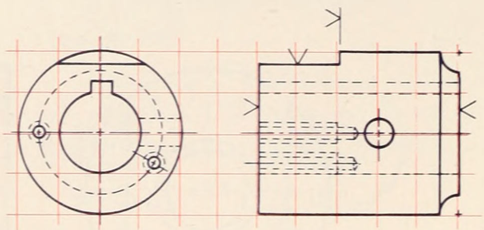
Problem 9-9



Problem 9-10



Problem 9-11



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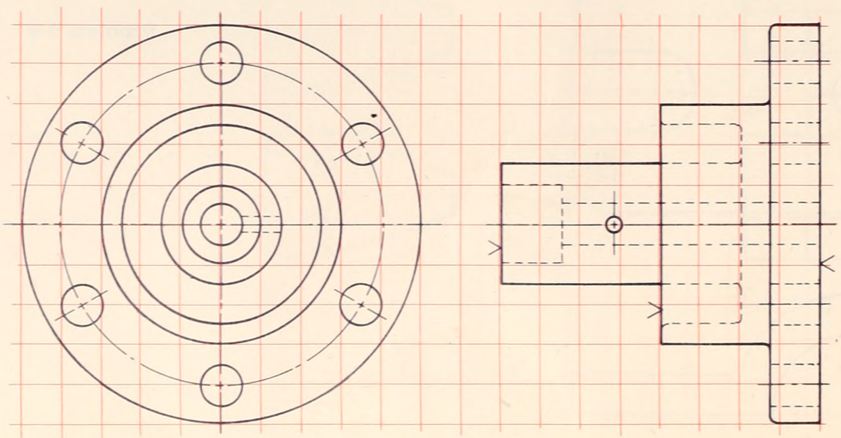
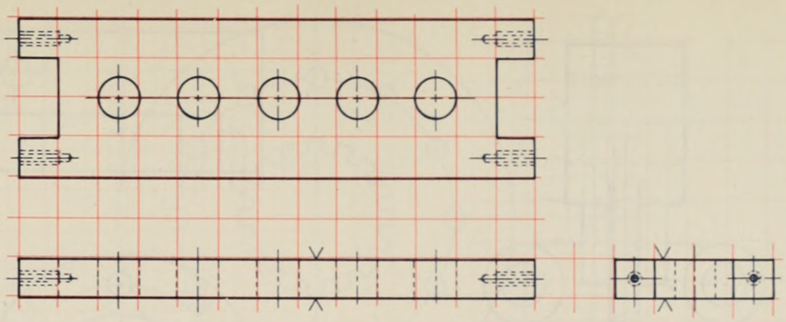
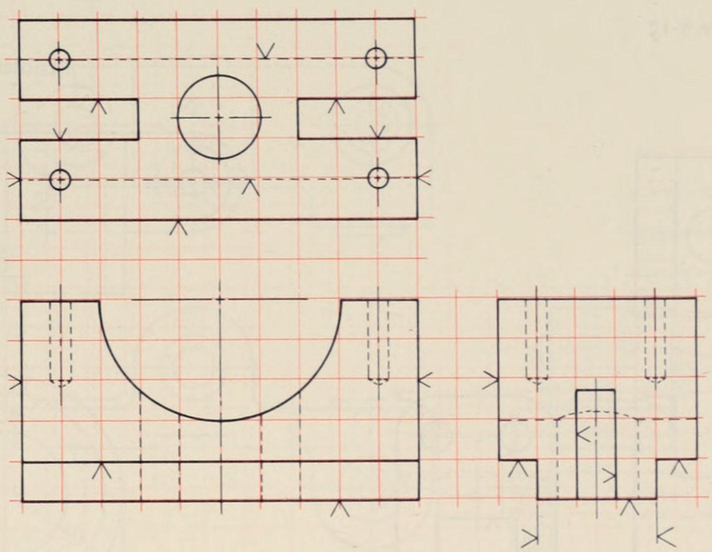


Problem 9-13



Problem 9-14



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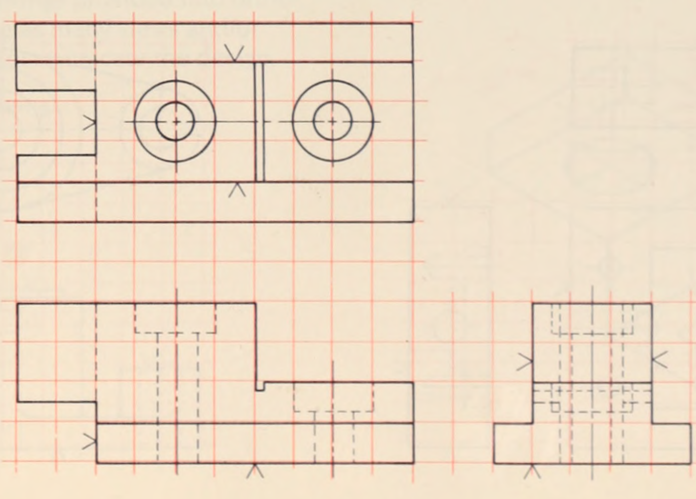

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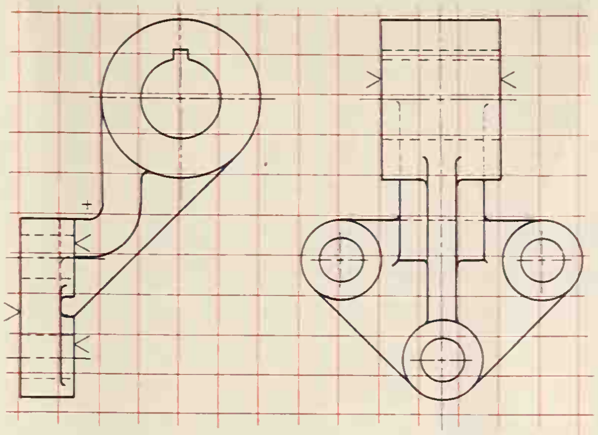

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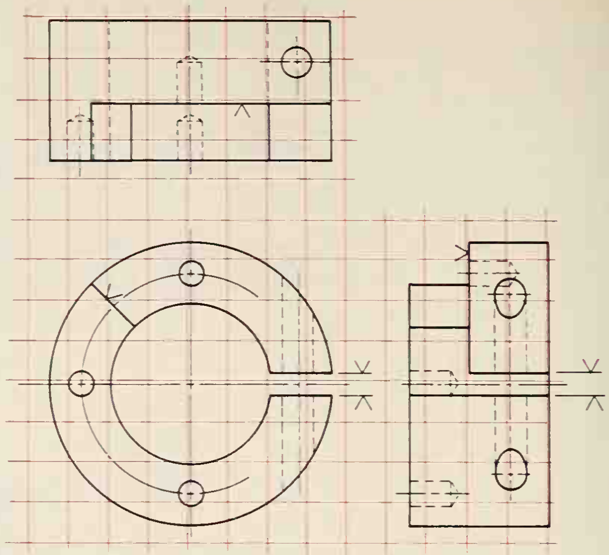

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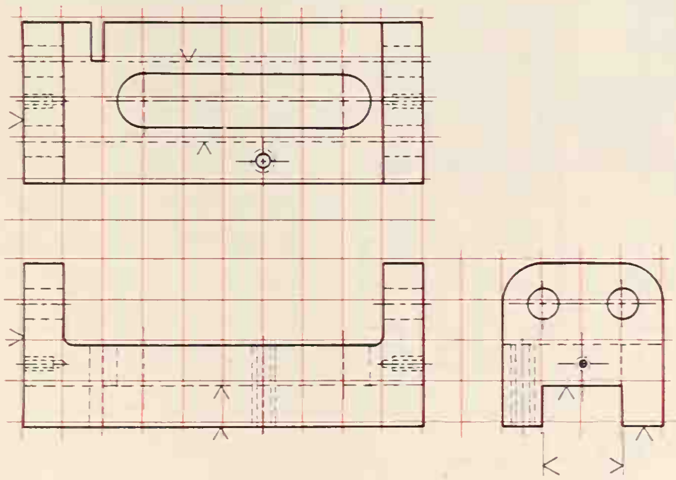

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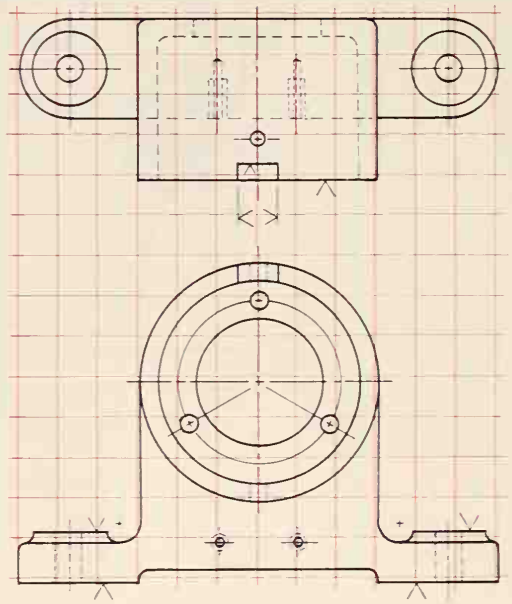
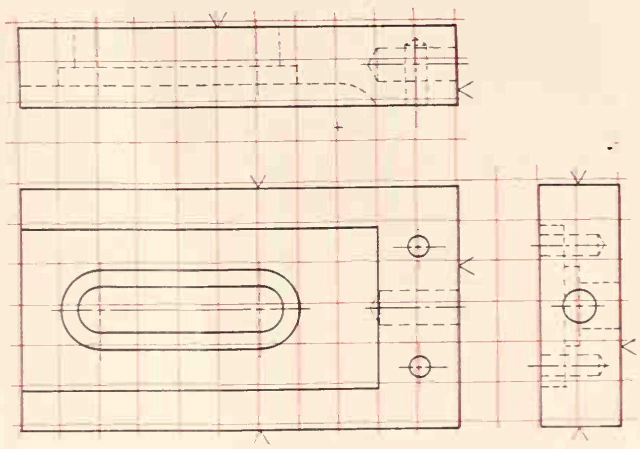
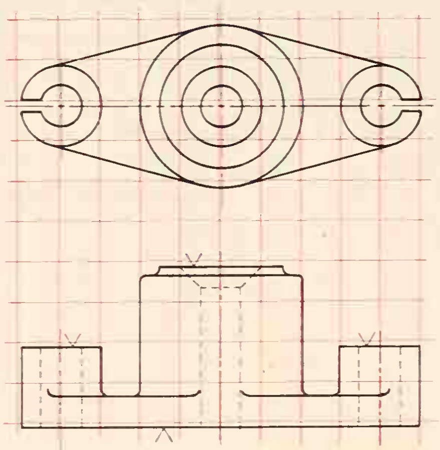


Problem 9-21



Problem 9-19



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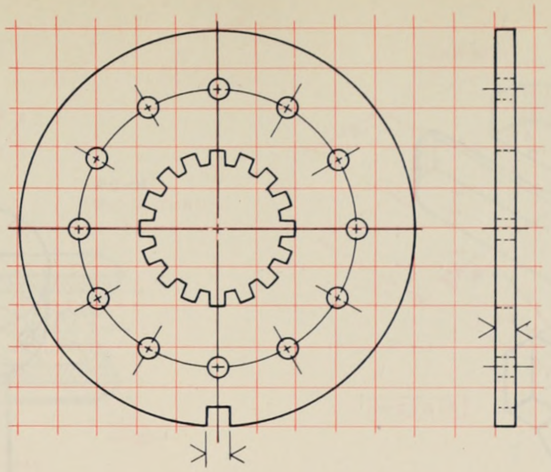
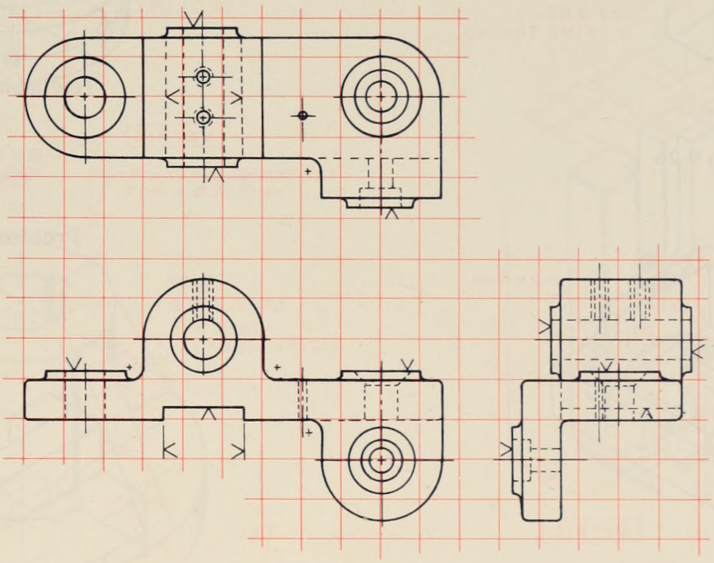


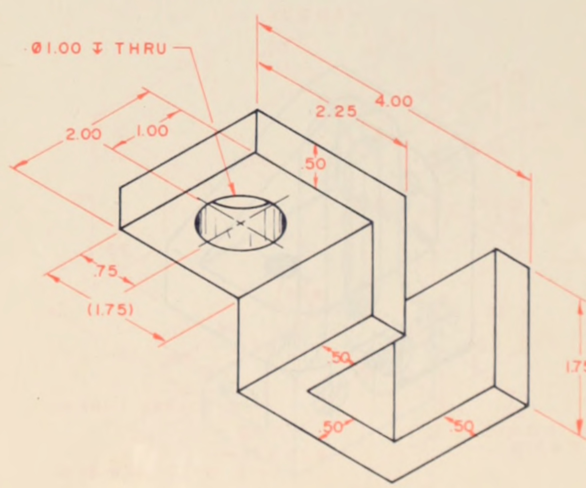
Problem 9-23



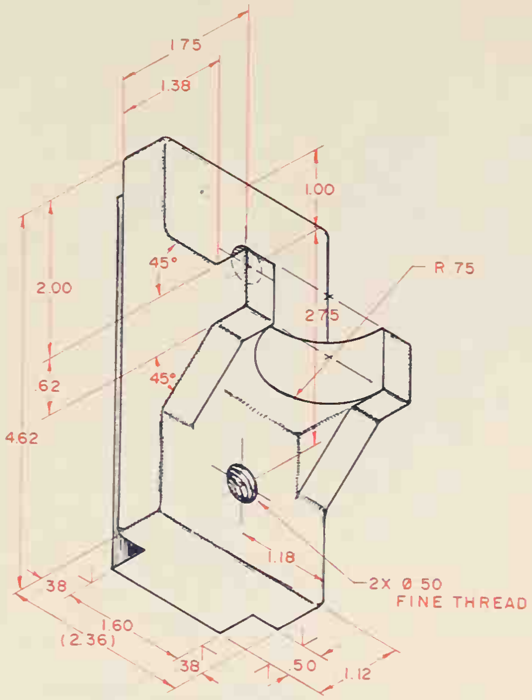
Problem 9-24

Problems 9-25 through 9-46

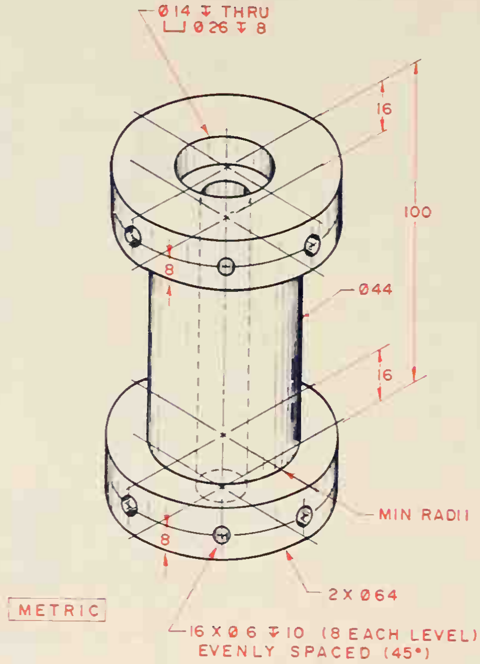
1. Convert the isometric drawings provided into orthographic drawings, showing as many views and/or sections as necessary to communicate the design.
2. Fully dimension your drawing.



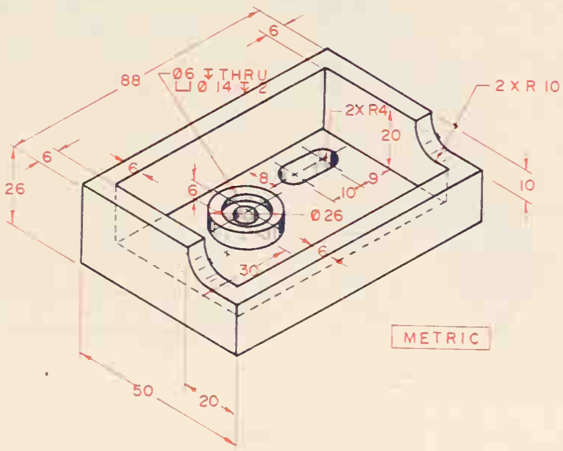
Problem 9-25



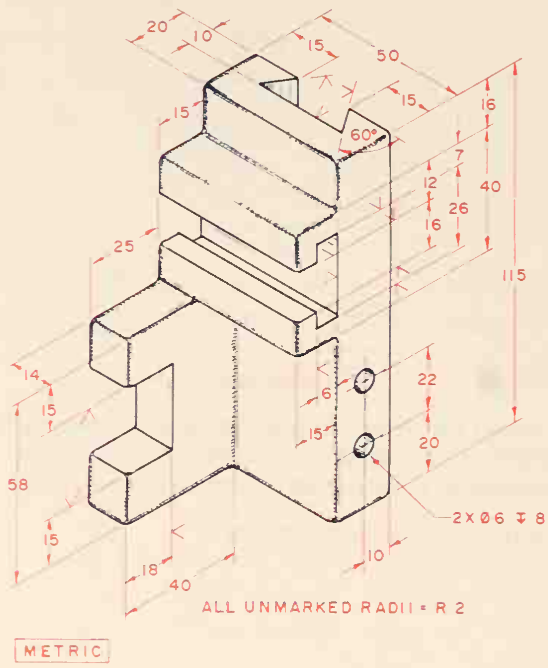
Problem 9-26



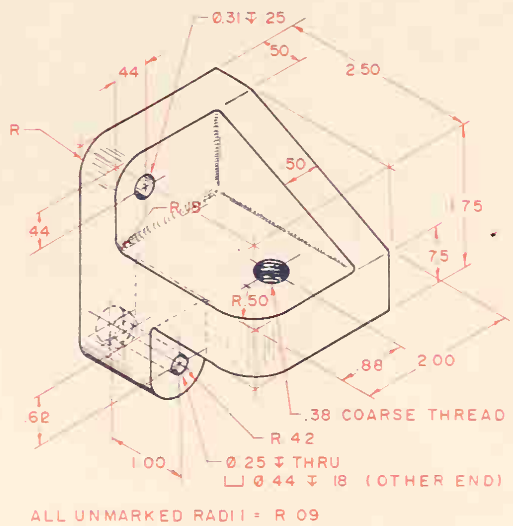
Problem 9-29



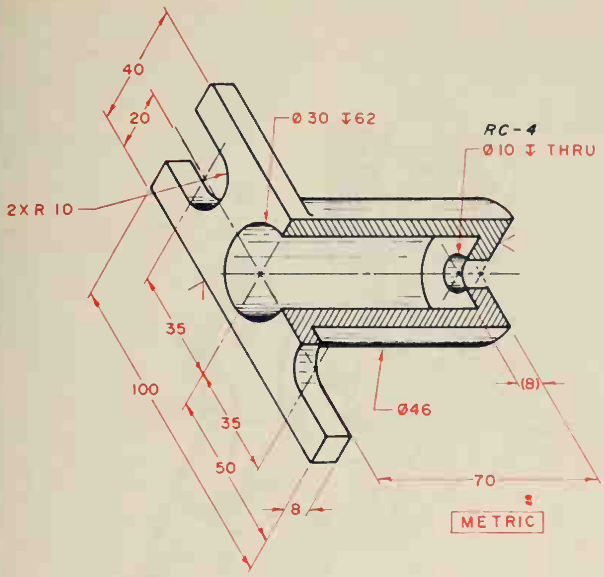
Problem 9-27



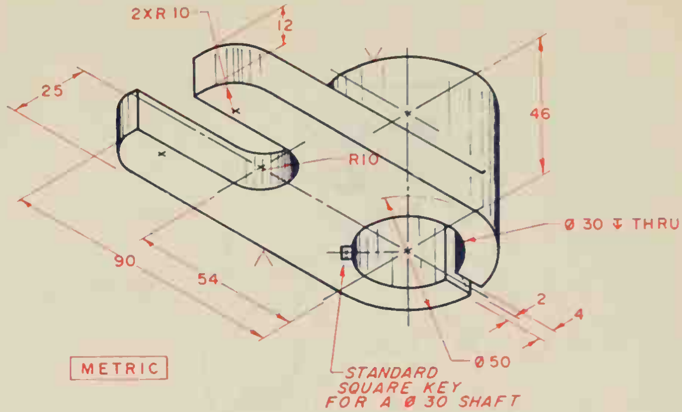
Problem 9-30



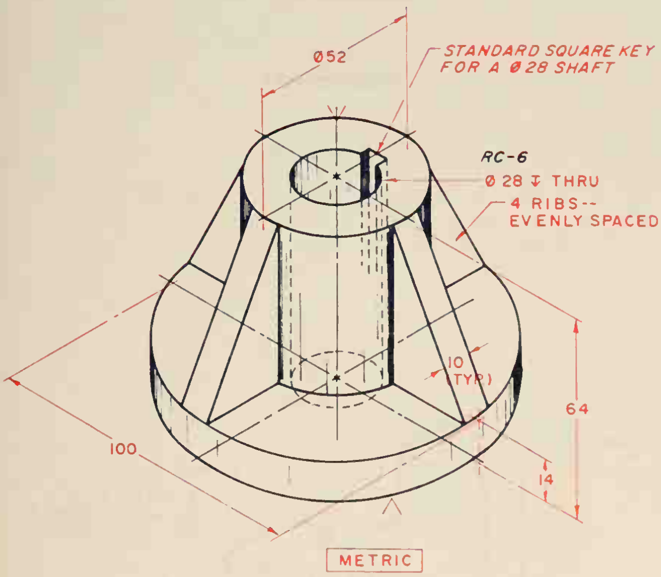
Problem 9-28



Problem 9-31



Problem 9-34



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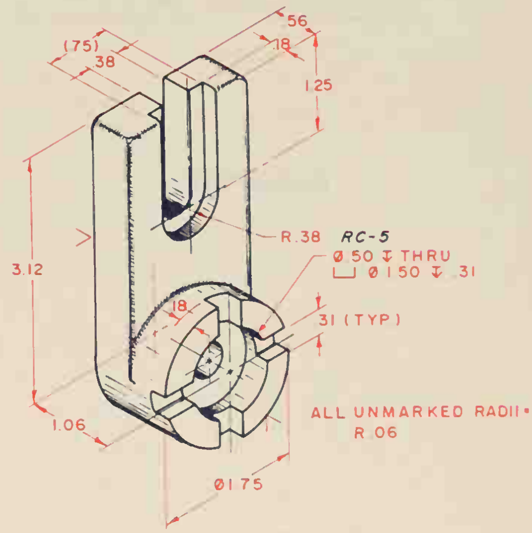

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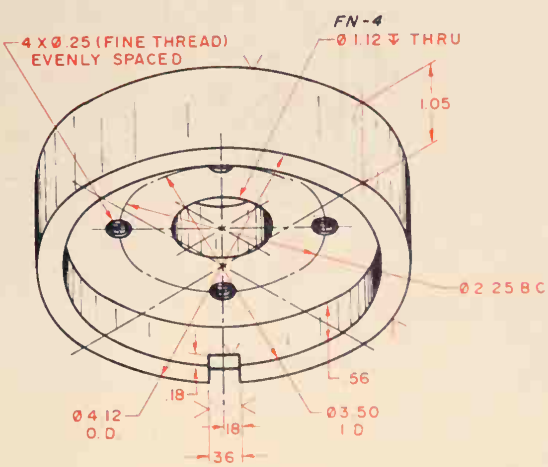
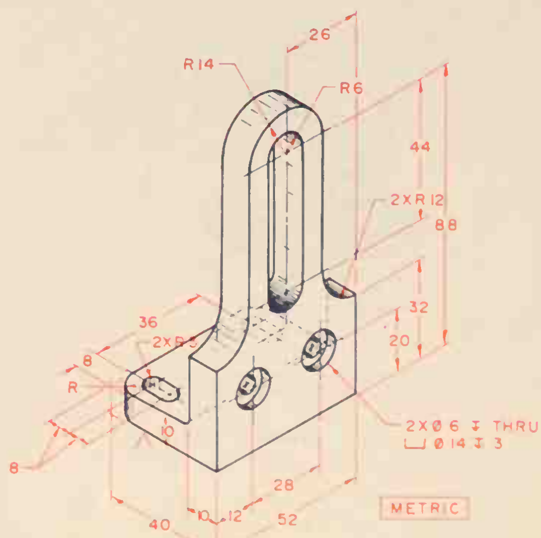
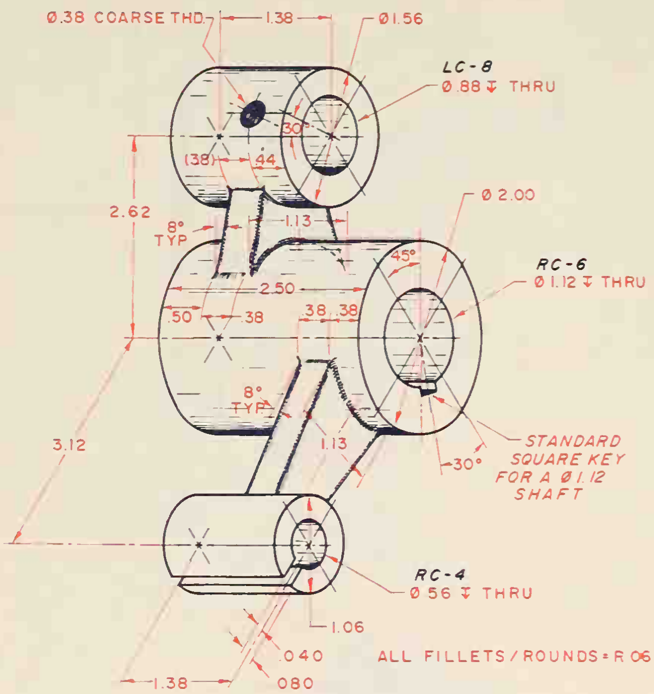


Problem 9-33



Problem 9-36



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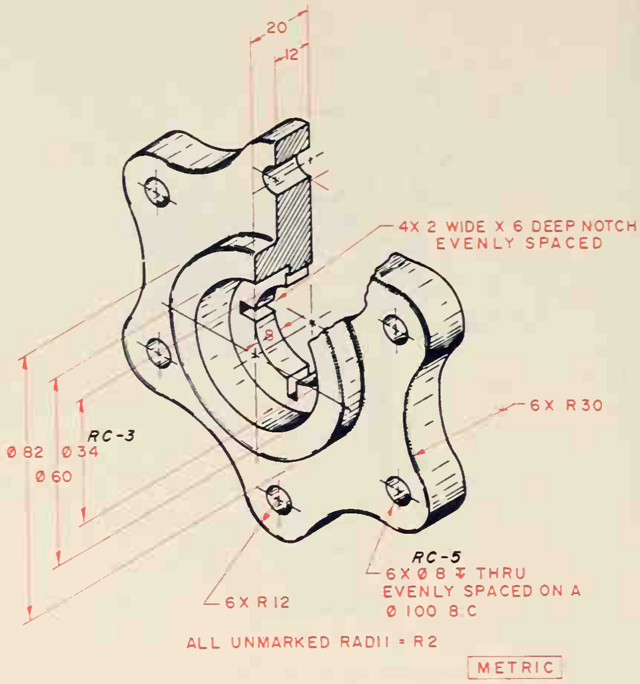
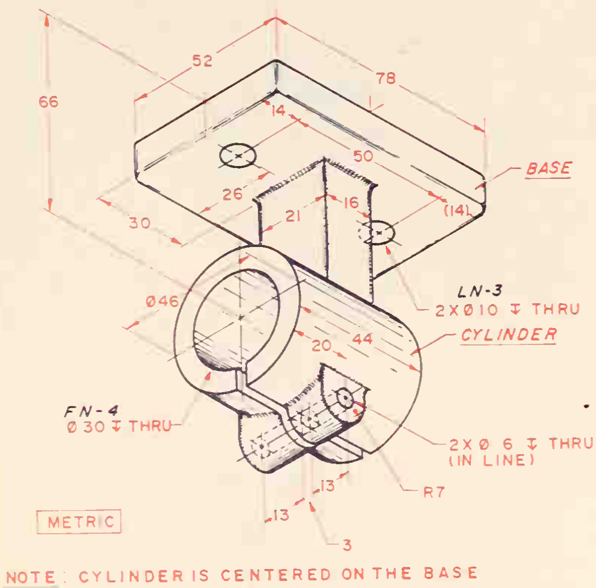
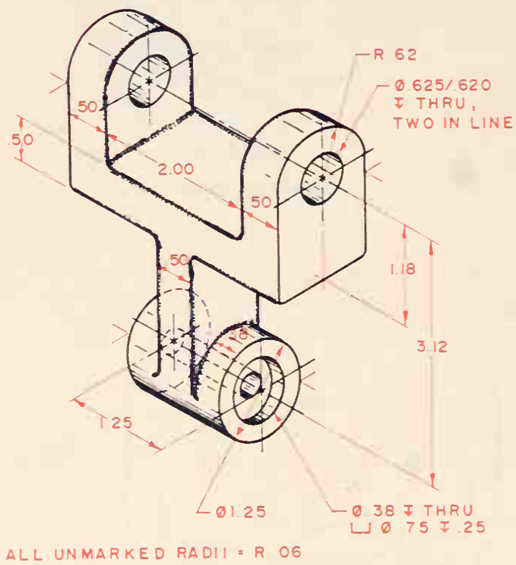


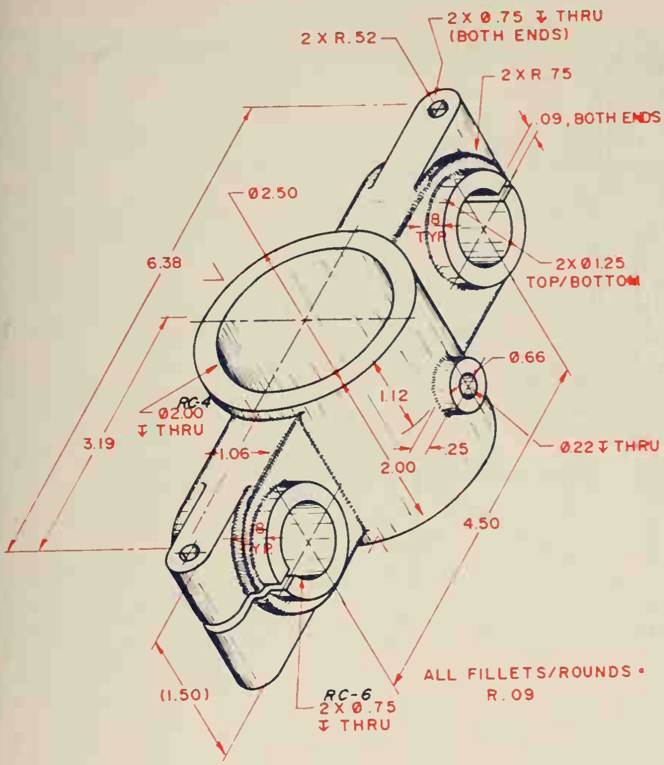
Problem 9-39



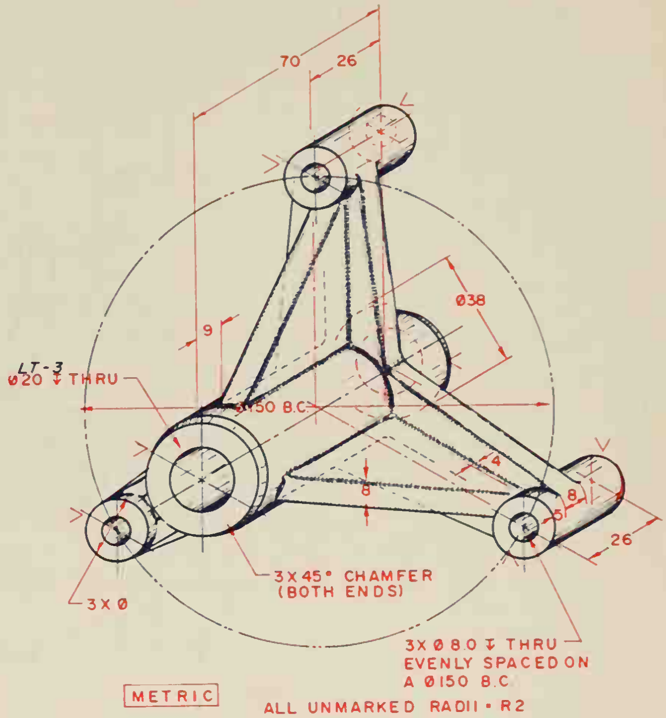
Problem 9-38



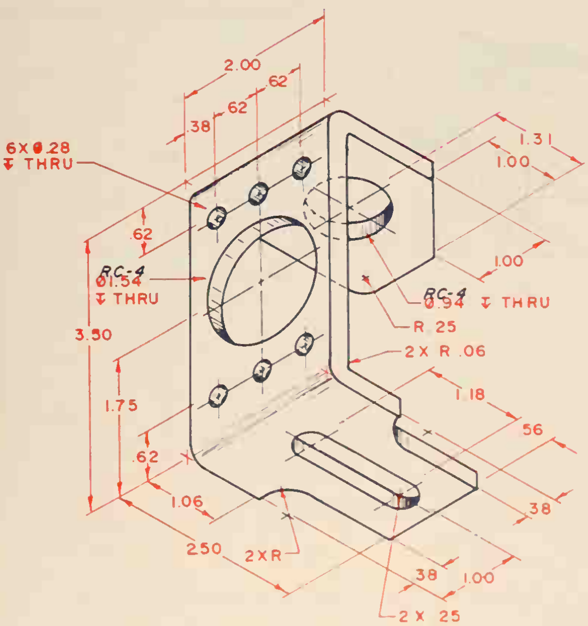
Problem 9-40



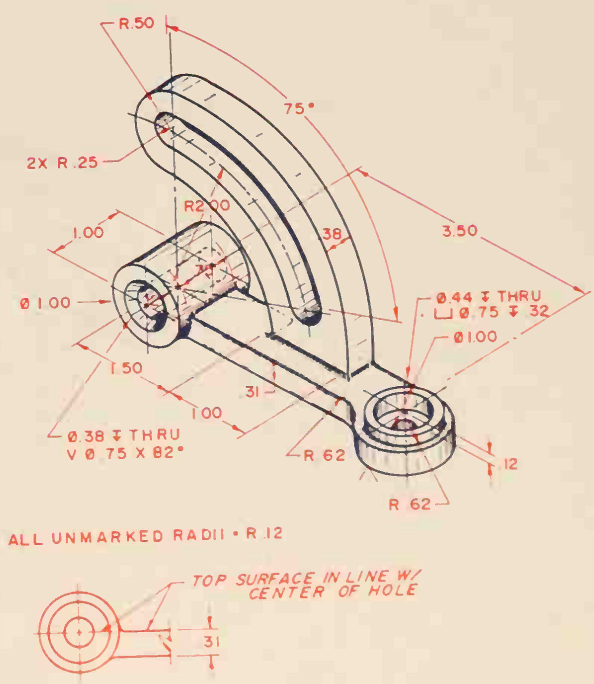
Problem 9-41



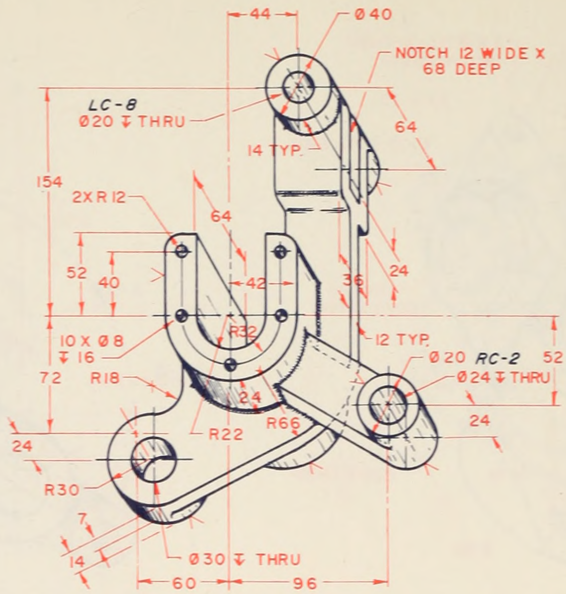
Problem 9-43



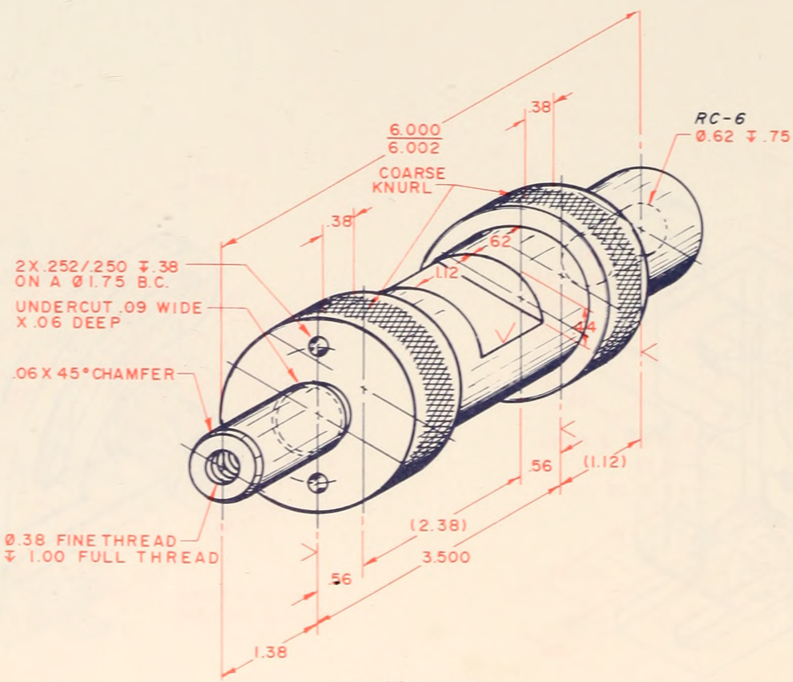
Problem 9-42



Problem 9-44



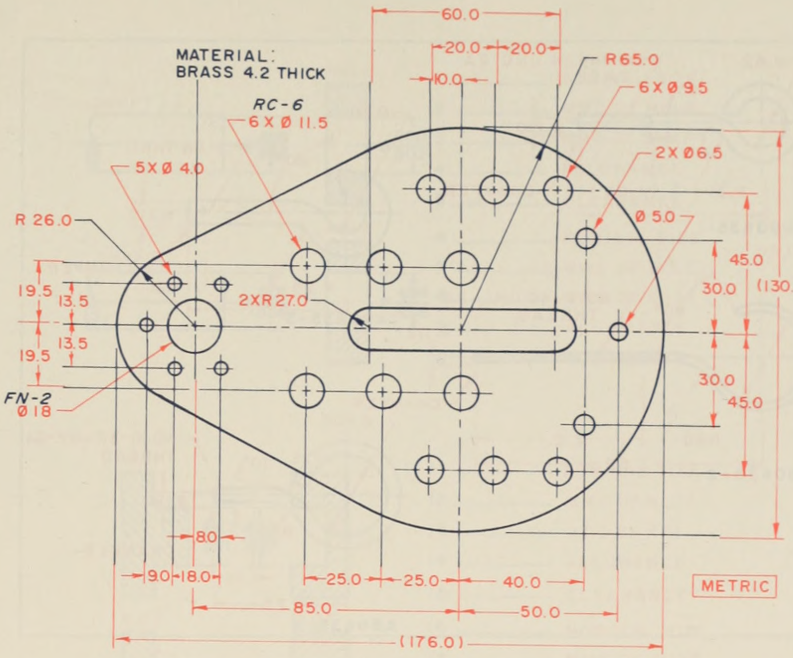
Problem 9-45



Problem 9-46

Problem 9-47

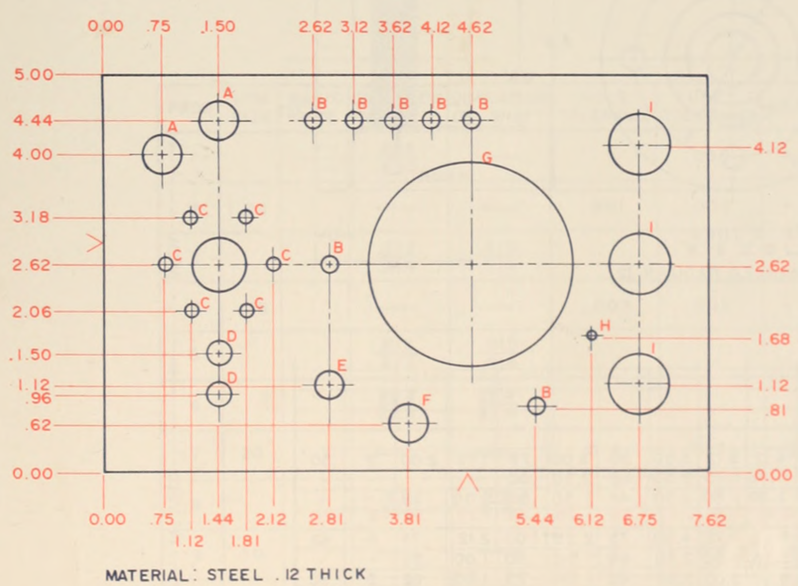
Convert Problem 9-47 into a tabular drawing.



Problem 9-47

Problem 9-48

Convert Problem 9-48 into a standard coordinate dimensioning system drawing.

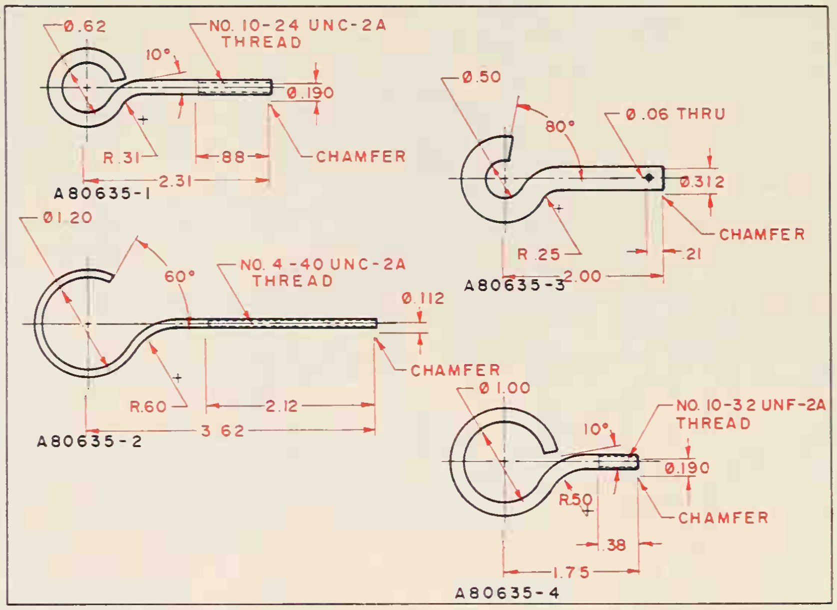


HOLE	SIZE
I	.750/.752
H	.120
G	2.562/2.565
F	.510/.512
E	.375/.380
D	.320
C	.188
B	.218/.220
A	.500

Problem 9-48

Problem 9-49

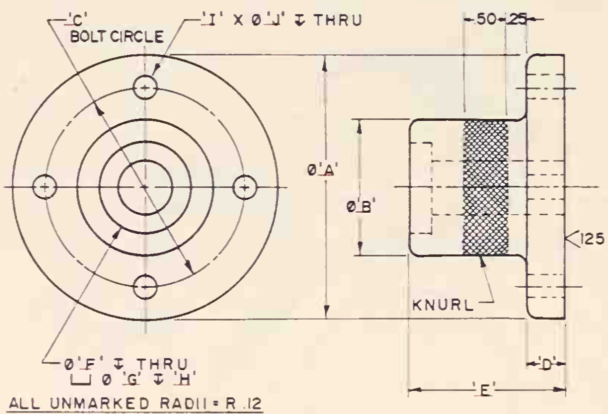
Convert Problem 9-49 into a tabular drawing.



Problem 9-49

Problem 9-50

Draw parts AO608-5 and AO608-8 full size.

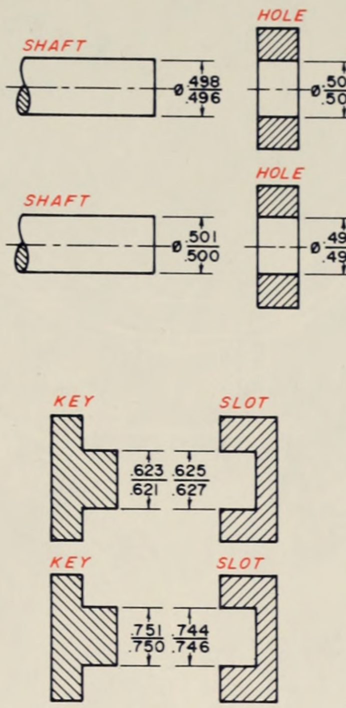


PART NO.	A	B	C	D	E	F	G	H	I	J
A0608-8	4.12	3.12	3.50	.50	3.00	.75	1.50	2.00	2	.50
A0608-7	3.38	1.75	2.50	.62	2.50	.50	-	-	-	-
A0608-6	3.50	1.50	2.50	.44	1.50	.50	1.00	.38	-	-
A0608-5	4.10	1.12	2.62	.25	1.25	.38	.75	.50	6	.38
A0608-4	5.25	3.12	4.00	.75	2.25	1.00	2.12	.75	8	.62
A0608-3	3.25	1.50	2.38	.44	1.50	.50	1.00	.38	-	-
A0608-2	4.00	3.00	3.50	.62	1.00	.75	1.50	.62	3	.50
A0608-1	3.38	1.75	2.50	.50	2.00	.62	1.12	.25	4	.31

Problem 9-50

Problems 9-51 and 9-52

Carefully fill in all blank lines.

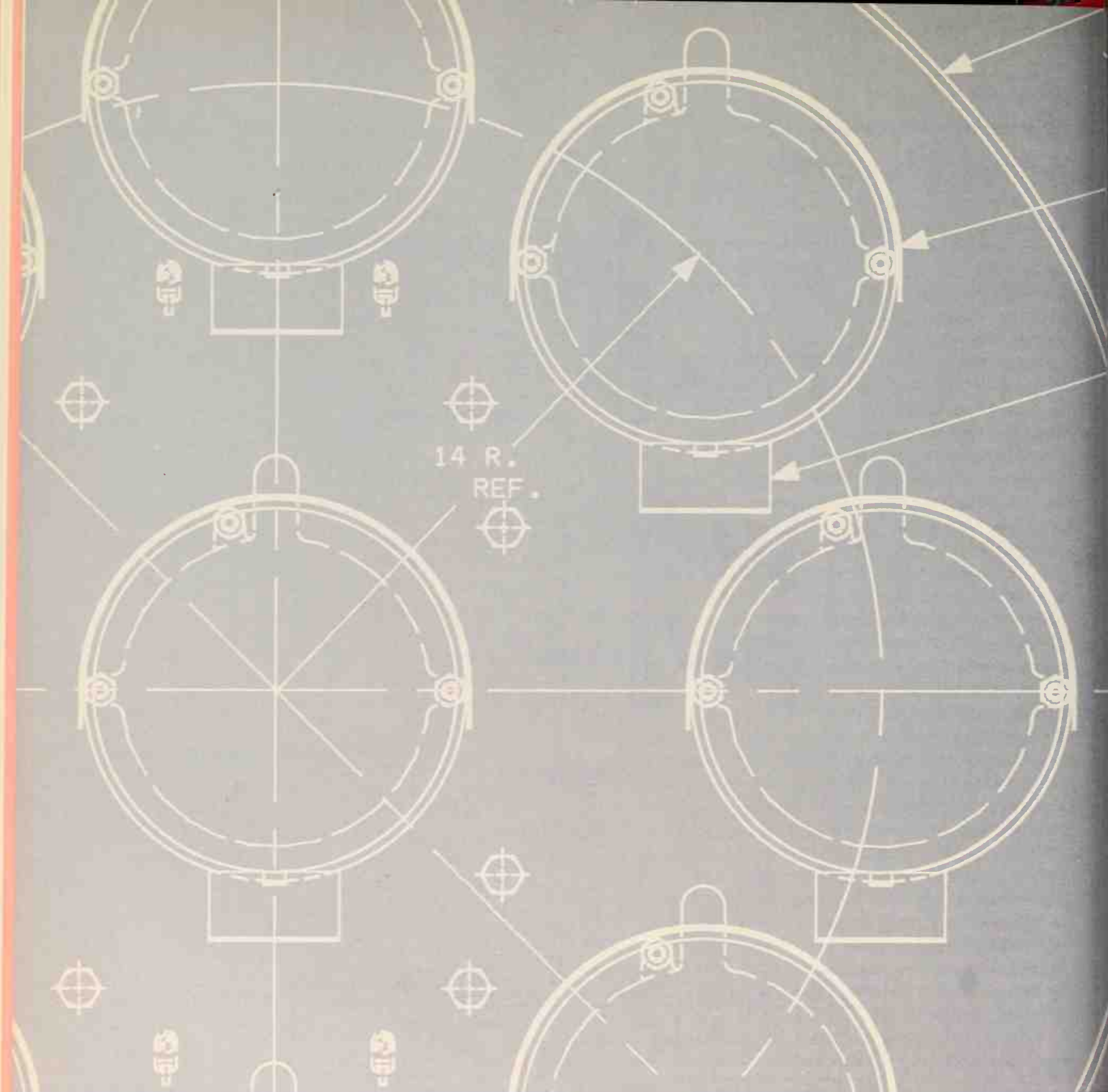


1 ______ NOMINAL SIZE
2 ______ MMC OF HOLE
3 ______ MMC OF SHAFT
4 ______ ALLOWANCE
5 ______ CLEARANCE
6 ______ NOMINAL SIZE
7 ______ MMC OF HOLE
8 ______ MMC OF SHAFT
9 ______ ALLOWANCE
10 ______ CLEARANCE
11 ______ NOMINAL SIZE
12 ______ MMC OF SLOT
13 ______ MMC OF KEY
14 ______ ALLOWANCE
15 ______ CLEARANCE
16 ______ NOMINAL SIZE
17 ______ MMC OF SLOT
18 ______ MMC OF KEY
19 ______ ALLOWANCE
20 ______ CLEARANCE

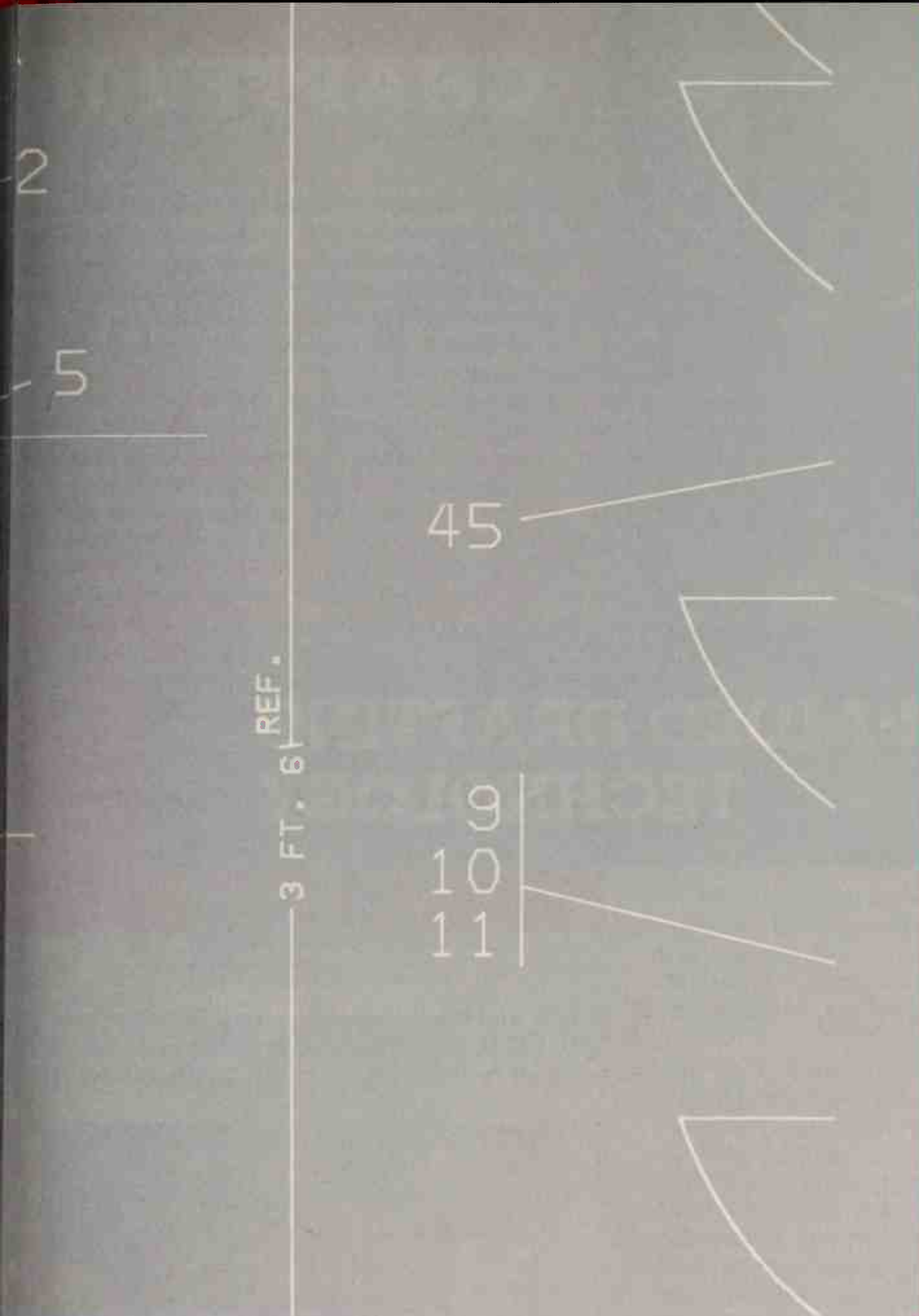
Problem 9-51

	PROB	NOM SIZE	BASIC SIZE	DIMENSION OF HOLE	DIMENSION OF SHAFT	HOLE TOLERANCE	SHAFT TOLERANCE	ALLOWANCE	CLEARANCE
INCH	1			.625 / .630	——		.005	+.002	
INCH	2	1.25		——	——	.001	.002	+.001	
INCH	3			.312 / .314	.316 / .314				
INCH	4	.75		——	——	.003	.002	+.001	
INCH	5			.812 / .813	.815 / .814				
METRIC	6			22.2 / 22.3	22.5 / 22.4				
METRIC	7	20		——	——	0.4	0.3	+ 0.2	
METRIC	8			9.6 / 9.4	9.8 / 9.4				
METRIC	9	30		——	——	0.2	0.4	+ 0.2	
METRIC	10			15.6 / 15.4	——		0.6	+ 0.4	

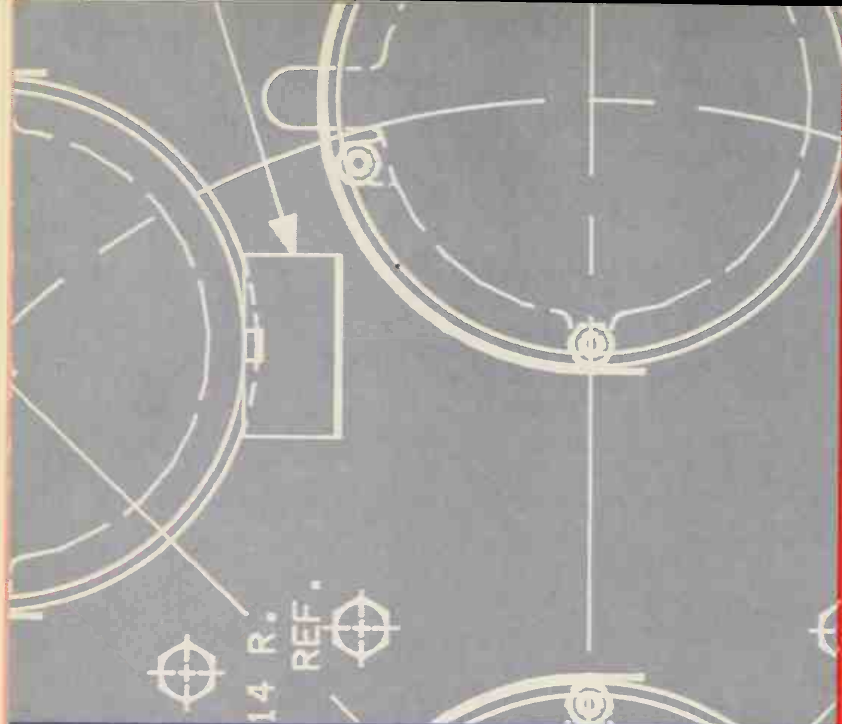
Problem 9-52


14 R.
REF.

SECTION THREE



COMPUTER-AIDED DRAFTING



CHAPTER 10

This chapter provides an in-depth treatment of modern computer-aided drafting (CAD) technology. The relationship of manual drafting and CAD is explained. The major topics covered include an overview of CAD, CAD systems, CAD software, CAD users, modern CAD system configurations, and the advantages of CAD.

COMPUTER-AIDED DRAFTING TECHNOLOGY

Overview of CAD

The dawning of the age of computers brought significant changes to the fields of design, drafting, engineering, and the various other fields related to these areas. You learned in the Introduction that the fundamental nucleus of these fields – the design process – was altered by computers in two ways: 1) the fourth step in the traditional design process, the making and testing of models or prototypes, was replaced by the developing and testing of three-dimensional computer models; and 2) the tools and techniques used in accomplishing each step of the process were significantly changed.

During the 1960s, shortly after the development of the integrated circuit (IC), the computer began to be used to save time, work, and money in hundreds of different fields. One of the more innovative uses of the computer was in the area of design and drafting, Figure 10-1.

Defining Terms

The rapid growth of the use of computers in the world of design and drafting brought forth a deluge of new, and often confusing, terms. Such terms as CAD, CADD, CG, CAE, AD and hundreds of others spawned by the computer revolution began to be

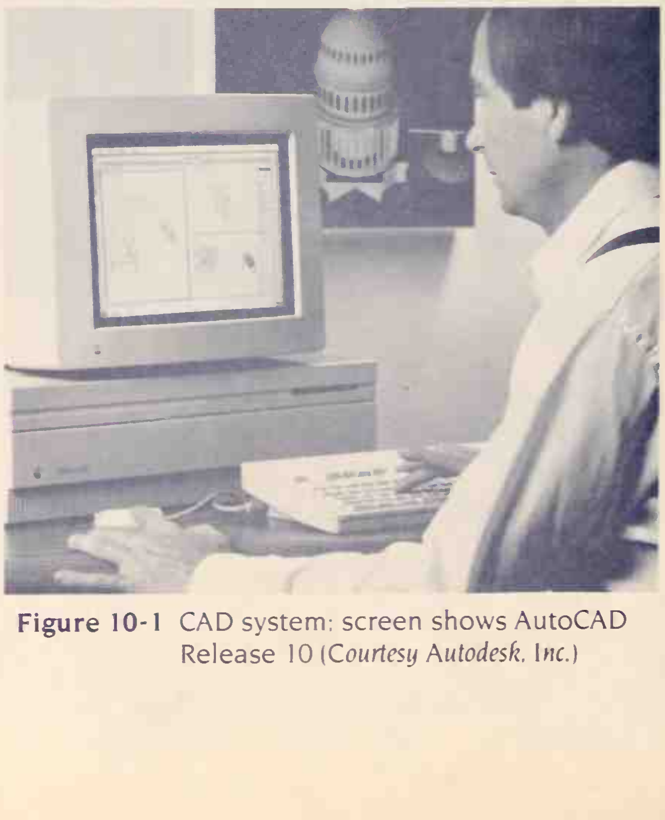


Figure 10-1 CAD system: screen shows AutoCAD Release 10 (*Courtesy Autodesk, Inc.*)

heard in drafting and design departments. As a result, drafting and design practitioners found themselves confused by it all.

The reader should be conversant in the language of computers as it applies to design and drafting. The first step is to develop an understanding of the term "computer-aided drafting" or CAD.

Before attempting to form a definition for CAD, the definition of "drafting" should be thoroughly understood. Most people think of drafting as simply the drawing of plans. True, drafters do draw plans. However, this is a very limited definition because drafters do much more than draw plans.

To understand drafting in its broadest sense, one must begin with the design process. The *design process* is an organized, systematic procedure used to accomplish a design that is needed to solve a problem or meet a need, Figure 10-2. Each step in the design process requires various types of documentation, such as sketches, preliminary drawings, working drawings, calculations, bills of material, parts lists, and schedules.

Producing or "drafting" this documentation is the job of the drafter. Therefore, *drafting* means producing the documentation required in support of the design process. With this understanding of drafting as a concept, one may now begin to develop an understanding of CAD. *Computer-aided drafting* or CAD means using the computer and peripheral devices in producing the documentation needed in support of the design process. Put another way, CAD means using the computer and peripheral devices to do drafting.

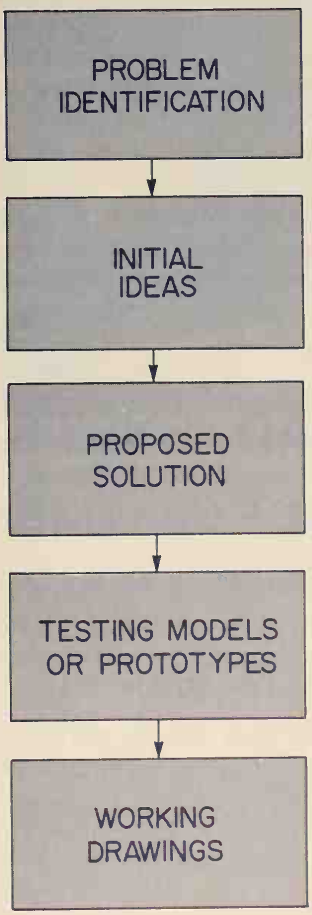


Figure 10-2 The modern design process

A well-informed drafter should be able to distinguish CAD from among the various other related terms frequently heard in modern drafting settings, such as AD, CADD, CAE, CG, and CAM.

CAD is usually taken to mean computer-aided drafting, but it can also be used to mean *computer-aided design*. It is up to the person using the term to make the distinction. AD means *automated drafting*, and it is synonymous with CAD or computer-aided drafting. Originally, AD was used when referring to the use of the computer to do drafting, and CAD was used when referring to the use of the computer as a design tool. However, AD did not catch on because it is a less distinctive term than CAD. Consequently, CAD began to be used to mean both computer-aided drafting and computer-aided design.

CADD is the acronym for *computer-aided design and drafting*. This is a broad concept in which a computer system is used for both design and drafting.

CAE is the acronym for *computer-aided engineering*. This is a newer term that is replacing the term CAD when it is used to mean computer-aided design. The term CAE serves to eliminate the computer-aided design/computer-aided drafting confusion when using the term CAD.

CG is short for *computer graphics*. This is a term that is used and misused a great deal. It is frequently used in place of CAD (drafting). However, in reality, it is a much broader term. CG means using the computer and peripheral devices for producing any type of graphic image, technical or artistic.

None of these terms has been formally standardized. However, there is a definite trend toward greater use of CAD when speaking of drafting, and CAE when speaking of design. CADD is the more general term used when speaking of both.

The manufacturing equivalent of CAD is *computer-aided manufacturing* or CAM. CAM refers to computer-controlled automation of the various manufacturing processes used in modern industry. CAD/CAM is the ultimate in productivity improvement because it links together the processes of design, drafting, and manufacturing. The CAD/CAM process involves designing a product on the computer, using the computer to produce necessary documentation, and using the data base stored in the computer from the design and drafting phases to issue the manufacturing instructions to automated machines and industrial robots.

Differences between Manual Drafting and CAD

The techniques used by manual drafters in documenting a design include freehand lettering, manual scaling, and mechanical line work. CAD technicians accomplish these same tasks by interacting with a keyboard, graphics display, text display, digitizer, and function menu, Figure 10-3.

Another important difference between manual drafting and CAD is in the methods used for storing design documentation. Manual drafters store drawings in large flat files. Calculations, parts lists, bills of material, and schedules are normally stored in folders in filing cabinets. CAD technicians store all design documentation on magnetic tapes or disks, Figures 10-4 and 10-5.

Figure 10-3 Tools of the CAD technician (*Courtesy VersaCAD Corporation*)

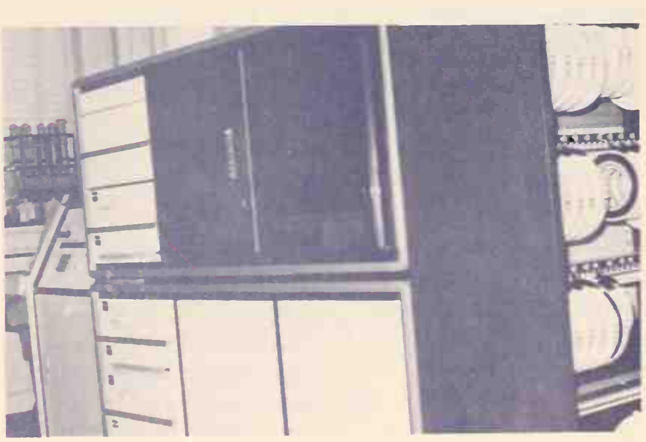


Figure 10-4 Storage on magnetic tape (*Courtesy Clinton Corn Processing Co.*)

Figure 10-5 Magnetic disk storage (*Courtesy Autodesk, Inc.*)

Computer-Aided Drafting Systems

CAD *system* is one of the most frequently heard terms in modern drafting rooms. People who use this term are usually referring to a configuration of computer hardware or the tools of the CAD technician. However, this is a misuse of the term. CAD hardware is only one of three components which must be present in order to have a CAD system.

A CAD system actually consists of hardware, software, and users, Figure 10-6. A collection of CAD hardware is properly referred to as a *hardware configuration*. In order to turn a hardware configuration into a CAD system, software and well-trained users must be added.

CAD SYSTEM =

HARDWARE + SOFTWARE + USERS

Figure 10-6 Components of a CAD system

CAD Hardware

Hardware is the term given to the computer's physical equipment or devices. Many different companies manufacture CAD hardware. Consequently, numerous configurations are on the market. However, a typical hardware configuration consists of a graphics display, a keyboard, a text display, a digitizer equipped with either a light pen or a puck, function menus, a plotter, and a processor, Figure 10-7.

Figure 10-7 Typical hardware configuration (*Courtesy Micro Control Systems Inc.*)

The Graphics Display

The *graphics display* is an output device resembling a television that displays the data on which the CAD technician is working. As a drawing or any other type of documentation is created, it is displayed on the screen of the graphics terminal, Figure 10-8.

Figure 10-8 Viewing the display on a graphics terminal (*Courtesy Autodesk, Inc.*)

There are three types of graphics displays: 1) refresh displays, 2) raster displays, and 3) storage tube displays. In a *refresh display*, the image is traced on the back of the screen by an electron beam. This image must be constantly retraced or "refreshed." *Raster displays* create images by illuminating *pixels* (picture elements) on the screen. The more pixels available on the screen for illumination, the higher the quality of the image. *High resolution* produces a high-quality image. *Storage tube displays* create images by tracing them on the back of the display screen with an electron beam like refresh displays. However, unlike refresh displays, storage tube images are stored and do not have to be refreshed. Graphics displays may be color or monochrome (amber or green) devices.

The Keyboard

The keyboard is one of the most frequently used input devices in a CAD system. *Keyboards* are used for entering text, system commands, X-Y or X-Y-Z coordinates, and any other type of alphanumeric input.

Most CAD systems have keyboards which contain both the standard alphanumeric keys and special auxiliary keys, Figure 10-9. The special auxiliary keys may be part of a separate numeric pad or a group of display control keys.

Figure 10-9 Typical keyboard (*Courtesy Micro Control Systems Inc.*)

The Text Display

The *text display* is an output device with a screen for displaying user prompts, instructions, and other alphanumeric data. Most text displays are noncolor cathode-ray tube (CRT) devices.

The Digitizer

The *digitizer* is a special electromechanical input device that resembles an electronic tablet. In fact, the digitizer is frequently referred to as the *tablet*. Some CAD systems have digitizers that are as small as tablets, and some have digitizers that are as large as conventional drafting tables, Figures 10-10 and 10-11.

A digitizer can be used for a number of different functions. It can be used in conjunction with a light pen or a puck to control the screen cursor, Figure 10-10. A *cursor* is the small crosshairs symbol on the graphics display used in creating, locating, and manipulating graphic and alphanumeric data.

A digitizer can be used as a place to mount menus for giving system commands or calling up stored symbols from memory. It can also be used for electronically tracing (digitizing) graphic data so that they can be entered into a CAD system.

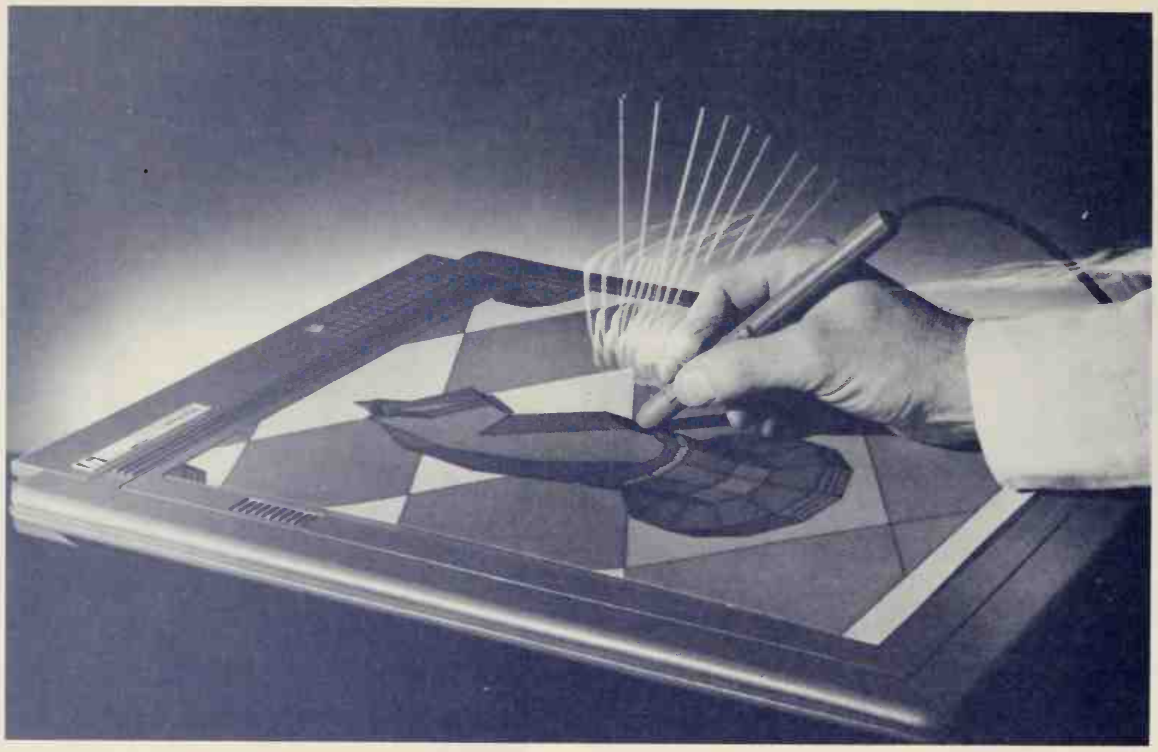


Figure 10-10 An example of using a digitizer as a drawing tablet (*Courtesy* Houston Instru*ment* Division, AMETEK, *Inc.*)

Figure 10-11 Complete hardware configuration with large digitizing table (*Courtesy* Auto-Trol *Technology Corp.*)

Function Menus

Menus are lists of system commands and stored data, or overlays that serve the same purpose, which correspond with storage locations in a CAD system's memory. They are used as a means of speeding and simplifying human interaction with the CAD system. One of the fastest, easiest ways to enter a system command is to have the command on a menu. Just as you need a menu when you sit down in a restaurant so that you know what options you have for ordering, you need a menu when you sit down at a CAD system so that you know what options you have for commanding the system.

The most frequently used types of menus are *screen-displayed menus* and *tablet-mounted menus*. A command on a screen-displayed menu may be activated by touching it with a light pen, moving the screen cursor to its location on the screen, or pressing a key that corresponds with the command. Tablet-mounted menu commands are activated by touching the appropriate position on the menu with a light pen or the sight of the puck, Figure 10-12.

In addition to system commands, menus may contain frequently used symbols or items of graphic data. If a certain symbol is used frequently, it may be created once, saved, and assigned to a specific position on a menu. Then, when needed, it can be called up from storage in a matter of milliseconds rather than having to be completely redrawn each time it is needed on a drawing.

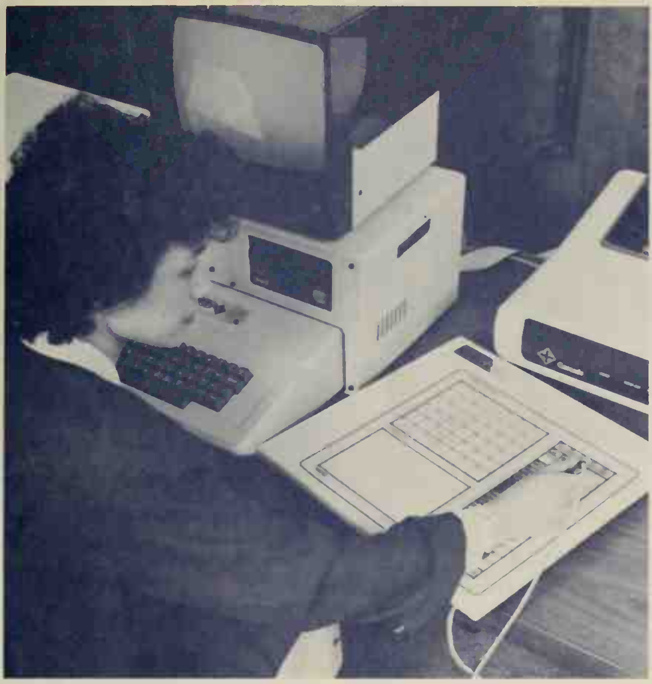


Figure 10-12 Activating menu commands (*Courtesy Cascade Development Corp.*)

The Plotter

The *plotter* is the output device which actually draws (plots) drawings and other types of documentation. Three types of plotters are used in CAD systems: pen plotters, electrostatic plotters, and photoplotters.

Pen plotters may be bed plotters or drum plotters. They create drawings by converting into lines X-Y coordinates received from the processor in the form of electrical impulses. Pen plotters are rated according to their accuracy, repeatability, resolution, and plotting speed. Most pen plotters can plot drawings accurately to plus or minus .001" or better.

Repeatability in plotting is the ability to redraw lines without creating a double image. This is important because on many plotters line thickness or density is increased by retracing lines until the desired density is achieved.

Resolution in plotting is judged by the shortest line segment the plotter is able to plot. This becomes a critical factor when plotting circles, arcs, and curves, all of which are formed by a series of short, straight-line segments. The shorter the line segments, the better the resolution. Resolution of .001" is common for pen plotters. A *plotting speed* of 40 inches per second is a common, and frequently exceeded, mean plotting speed with modern plotters.

Electrostatic plotters are much faster than pen plotters, but they are not as accurate and they require special electrostatic paper. This type of plotting paper is not dimensionally stable; a factor which limits the applications of electrostatic plotters.

Photoplotters are used in those situations requiring extremely close tolerances and dimensional stability, such as in the production of printed circuit board (PCB) artwork. Of the three types of plotters, the pen plotter is the one most frequently used.

The Processor

The *processor* is the computer in a computer-aided drafting system. As in any computer, processors have a memory component and a logic component. In addition, many CAD system processors have an added feature: a graphics processor, Figure 10-13.

A processor's memory is rated according to the amount of data it can hold. Individual memory location sizes are rated in *bits* or binary digits. This is why some processors are referred to as 8-, 16-, or 32-bit processors. An 8-bit processor is slower than a 16- or 32-bit processor. The 32-bit processor is the fastest.

Overall memory size is rated in *bytes* (the commonly accepted ratio is 1 byte = 8 bits). Because a byte represents a relatively small amount of data, memory sizes are usually given in kilobytes. A 256-kilobyte memory would not be uncommon in a CAD system's processor.

The term *kilo* normally means 1000. However, when used in conjunction with computers, it means 1024. To determine the actual size of a 256-kilobyte processor, multiply $1024 \times 256 = 262{,}144$. To convert this to bits, multiply $262{,}144 \times 8 = 2{,}097{,}152$.

The processor console also houses a disk or tape drive unit for secondary storage devices such as disks, diskettes or magnetic tapes.

CAD Software

Software is the name given to the various programs that actually make the CAD system work, and any printed materials such as instruction sheets or operator's manuals, for instance. There are three basic types of software for CAD systems: 1) operational software; 2) application software; and 3) user-defined software.

Operational software consists of programs which make the system perform general operational tasks such as accepting commands, storing data, retrieving data, and so forth.

Application software consists of programs that command the CAD system to perform drafting functions in such specific application areas as architectural, mechanical, structural, electronic, and civil drafting.

User-defined software usually is restricted to such various user-specific needs as symbols that are added to a symbols library and a menu. Users do not normally write the code for CAD software.

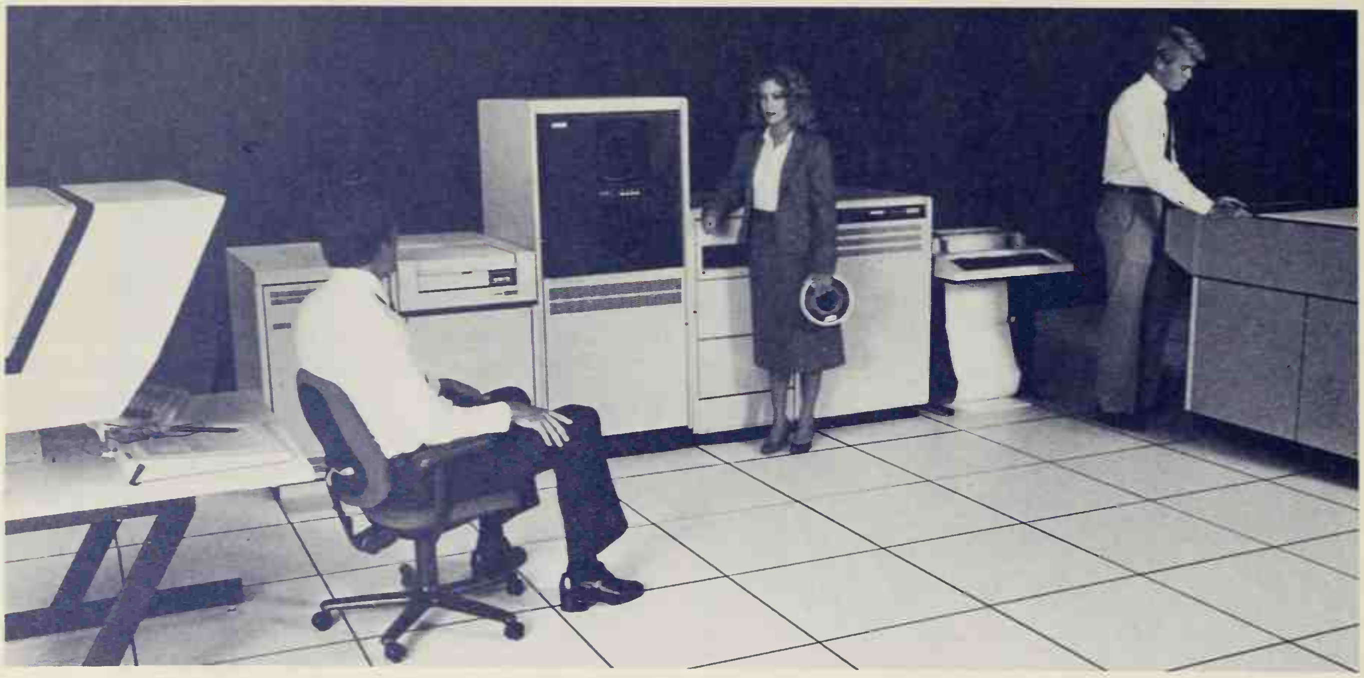


Figure 10-13 One type of graphics processor (*Courtesy Calma Company*)

CAD Users

Users of CAD systems can be placed in two categories: 1) CAD system operators, and 2) CAD technicians. CAD *operators* are people who are able to operate a CAD system in terms of inputting, manipulating, and outputting data. However, they have little or no background in design, drafting or engineering.

CAD *technicians*, on the other hand, have both system operational skills and strong backgrounds in design, drafting or engineering. For CAD technicians, a CAD system is simply a tool to help them do their jobs faster and better.

Modern CAD System Configurations

There are more than 100 turnkey CAD systems on the market now, and the list will probably continue to increase. Some are general-purpose systems which can be used in a number of different drafting fields. Others are dedicated systems designed for one specific application.

Modern CAD systems range from systems based on large mainframe computers to small microcomputer-based configurations. Figure 10-14 shows an example of a modern CAD system.

Advantages of CAD

The applications of computer-aided drafting grew rapidly because of its many advantages over manual drafting. CAD is being used in a variety of settings in both large and small companies. When compared

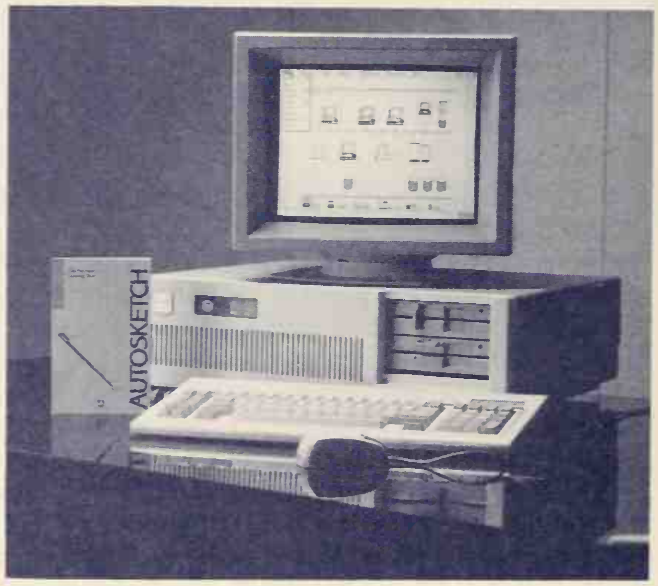


Figure 10-14 Modern CAD system (*Courtesy Autodesk, Inc.*)

with manual drafting, CAD is more accurate, faster, neater, more consistent, and better in terms of storing, correcting, and revising drawings, Figure 10-15.

CAD hardware is consistently accurate to better than .001 inch. Manual scaling and drawing cannot match this figure consistently, even under the most positive conditions. In fact, inaccuracy is a built-in human characteristic. Such typical drafting tasks as lettering and line work are slow and tedious for manual drafters; but, for CAD technicians, they are fast and easy because they are accomplished by simply pressing buttons and executing commands.

MORE ACCURATE
FASTER
NEATER
MORE CONSISTENT
BETTER STORAGE
EASIER CORRECTIONS
EASIER REVISIONS

Figure 10-15 Advantages of CAD

The computer actually does the work for the person and it does it very fast. Using the computer, a drafting technician can produce lettering as much as 25 times faster than by doing it manually. A drafting technician with typing skills can improve on this figure considerably.

Whereas a manual drafter might draw at an average rate of four to eight inches per minute, it is not uncommon for a CAD system's plotter to create drawings at a rate of 40 inches per *second*.

Neatness and consistency in line work and lettering are the major weaknesses of manual drafting and the major strengths of CAD. Since documentation in CAD is produced electromechanically, it is not subject to the negative impact of such factors as fatigue, boredom or a lack of skills. Figures 10-16 and 10-17 illustrate the neatness and consistency that is characteristic of documentation prepared on a CAD system.

Some of the most important advantages of CAD can be found in the area of corrections and revisions. On the job, a great deal of time is devoted to correcting and revising drawings and other types of documentation. Time spent correcting and revising documentation is nonproductive time. Because of the drawing manipulation capabilities of CAD systems (for instance, such command functions as MOVE, COPY, DELETE, ROTATE, and ZOOM), correcting and revising time can be cut by as much as 75 percent in many cases. The time and work-saving potential of CAD in terms of corrections and revisions is even more important than that associated with the original creation of design documentation.

An additional advantage of CAD over manual drafting involves storage of documentation. In CAD, one 5.25-inch floppy disk might hold as much documentation as a large file drawer. With CAD, years of drafting work can be stored in a container the size of a shoe box. Backup disks or copies of file disks can be made quickly, easily, and inexpensively, and stored in protective containers. Thus, the deterioration problems normally associated with traditional drafting media are eliminated.

MicroCADD

In the early 1980s a development known as "microCADD" began to revolutionize the fields of design, engineering, and drafting. MicroCADD, sometimes referred to as PC-CADD, means design and drafting accomplished using microcomputers. Both terms, microCADD and PC-CADD, are acceptable. However, caution is in order when using these terms. The problem stems from the fact that although PCs (personal computers) are all microcomputers, not all microcomputers are PCs. Further, not all PCs are capable of design and drafting applications.

Most microcomputers used in design and drafting applications have at least 512K bytes of RAM or more. They also have high-resolution monitors and dual-disk-drive configurations. Many are configured with a hard disk and one floppy drive.

MicroCADD in the Beginning

The rapid growth of microCADD is relatively new, but microCADD itself is not. There have been microCADD systems in use since the late 1970s. However, these earlier systems were seriously lacking in real design and drafting capabilities. Early microcomputers had neither the processing power nor the graphic capabilities needed in CADD. Consequently, microCADD got off to a bad start.

Early microCADD systems were slow, limited to only the most basic two-dimensional drafting tasks, and able to produce documentation of only marginal quality. Such systems were thought of as being "toys" and, for the most part, were rejected by the private sector.

For the most part, the problems associated with early microCADD systems grew out of problems with early microcomputers. Before microCADD could become a real alternative for companies that wished to convert to CADD but could not afford traditional systems, two things had to happen.

1. Development of the microcomputer had to reach the point where more memory and better processing speeds were available.
2. Development of the microcomputer had to reach the point where better graphic capabilities were available.

By the early 1980s both of the developments had taken place. More powerful 16-bit microcomputers were available. Microcomputers with 512K bytes of RAM became commonplace. Dual-disk-drive configurations or a combination hard disk with one floppy disk drive also became the norm. High-resolution color monitors became readily available at affordable prices. These developments paved the way for the acceptance of microCADD.

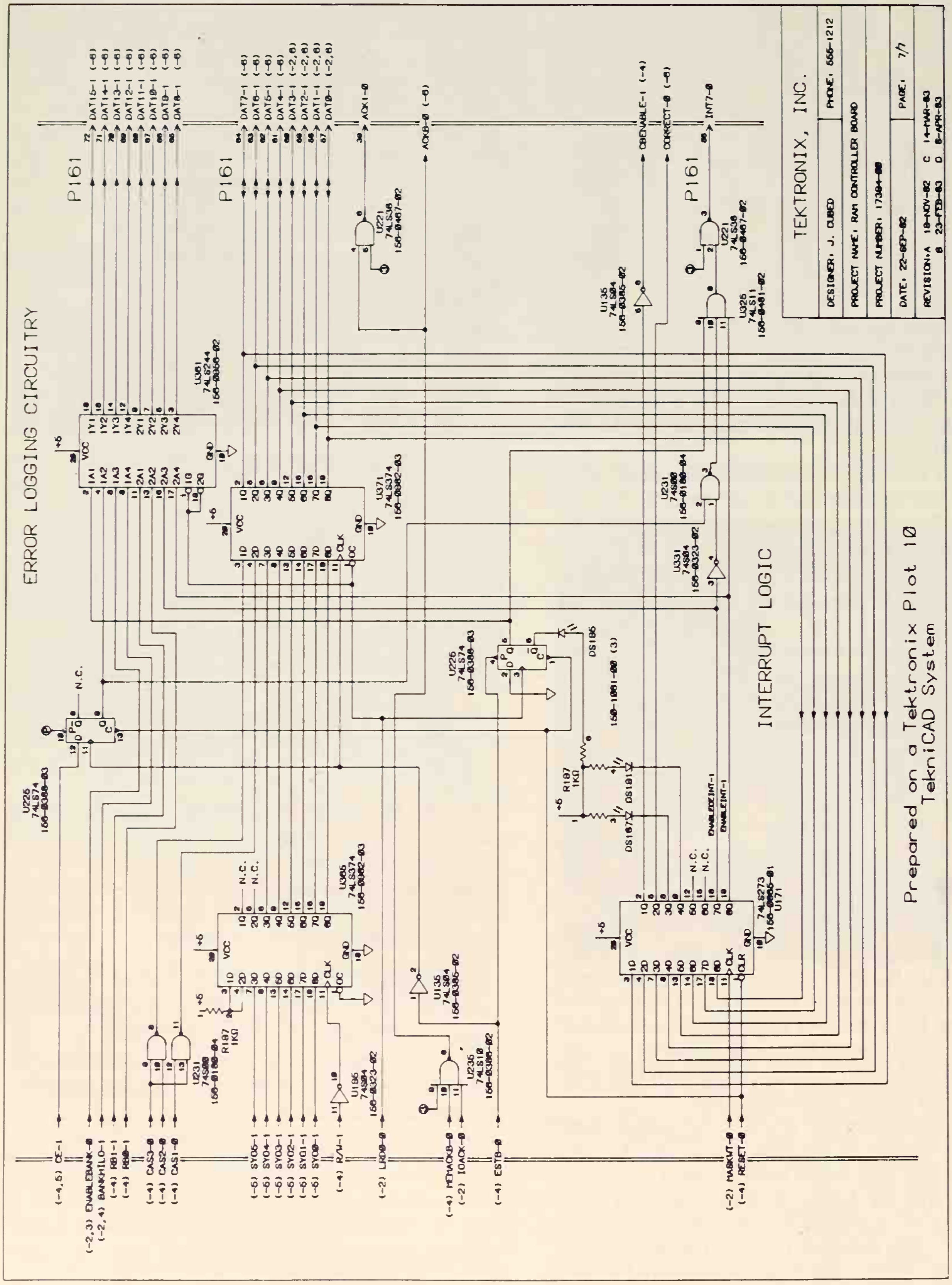


Figure 10-16 Drawing produced on a CAD system (*Courtesy Tektronix, Inc.*)

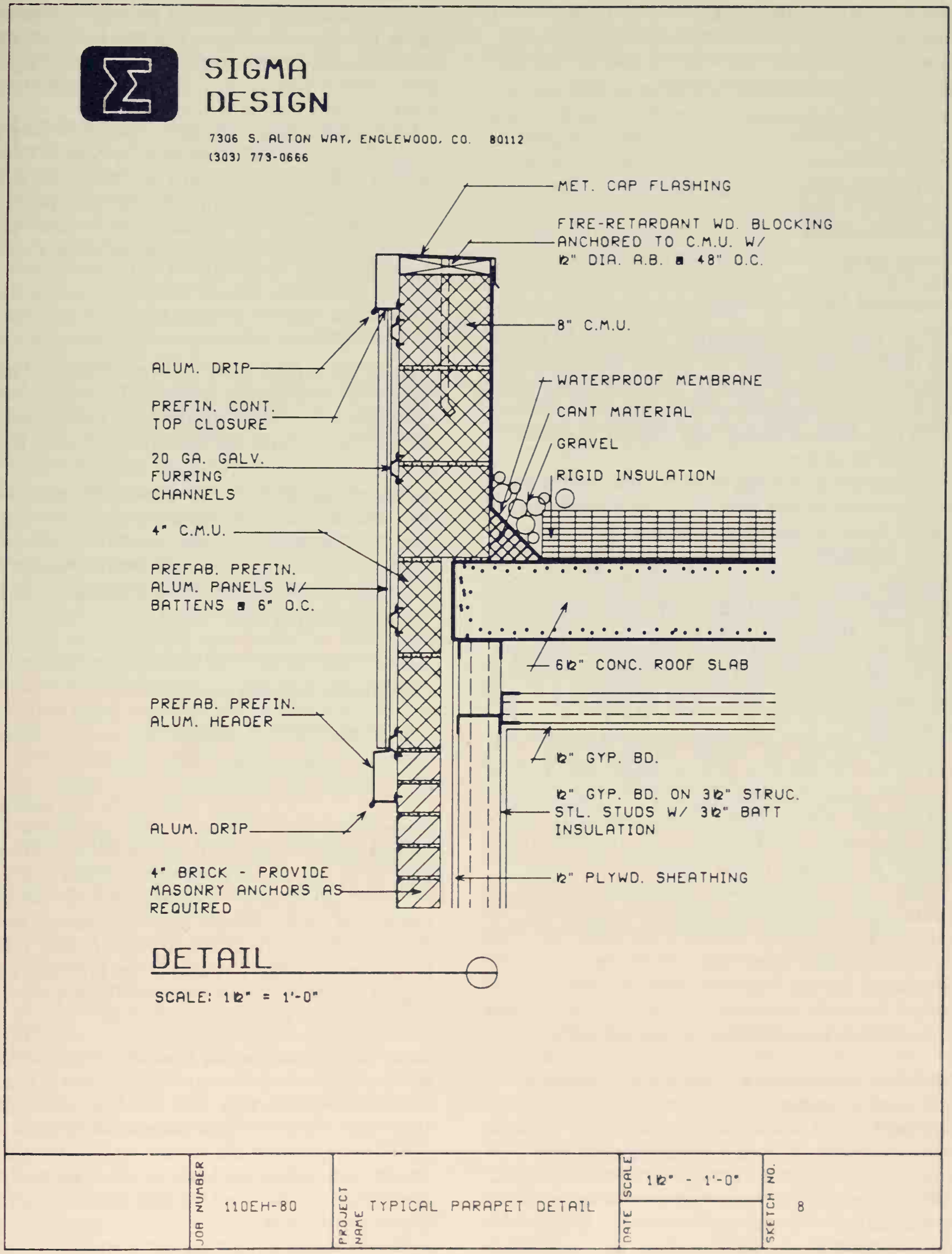


Figure 10-17 Drawing produced on a CAD system (*Courtesy Sigma Design*)

Advantages of MicroCADD

MicroCADD can be compared with both manual design and drafting and traditional CADD. When making such comparisons, one will find that microCADD offers users five major advantages.

1. Increased productivity
2. Low cost
3. Easy learning and use
4. Convenience
5. Versatility

Increased Productivity

If one compares microCADD with manual design and drafting techniques, increased productivity is probably its principal and most important advantage. The degree of improvement in productivity of microCADD over manual design and drafting depends on a number of factors.

Such factors as the application area and the skills and creativity of the user must be considered, of course. However, speaking in general terms, one can expect productivity ratios (of microCADD to manual drafting) from 3:1 to 5:1 in such applications as mechanical, manufacturing, construction, or architecture. If the application area is electronic, electrical, survey, civil engineering, or any other single-line symbol or schematic-oriented type of design and drafting, productivity ratios of from 5:1 to as high as 10:1 can be expected.

There are a number of reasons why microCADD is a more productive approach to design and drafting than manual techniques. Some of the more important reasons are: (1) faster data creation; (2) faster data manipulation; (3) faster, more convenient data storage; and (4) faster data output.

Some of the reasons why documentation can be created faster on a CADD system than manually are obvious. For example, even a slow typist can type text considerably faster than he or she could produce neat, legible freehand lettering. The same is true of linework. However, the greatest advantage with regard to creating graphic data probably comes from the concept of "nonrepeatability." Nonrepeatability means that once a symbol or any other type of geometric character is produced, it never has to be produced again. Once produced, it can be stored in primary storage or a secondary storage device, or in a menu, then called up and used repeatedly.

The principal time-saving factor in microCADD as compared with manual drafting comes in the manipulation of graphic data. Two of the most time-consuming tasks in manual design and drafting are correcting and revising the documentation for designs. Because of the editing capabilities of a microCADD system—as well as such standard manipulation functions as mirror, rotate, scale, move, and copy—corrections and revisions can be made quickly and easily. The manual drafter is not able to call up standard symbols or other graphic configurations, rotate them, mirror them, move them, scale them up or down, or copy them a number of times.

Additional productivity gains come from the storage advantages of a microCADD system. It is much simpler and faster to call up a file containing a drawing or drawings from computer storage than it is to rummage through file drawers, locate drawings in question, and pull them out of the drawer without damaging them.

Lower Costs

When low cost is used as an advantage of microCADD, the comparison is generally between microCADD and the larger traditional CADD systems. MicroCADD systems are less expensive than the traditional large systems that are based on mini- and mainframe computers. The most obvious reason for the difference in prices, of course, is the lower initial cost of a microCADD system compared with a traditional system. However, as indicated below, lower initial costs represent only one of the reasons.

1. Lower initial cost
2. Lower maintenance costs
3. Shorter payback period
4. Fewer facility adaptations
5. Less user training

Lower Initial Cost. The price of a traditional CADD system might range from as low as $25,000 to as high as $3 million, or even higher. From $50,000 to $150,000 would be the medium range for the typical traditional CADD system. The medium range for a typical microCADD system is only $10,000. It is this initial low cost that represents the principal advantage of microCADD in the minds of most people who must justify an investment in CADD.

Lower Maintenance Costs. Like the initial costs, the maintenance costs for microCADD are lower than those associated with traditional CADD systems. Users typically purchase maintenance agreements on CADD systems from the vendor. In this way the vendor is responsible for keeping the system in good operating condition and for repairing it quickly when breakdowns occur.

Maintenance agreements vary significantly among vendors, depending on the application and a variety of other factors. However, a traditional CADD system that costs in the $250,000 range may have a maintenance agreement that costs as much as $50,000. This cost must be added to the yearly cost of the system. On the other hand, a $10,000 microCADD system might have a maintenance agreement that costs as little as $500 a year. A figure of 15% of the purchase price is a good rule of thumb.

Shorter Payback Period. One of the principal costs of doing business is the cost of money, or the interest rate that must be paid on borrowed money. Whether purchasing a traditional CADD system or a microCADD system, a business is probably going to borrow the money and, consequently, pay interest on a loan. In this case the advantage of microCADD is that the payback period is shorter. Consequently, the total amount of interest paid on the loan will be less. The interest rate itself may also be less as a result of the shorter payback period. Managers who must justify a CADD conversion are particularly appreciative of this advantage because it represents considerably less risk on their part than would a traditional CADD conversion.

Fewer Facility Adaptations. Most microCADD systems will fit on top of the average desk and occupy very little space. This is not true of traditional CADD systems. Typically, traditional CADD systems will require a number of facility adaptations in order to be properly accommodated. These facility adaptations include such things as the installation of additional electrical outlets, built-up flooring, climate control, and dust control adaptations. MicroCADD systems, on the other hand, rarely require facility adaptations. Although there are vendors that manufacture special furniture for microcomputers and microCADD systems, special furniture is not a necessity when converting to microCADD.

Less User Training. It can take from six months to a year to become proficient in the use of a traditional CADD system. The training time required to learn to operate a traditional system will vary because the systems vary in size and degree of complexity. However, traditional CADD systems are more sophisticated, more complex, and hence more difficult to learn to operate than microCADD systems. This means (1) that users spend more time in a learning mode than in a productive mode during the initial phase of a CADD conversion, and (2) that the initial productivity curve will probably go down to a level below that of the manual format.

MicroCADD systems, on the other hand, tend to be simple and easy to learn and operate. An experienced engineer, architect, designer, or drafter can expect to be reasonably skilled in operating a microCADD system within a matter of a few days or a week. This shortens the amount of time users spend in a learning mode and, in turn, the amount of time that the productivity curve will remain below the level prior to the conversion.

Convenience

MicroCADD systems are more convenient than traditional CADD systems in several ways. The first and possibly most important way is that they are more convenient to purchase. Whereas most traditional CADD systems must be purchased directly from the specific vendors that manufacture and market them, microCADD systems may be purchased directly from vendors, indirectly through computer stores, or even by mail order. Frequently, a microCADD software package may be run on a microcomputer that already exists in a firm. Whereas a traditional CADD system requires a separate workstation for the operator, a microCADD system can fit easily and conveniently on most office-size desks. MicroCADD systems are light and portable. Consequently, they are easily moved and accommodated.

Versatility

One of the most important advantages of a microCADD system is its versatility. A microCADD system may be used for standard design and drafting tasks, but it is not limited to these tasks. MicroCADD systems can be used for all of the many other purposes to which microcomputers are often put. Of course, the most important and most frequent use of microCADD systems is in performing such traditional design and drafting functions as design analysis, solid modeling, finite-element analysis, kinematics, and two- and three-dimensional drafting.

In addition to the design and drafting uses of microCADD systems, there are other uses, such as project management, office automation, electronic spreadsheets, decision support, and data base management. All of these capabilities are within the realm of what a microCADD system can do for users.

Limitations of MicroCADD

The advantages of microCADD presented in the preceding section paint a rosy picture. However, as is always the case, there is a price to pay in trade-offs for the advantages gained from microCADD. MicroCADD is not without its limitations. Some of the most serious limitations are: less memory, less processing potential, project size limitations, lack of a common data base among microCADD systems within the same organization, limited output potential, less vendor support, and fewer operating capabilities.

Less Memory and Processing Potential

It goes without saying that microcomputers have less memory than the minicomputers and mainframe computers on which traditional CADD systems are based. This is one of the principal reasons why they cost less. With less memory, microCADD systems are restricted to less complex design and drafting tasks. Traditional CADD systems can handle large projects involving such complex tasks as finite element analysis, surface modeling, and solid modeling. MicroCADD systems also can handle these tasks on a more limited basis, but they are better suited for two-dimensional drafting applications, wireframe three-dimensional applications, and smaller engineering projects.

Depending on the tasks being performed and the individual circumstances of the job, microCADD systems usually process data more slowly than do traditional CADD systems. This is because most microCADD systems are based on 16-bit computers, whereas traditional CADD systems are based on 32- or even 36-bit computers. This means that microCADD systems can retrieve data from memory in smaller amounts at a time.

Project Size Limitations

Because of the memory and processing speed limitations of microCADD systems, they are restricted to handling smaller projects than traditional CADD systems. Some design projects, particularly those that would involve solid modeling, surface modeling, or finite element analysis, contain too much data to be performed efficiently on a microCADD system. Such projects would either overburden the microCADD system's memory or, at the least, slow down the system significantly. It is conceivable that a design project that could be handled in a matter of minutes or hours by a traditional CADD system might take a microCADD system all day or even several days. For this reason, microCADD systems are best used on smaller design and drafting projects.

Lack of a Common Data Base

In a traditional CADD system, all of the users at each individual workstation are tied into the same mini- or mainframe computer. Consequently, they share a common data base and each user is able to access the data of the other users. This allows for one of the most important advantages of CADD over manual drafting—networking. In a networked system, one checker sitting at one workstation can access the jobs being worked on by several designers and drafters working at other workstations. In this way, he or she is able to monitor their work, check the work as it progresses, and make corrections as needed.

The lack of a common data base in microCADD systems does not allow for networking. Each microCADD system is an independent stand-alone system with its own memory. Consequently, a person sitting at one microCADD terminal has no way to access on-line the data being processed by a user sitting at another microCADD station. This is a serious problem that microCADD vendors are working to solve.

The local area network (LAN) is being looked to as a solution to this problem. LANs tie a specified number of microcomputers together, affording users the same networking capabilities now available to traditional CADD users.

More Limited Output Potential

There are a variety of different types of hard-copy output devices that can be used with CADD systems. These include flatbed pen plotters, drum pen plotters, electrostatic plotters, photoplotters, printers, and printer/plotters. At this point in the development of microCADD technology, most microCADD systems are limited to a pen plotter, printer, and printer/plotter. Additionally, some of the models of pen plotters developed specifically for use with microCADD systems have a lower resolution rating than those typically used with traditional systems. This has a minor but nonetheless negative effect on the quality of the output.

Less Vendor Support

When purchasing a traditional CADD system, there is typically a great deal of vendor support in the form of installation, setup, testing, debugging, maintenance, troubleshooting, repair, and employee training. This is not always the case with microCADD. With microCADD systems, it is often the responsibility of the buyer to install the system, set it up, get it operating, and call for help if debugging is necessary.

The contact people for traditional CADD systems are typically more knowledgeable of CADD and the individual user's needs than are those associated with microCADD vendors. The contact person for a microCADD vendor will typically be a sales or marketing person who may know little about the actual installation and operation of the CADD system that he or she is selling, and even less about the needs of the individual user. Because the profit margin on a microCADD system is less than that of a traditional CADD system, vendors are not able to offer buyers as many services as are the traditional vendors.

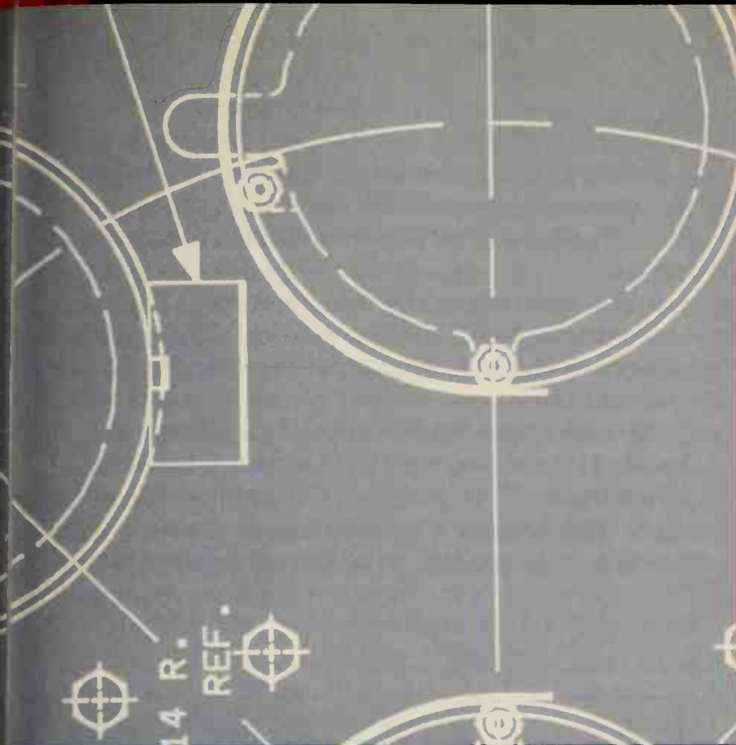
Fewer Operating Capabilities

A great deal of work goes into making traditional CADD systems as "user friendly" as possible. Consequently, there are a number of user-friendly operating functions built into the system. These are special functions that users can call on when confused or in need of clarification as to how best to handle a given situation. Such functions allow them to find the help they need without having to leave the system and go to other forms of documentation, such as technical manuals or user manuals.

In addition, because the programs for traditional CADD systems are more sophisticated, users are frequently able to accomplish a given task by pressing only one keyboard character or entering only one menu command. MicroCADD systems, on the other hand, do not typically contain the wide variety of user-friendly functions found in traditional CADD systems. Additionally, with microCADD systems users generally have to enter a series of commands or a number of keystrokes in order to accomplish the same task that a traditional system could accomplish with just one such movement.

Review

1. Explain how CAD changed the design process.
2. Define the term *drafting*.
3. Define the term *computer-aided drafting*.
4. What do each of the following acronyms stand for? CAD, AD, CADD, CAE, CG, CAM.
5. What are the most obvious differences between CAD and manual drafting?
6. List the typical tools of the CAD technician.
7. How do CAD technicians store design documentation?
8. What three components must be present in order to have a CAD system?
9. What are the components in a typical CAD hardware configuration?
10. What are the three types of graphics displays?
11. Name two categories of keys found on CAD system keyboards.
12. What does CRT stand for?
13. Explain three uses of a digitizer.
14. What is a function menu?
15. Name two different types of function menus.
16. Name three different types of plotters used in CAD systems.
17. What is the processor? Name its two most important components.
18. Name three types of CAD software.
19. List five advantages of CAD over manual drafting.
20. How will CAD affect your future as a drafting technician?



CHAPTER 11

This chapter covers the typical operations used in producing technical drawings on a modern CAD system. The major topics covered are general system operation, input commands, manipulation commands, and output commands. Students will develop a basic understanding of how to operate the modern CAD systems available in the workplace. Problems are provided at the end of the chapter for those who have a CAD system available.

COMPUTER-AIDED DRAFTING OPERATIONS

The tools of the CAD technician, as discussed in Chapter 10, consist of the keyboard, graphics display, text display, digitizer with puck or light pen, function menu, and plotter. The technician uses these tools in the three phases of producing design documentation in CAD: inputting data, manipulating data, and outputting data.

The basic operation of any computer system includes input, processing, and output. However, the processes involve actual human interaction to ensure that these drafting tasks are accomplished in the desired format. The computer or processor performs the processing tasks. To use a CAD system as a tool in producing the documentation for the design process, the drafter must first develop some basic operational skills, the subject of this chapter.

General System Operation

Just as one must learn how to manipulate pencils, pens, triangles, templates, and various other tools before using them to perform manual drafting tasks, one must also learn a number of general system operational skills before using a CAD system to perform drafting tasks. These general skills include: keying, digitizing, cursor control, entering system commands, and activating menu options.

Keying

Keying is simply typing. Figure 11-1. Although CAD technicians do not have to be accomplished typists, since only a minimum of keying is done on most CAD

Figure 11-1 Keying (*Courtesy Autodesk, Inc.*)

systems, they do need to be familiar with the locations of the various keys on the keyboard.

Keying is the process used for entering text on drawings, entering certain system commands, entering dimensions not entered automatically, and for logging-on to the system.

Digitizing

Digitizing is a process through which graphic data, such as a sketch or a drawing, is converted to digital data as it is input. It involves placing the sketch or drawing on the digitizing tablet and tracing it electronically with a puck. A light pen is sometimes used instead of a puck, Figure 11-2.

When digitizing, it is not necessary to trace an entire line as it is in manual tracing. Rather, the cross hairs in the puck's sight are aligned with the end points of lines and the puck button is pushed. Each time the button is pushed, the computer calculates the X-Y coordinates for that point and stores them in the computer's memory. Consequently, to the computer a drawing is just a series of X-Y coordinates.

Figure 11-2 Digitizing with a light pen (*Courtesy Micro Control Systems Inc.*)

Cursor Control

The CAD equivalent of the point of the drafter's pencil is a small cross-hair symbol on the graphics display called a *cursor*, Figure 11-3. It is used for drawing graphic data, specifying the location of text and graphic data on the display, identifying data that are to be deleted or otherwise manipulated, and for identifying commands on screen menus that are to be activated.

The cursor can be controlled in a number of different ways: with horizontal and vertical thumbwheels; with a trackball or joystick, such as those found on many video games; with a light pen; or with a puck and a digitizing tablet. This last method, puck and digitizing tablet, is the most frequently used method on modern CAD systems.

Figure 11-3 The cursor

Entering System Commands and Activating Menu Options

In manual drafting, drafters do the drawing themselves. However, in CAD, drafters only give commands; the computer actually does the work. Consequently, performing drafting tasks on a CAD system is similar to creating a drawing by giving commands to another drafter.

To simplify this process, all of the many commands needed to communicate with the CAD system are contained in the memory component of the processor. Consequently, CAD technicians need only activate the proper memory location in order to command the system to perform a certain task. Common commands include ARC, CIRCLE, LINE, POINT, TEXT, and so forth.

Each command that is stored in memory is listed on a menu so that CAD technicians know what commands are available to them. The menu may be displayed on the screen of the terminal or drawn on a paper or polyester film overlay and affixed to a digitizing tablet.

To activate a screen-displayed menu option, the CAD technician may touch the option on the screen with a light pen or key the option's code. For example, the menu in Figure 11-4 lists seventeen options. To activate the ARC option, the technician would key the letter "A" on the keyboard and, then, press either the RETURN or ENTER key. Pressing the RETURN or ENTER key is a necessary activation step in most cases when entering commands from a keyboard.

```
ARC
CIRCLE
INSERT:
LINE:-
PLINE:
POINT:
SHAPE:
SKETCH:
SOLID:
TEXT:
TRACE:

DISPLAY
EDIT
LAYERS
MODES

LASTMENU
ROOTMENU
```

Figure 11-4 Sample menu

To activate a tablet-mounted menu command, the technician would align the sight of the puck with the menu position occupied by the option in question, and then press the puck button, Figure 11-5.

Figure 11-5 Activating a menu command with a puck (*Courtesy Deborah M. Goetsch*)

Input Commands

Input commands are those commands given to the CAD system to make it create drawings, parts lists, bills of material, and all of the various other types of documentation associated with drafting. Drawings consist of two types of data: graphic and text.

All graphic data are created using standard geometric shapes in the proper combinations. These shapes include straight lines of different types (i.e. solid, hidden, stitched, and so forth) arcs, circles, curves, rectangles, ellipses and polygons, among others. All text data are created using letters, numbers, and other keyboard characters in combination or separately.

Input commands which cause the computer to create graphic and text data can be stored in a CAD system's memory and assigned to a menu. Figure 11-6 is an example of a screen-mounted menu. These are the commands a CAD technician would use in creating documentation.

```
ROOT
MENU

BLOCKS
DIM:
DISPLAY
DRAW
EDIT
HATCH:
INQUIRY
LAYERS
MODES
PLOT
UTILITY
```

Figure 11-6 Screen-mounted menu

With a menu displayed on the text terminal (Figure 11-6), creating documentation is simply a matter of activating menu commands and following the directions provided in the *prompts* which correspond with each command. However, before getting this far, the CAD technician must first complete such preliminaries as logging-on to the system, calling-up stored work files, and, when necessary, creating new work files.

Logging-on, Calling-up Files, and Creating New Files

Every CAD system has a "log-on" sequence that must be completed in order to gain access to the system. Logging-on prevents unauthorized use of the system. The *log-on sequence* for most CAD systems involves keying answers to questions that are displayed on the text terminal as each step in the sequence is satisfied. For example, after turning on the system, a CAD technician might go through the following procedure:

The following message appears on the text display once the power has been turned on:

WELCOME TO THE MEGADRAFT CAD SYSTEM.
WHAT IS YOUR USER CODE?

Each operator of this particular system has been assigned a user code that only the operator, and perhaps the drafting manager, knows. The code must be entered in order to proceed. Let us say the operator's social security number is used as the code. The operator keys:

276-98-9790

The operator then presses the RETURN key. At this point a new prompt appears on the text display:

OLD OR NEW FILE?

Documentation in CAD is stored in files. Each file has a code or designation that distinguishes it. After deciding to work on an old file, the operator types OLD, and then presses the RETURN key. At this point, a new prompt appears on the text display:

FILE NAME?

Let us say the code for the desired work file is JOB NUMBER 1701. The operator types this and presses the RETURN. A new prompt appears on the text display:

FILE ACCESSED. DO YOU NEED A LISTING OF FILE'S CONTENTS?

This file might contain several drawings, parts lists, and various other types of documentation, each with its own access code. The user may not remember the code of the drawing needed. When this is the case, a listing of the contents of the file can be brought to the text display by pressing the Y key for "yes." When this is done, a complete list of the contents of the subject file will be displayed on the graphics terminal, Figure 11-7.

To call-up one of the items within the file, the user types in its code (say number 1 to see the ASSEMBLY DRAWING) and presses the RETURN key. The subject data will immediately appear on the graphics display.

When the code for the desired data is known, the user indicates that a listing is not required by pressing the N key for "no." When this is done, another prompt appears:

CODE PLEASE

At this point, the user enters the appropriate code and then desired data appears on the display screen.

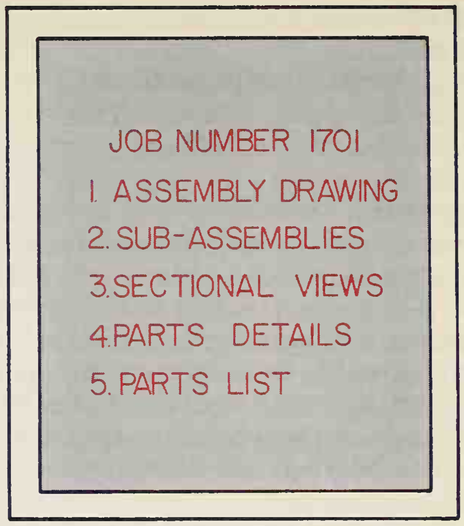


Figure 11-7 File contents displayed on the graphics terminal

In summary, the following is a typical log-on sequence for a CAD system:

WELCOME TO THE MEGADRAFT CAD SYSTEM.

WHAT IS YOUR USER CODE?

Drafter keys response.

OLD OR NEW FILE?

Drafter keys response.

FILE NAME?

Drafter keys response.

FILE ACCESSED. DO YOU NEED A LISTING OF FILE'S CONTENTS?

Drafter keys response.

To create a new file, the operator would press the N key for "new" when confronted by the OLD OR NEW FILE prompt. The operator will then receive a blank graphics display screen on which to begin creating the desired documentation. Now the job is one of activating menu commands and responding to prompts.

Figure 11-8 Making a solid line

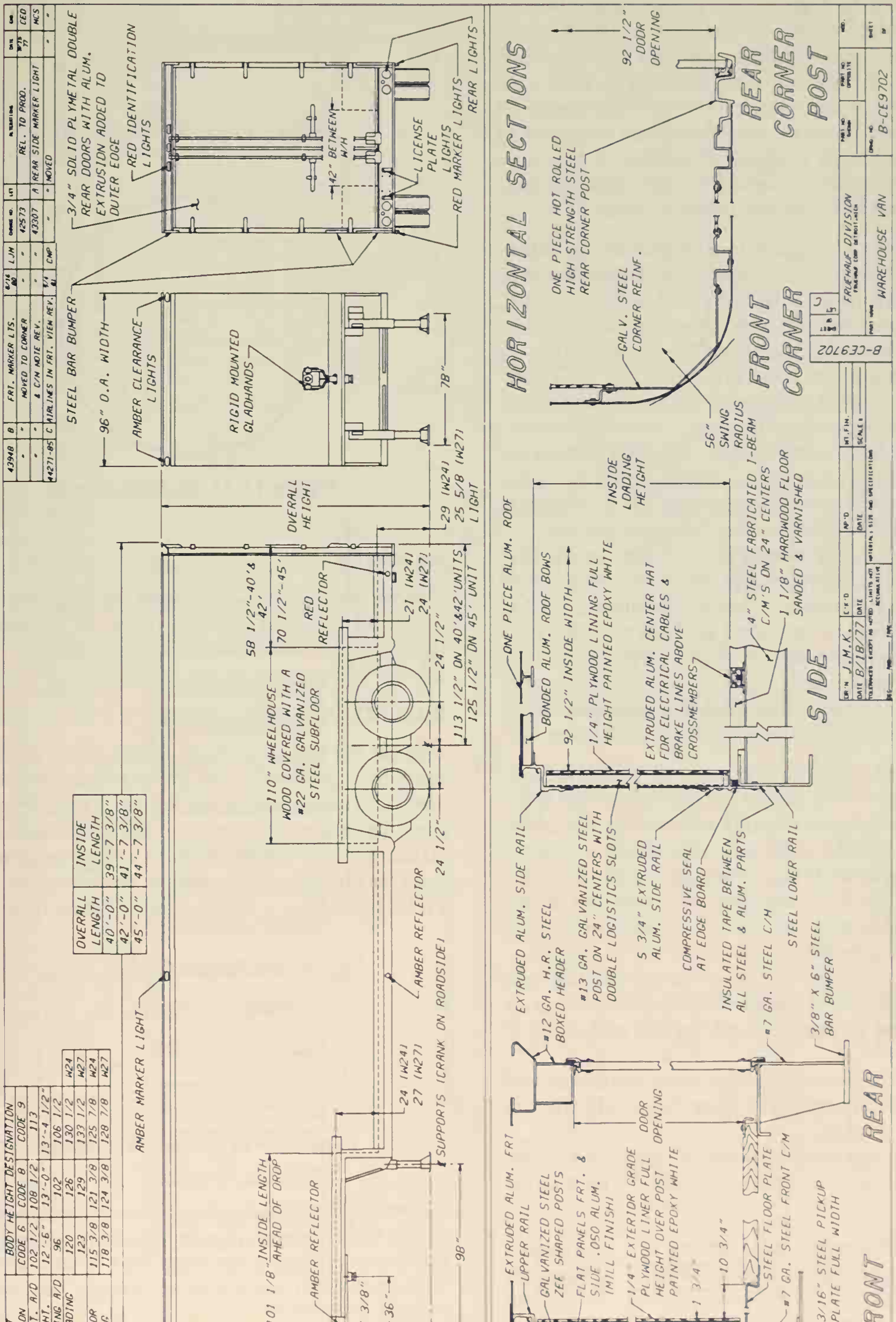


Figure 11-9 Sample CAD drawing (*Courtesy Fruehauf Division, Fruehauf Corp.*)

Giving Commands and Responding to Prompts

Refer again to Figure 11-6 for an example of a screen-mounted menu. It contains a list of input, manipulation, and output commands. By activating the input commands and responding to their corresponding prompts, CAD technicians can create all of the various types of documentation required to support the design process. Examples of how several of these commands and their prompts are used are presented in the following paragraphs.

Lines. The menu in Figure 11-6 provides for all drawing commands. This means that the DRAW function is used to call up submenus for making object lines, leader lines, center lines, and other nonhidden lines.

To create solid lines, activate the DRAW option on the ROOT menu and the LINE option on the DRAW submenu. A prompt will appear on the display asking for a beginning point for the line.

Using the puck and digitizer, the CAD technician now moves the cursor on the display to the point for the beginning of the line and presses the puck button. A new prompt will ask for the line's end point.

The cursor is now moved to the point on the display which is to be the end point of the line and the puck botton is pressed. This establishes the line. The process may be repeated as many times as necessary. The system will stay in the LINE mode until the CAD technician activates a different menu option. The LINE function is illustrated in Figure 11-8, page 410. Examine the solid lines in Figure 11-9, page 411.

Arcs and Circles. The DRAW command is used for calling up a submenu to create circles. To use this function, the CIRCLE command is activatd on the DRAW submenu. A CIRCLE submenu will appear, giving the technician several different ways for making circles. One method involves indicating the center and radius. Select this option. A prompt will appear on the text display, asking for the center point.

Move the cursor to the point on the display that will be the center of the circle and press the puck botton. A new prompt will ask for the end point of the radius.

Move the cursor to the end point of the radius and press the puck botton. The specified circle will appear on the display.

Making an arc is very similar to making a circle. Making an arc is illustrated in Figure 11-10, a circle in Figure 11-11.

Rectangles. Any rectangular object can be created using the LINES function, but a faster, easier way is to use the RECTANGLES function contained in some software packages. To create rectangles using this function, activate the RECTANGLES command. A prompt will appear on the display:

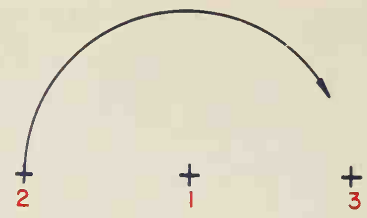


Figure 11-10 Making an arc

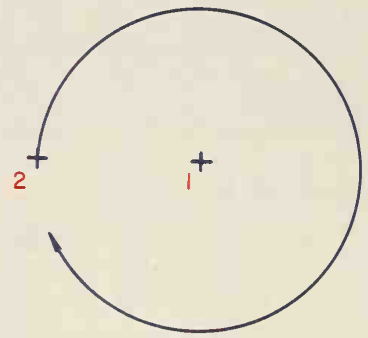


Figure 11-11 Making a circle

INDICATE CORNER

Move the cursor to a point on the graphics display which corresponds with any corner of the rectangle being created and press the puck button. A new prompt will appear on the display:

INDICATE OPPOSITE CORNER

Move the cursor diagonally to a point that represents the opposite corner of the rectangle being created and press the puck button. Using these two opposite points, the computer will calculate and draw all four sides of the rectangle. A complete procedure used in creating rectangles is illustrated in Figure 11-12. Examine the rectangles in Figure 11-13.

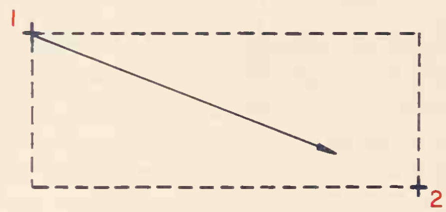


Figure 11-12 Making a rectangle

Automatic Dimensioning. One of the advantages of CAD is that the computer is able to calculate dimensions for the user. This saves time and is very accurate. To automatically dimension objects, activate the AUTO DIMENSION command. A prompt will appear on the display:

INDICATE DIMENSION BEGINNING

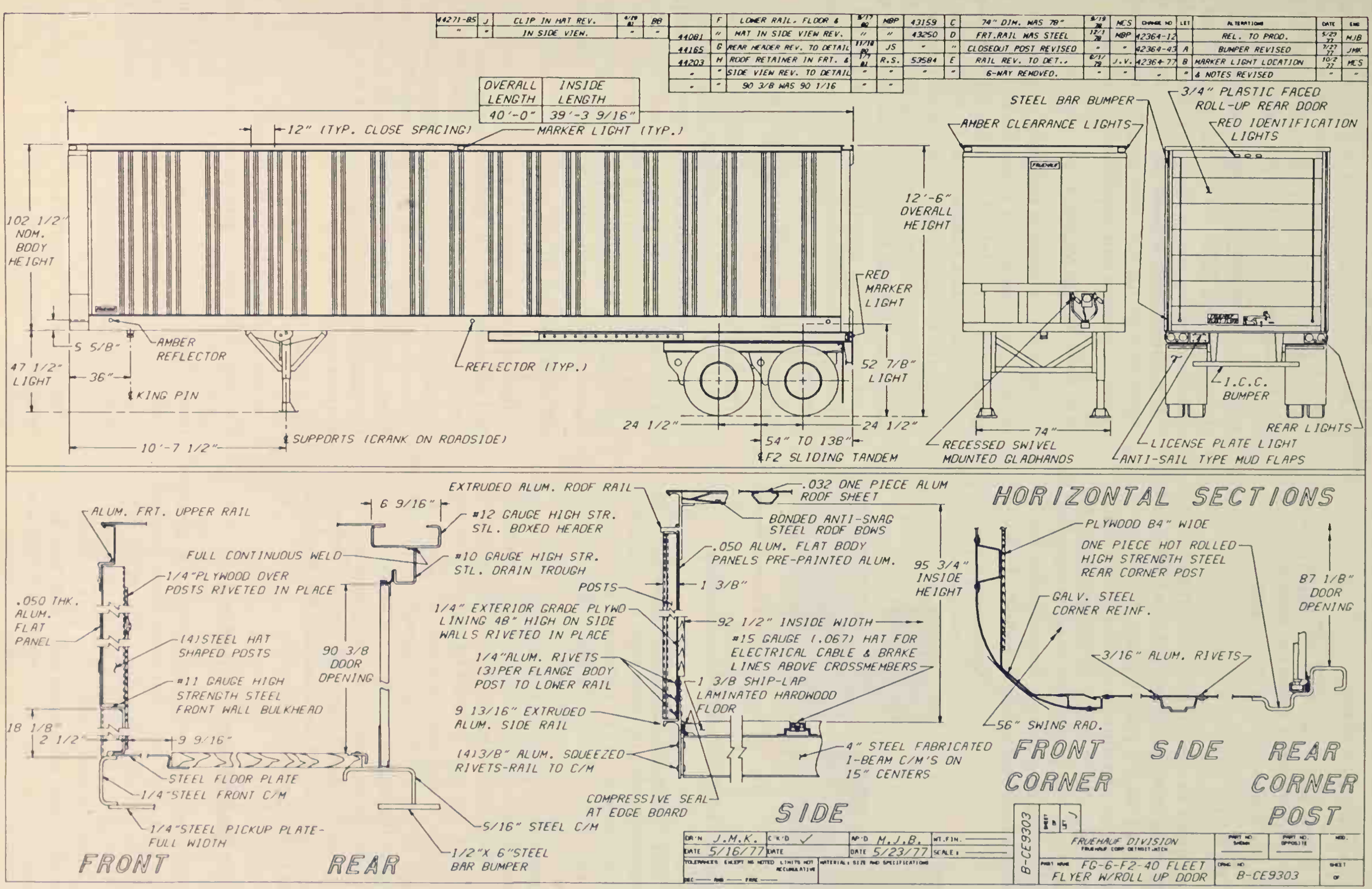


Figure 11-13 Sample CAD drawing (*Courtesy* Fruehauf Division, Fruehauf *Corp.*)

Move the cursor to the point on the display where the dimension will begin and press the puck button. A new prompt will appear on the graphics display:

INDICATE DIMENSION ENDING

Move the cursor to the point on the display where the dimension will end and press the puck button. A new prompt will appear on the text display:

INDICATE DISTANCE FROM OBJECT

Move the cursor to a point on the display to indicate how far away from the object the dimension line should be and press the puck button. At this point, the extension lines, the dimension line, arrowheads, and the dimension will appear on the graphics display as specified. The procedure used in automatically dimensioning an object is illustrated in Figure 11-14. Examine the dimensions in Figure 11-15.

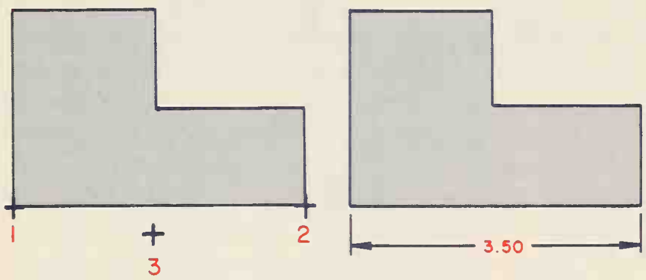


Figure 11-14 Automatic dimensioning

Text. The TEXT command is used for entering words, notes, dimensions, and any other type of annotation. To use this function, the TEXT command is activated. A prompt will appear on the display, asking for text.

At this point, type in the desired text. As you type, the text data will appear on the display. When the typing is completed, the technician should check the spelling, wording, and spacing. If there are mistakes, the BACKSPACE key can be used to make the necessary corrections. If the data are correct, press the RETURN key. A new prompt will appear on the display, asking for the location of the text string.

At this point, move the cursor to a point which marks the lower left-hand corner of the first letter in that string and press the puck button. The text data will appear in the specified location.

Manipulation Commands

Manipulation commands are those commands which allow drafters to alter data that have been entered into the system. Manipulation functions on the sample menu in Figure 11-6 are contained in the EDIT submenu. These functions allow the CAD technician to perform such tasks as altering the size of text data, and copying, moving, scaling, rotating, mirroring, and deleting both alphanumeric and graphic data.

Activating Manipulation Commands

By activating the desired manipulation commands and responding to their corresponding prompts, CAD technicians can perform all of the various manipulations of data. Examples of how sample manipulation commands and their prompts are actually used are presented in the following paragraphs.

Move. The MOVE command is used for rearranging data that have been incorrectly positioned on the graphics display (i.e., a front view that was placed in the position that should be occupied by the top view). To use this function, activate the MOVE command. A prompt will appear on the display:

BOX DATA TO BE MOVED

Create a box around the data to be moved by 1) moving the cursor to a point on the screen that is above and to the left of the data to be moved and pressing the puck button, and 2) moving the cursor diagonally to a point that is below and to the right of the data to be moved and pressing the puck button. Make sure that the box encompasses all of the data to be moved, but only the data to be moved, Figure 11-16. At this point, a new prompt will appear on the display:

INDICATE MOVE FROM POINT

The CAD technician must select a convenient point to use as a marker point when moving data. The point is used for aligning the data in its new position and is known as the "move from point." See point 1 in Figure 11-16. To identify the "move from point," move the cursor to the desired point, and press the puck button. A new prompt will appear on the display:

INDICATE MOVE TO POINT

The "move to point" is the point with which you will align the cursor in specifying the new location of the data. To identify this point, move the cursor to the desired position and press the puck button. The data will appear in the position specified, but it will blink on and off at this point. This is represented by the phantom lines in Figure 11-16. A new prompt will appear on the display:

NEW POSITION CORRECT? Y OR N

If the new position is the correct position, type Y for "yes." The blinking lines of the moved data will solidify and the data in the old position will disappear. If the new position is incorrect, type N for "no," and the blinking will stop, the lines will disappear, and the process may be repeated. This last prompt is simply a built-in double check.

Copy. The COPY command saves CAD technicians time when working on a drawing that contains the same object or symbol repeatedly when that symbol

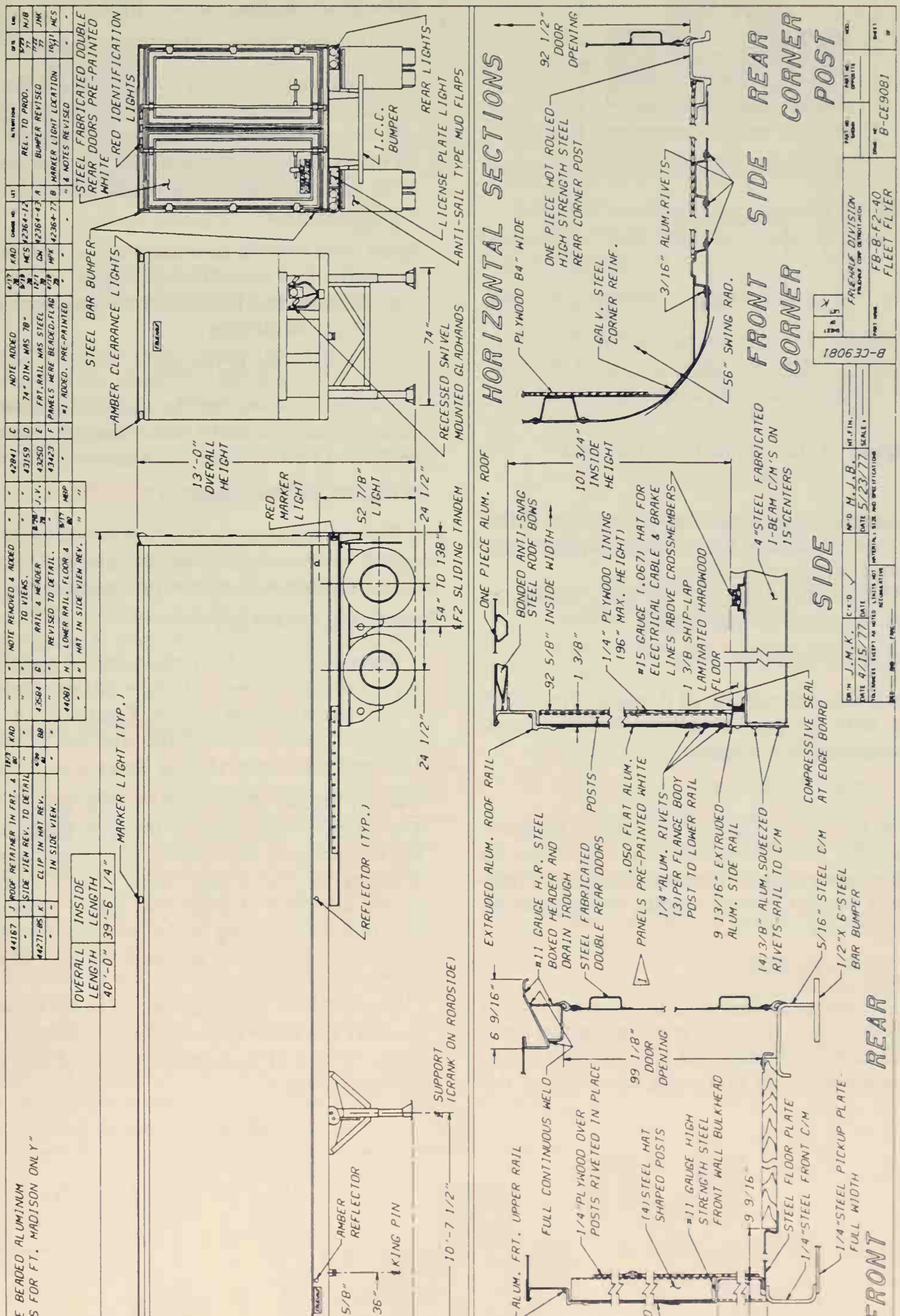


Figure 11-15 Sample CAD drawing (Courtesy *Fruehauf* Division, *Fruehauf* Corp.)

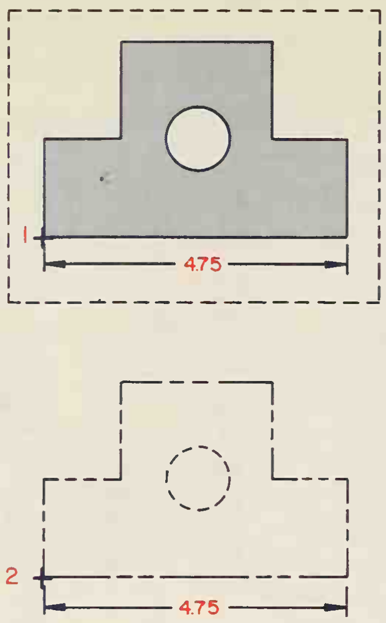


Figure 11-16 The MOVE command

is not contained in a symbols library. Once the object has been created the first time, it can simply be copied as many times as necessary.

To use this function, activate the copy command. A prompt will appear on the display:

BOX DATA TO BE COPIED

The box is created exactly as it was in the MOVE command. With the box completed, a new prompt will appear on the text display:

INDICATE COPY FROM POINT

This point (point 1 in Figure 11-17) serves the same purpose as the "move from point." It is selected by aligning the cursor with the desired point and pressing the puck botton. A new prompt will appear on the display:

INDICATE COPY TO POINT

This point (point 2 in Figure 11-17) serves the same purpose as the "move to point." It is specified by aligning the cursor with the desired position and pressing the puck button. At this point, the copy of the original data will appear in the specified location on the display in a blinking mode. This is represented by phantom lines in Figure 11-17. At this point, a new prompt will appear on the display:

COPIED POSITION CORRECT? Y OR N

If the new position is correct, type Y for "yes." The blinking lines of the copied data will solidify and the old view will remain. The process may be repeated as many times as necessary. If the new copy, at any time, is not properly positioned, type N for "no," and it will disappear.

Rotate. The ROTATE command allows CAD technicians to revolve data into different angles. To use this function, activate the ROTATE command. A prompt will appear on the display:

BOX DATA TO BE ROTATED

Create a box around the data to be rotated in the normal manner. Once this step has been accomplished, a new prompt will appear on the display:

INDICATE ROTATION POINT

Move the cursor to the desired point of rotation, Figure 11-18, and press the puck button. At this point a new prompt will appear on the display:

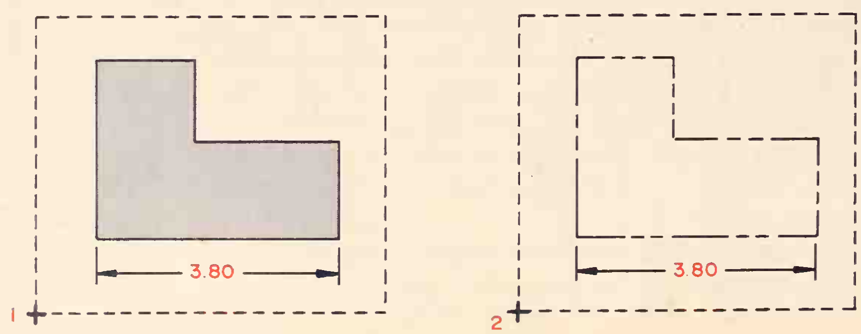
INDICATE NEW AXIS

Move the cursor from the point of rotation to create a line at the desired angle of the rotated object and press the puck button, Figure 11-18. The data will now revolve around the rotation point into the new angle, as shown in the figure.

ZOOM-IN *and* ZOOM-OUT. The ZOOM functions allow CAD technicians to move in close to a drawing for intricate detail work and move away from a drawing for pan views. Each ZOOM command in either direction changes the frame in multiples of two (either doubling or halving the frame). To use this function, simply activate the ZOOM-IN or the ZOOM-OUT command.

Figure 11-19 shows an object in its normal frame (center), the same object after one ZOOM-OUT command (left), and the same object after one ZOOM-IN command (right).

Figure 11-17 The COPY command



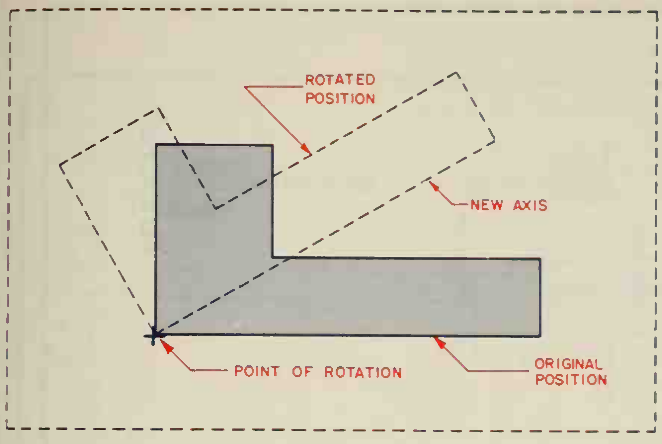


Figure 11-18 The ROTATE command

It should be noted that zooming in or out does not alter the size of the object being worked on. It simply moves the eye closer to or farther away from the object, giving the appearance of scaling it up or down.

Output Commands

Once data have been input and manipulated, the CAD technician may desire to output them in hard-copy form. The most commonly used type of hard copy in CAD is the pen-plotted drawing. The sample menu in Figure 11-6 contains an output option for plotting data: PLOT.

Using the PLOT Command

A CAD system's pen plotter (the most frequently used type of plotter) is set up to output hard copies of data according to certain specifications which may be adjusted. These specifications include the *window parameters* (the size of the area in which data will be plotted) and the plotting speed. A pen plotter will automatically do the necessary computations to plot data within a window of virtually any size. Plotting speeds for pen plotters may be adjusted from approximately 16 inches per second to as much as 60 inches per second, depending on the type of pen and the type of media being used.

Window and speed specifications are normally set and left. When this is the case, only the PLOT command is needed to accomplish the plotting task.

The PLOT command is used to make pen-plotted hard copies of data that are in the system. Before using the PLOT command, the SAVE command should be given. This ensures that the data to be plotted are first stored in a workfile so that they are not lost after plotting.

To plot a drawing, activate the PLOT command. A prompt will appear on the display:

PEN(S) INSTALLED? Y CONTINUES.

Type Y if you have remembered to place the pen or pens in their holders. A new prompt will appear on the display:

MEDIA LOADED? Y CONTINUES.

Type Y if the paper, vellum or polyester film is loaded. Once you have pressed the Y key, the data will be plotted at the rate set. Examine the plotted drawings in Figures 11-20 through 11-23.

Review

1. What are the three phases of producing design documentation in CAD?
2. List five general operational skills needed to operate any CAD system.
3. Name four ways in which keying is used in CAD.
4. What is the cursor?
5. Name five different ways of controlling the cursor.
6. List five hypothetical commands you might give a computer to have it create a drawing.
7. Name three different types of function menus.
8. Drawings consist of two types of data. What are they?
9. List at least seven standard geometric shapes used in creating graphic data.
10. Explain the term log-on sequence.

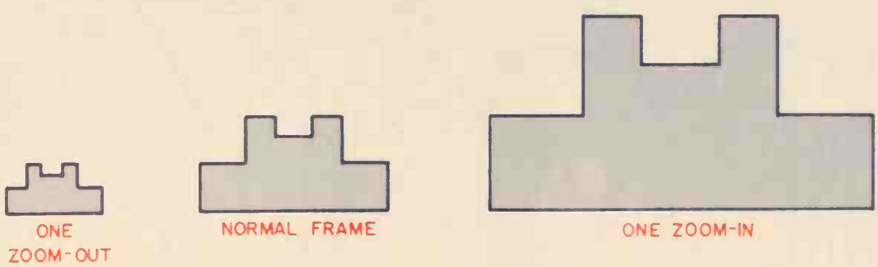


Figure 11-19 The ZOOM command

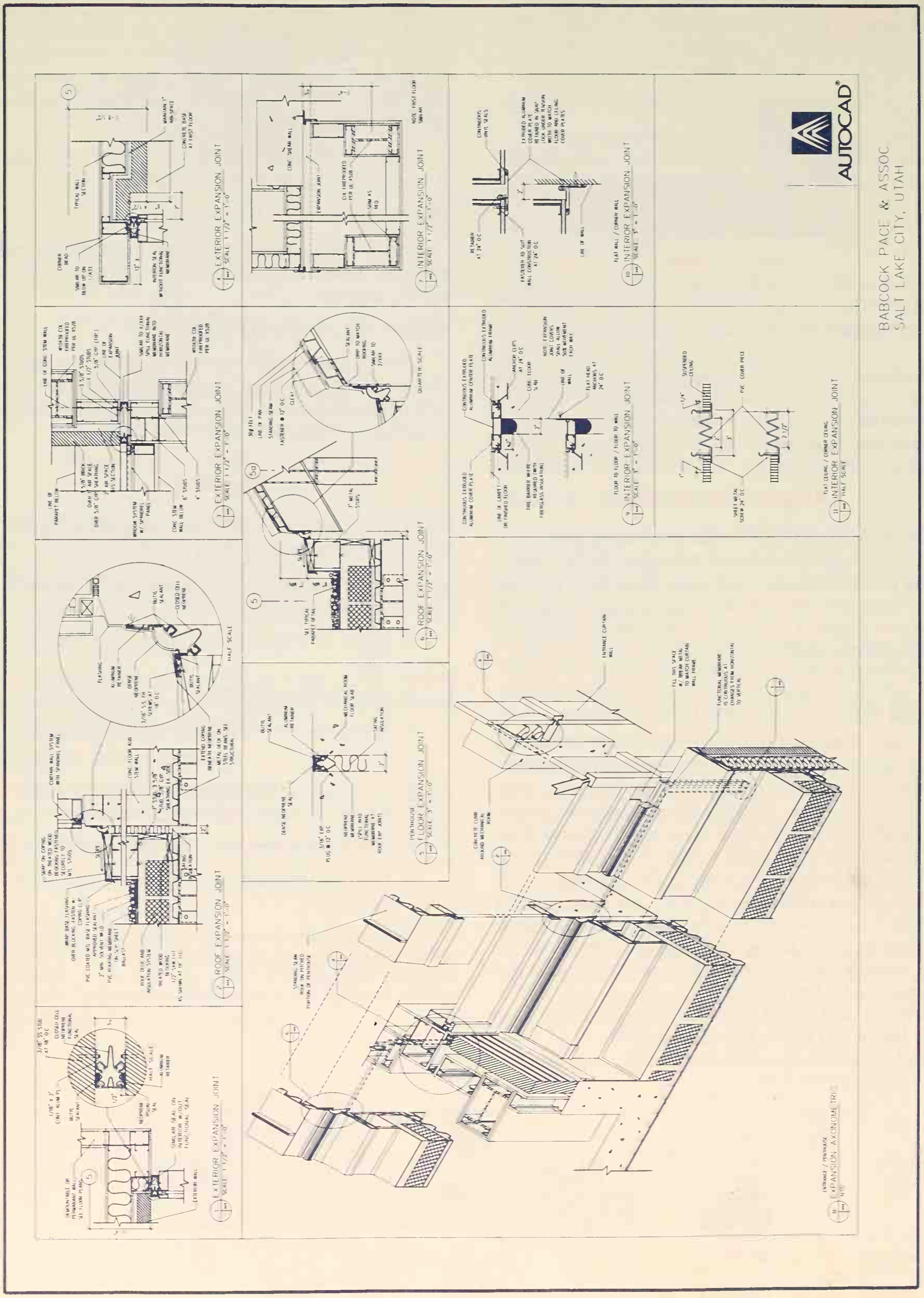


Figure 11-20 Sample CAD drawing (*Courtesy Autodesk, Inc.*)

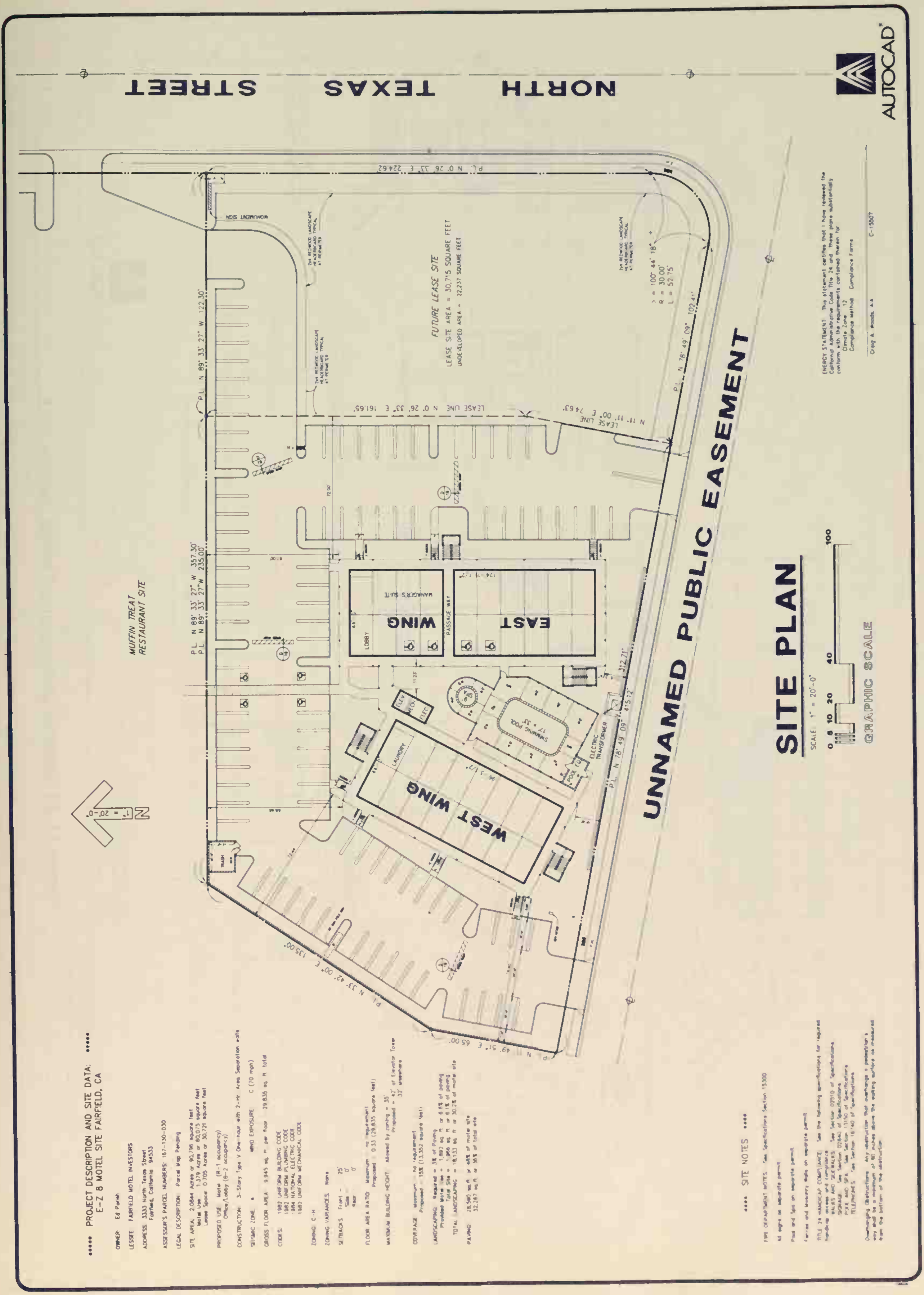


Figure 11-21 Sample CAD drawing (*Courtesy Autodesk, Inc.*)

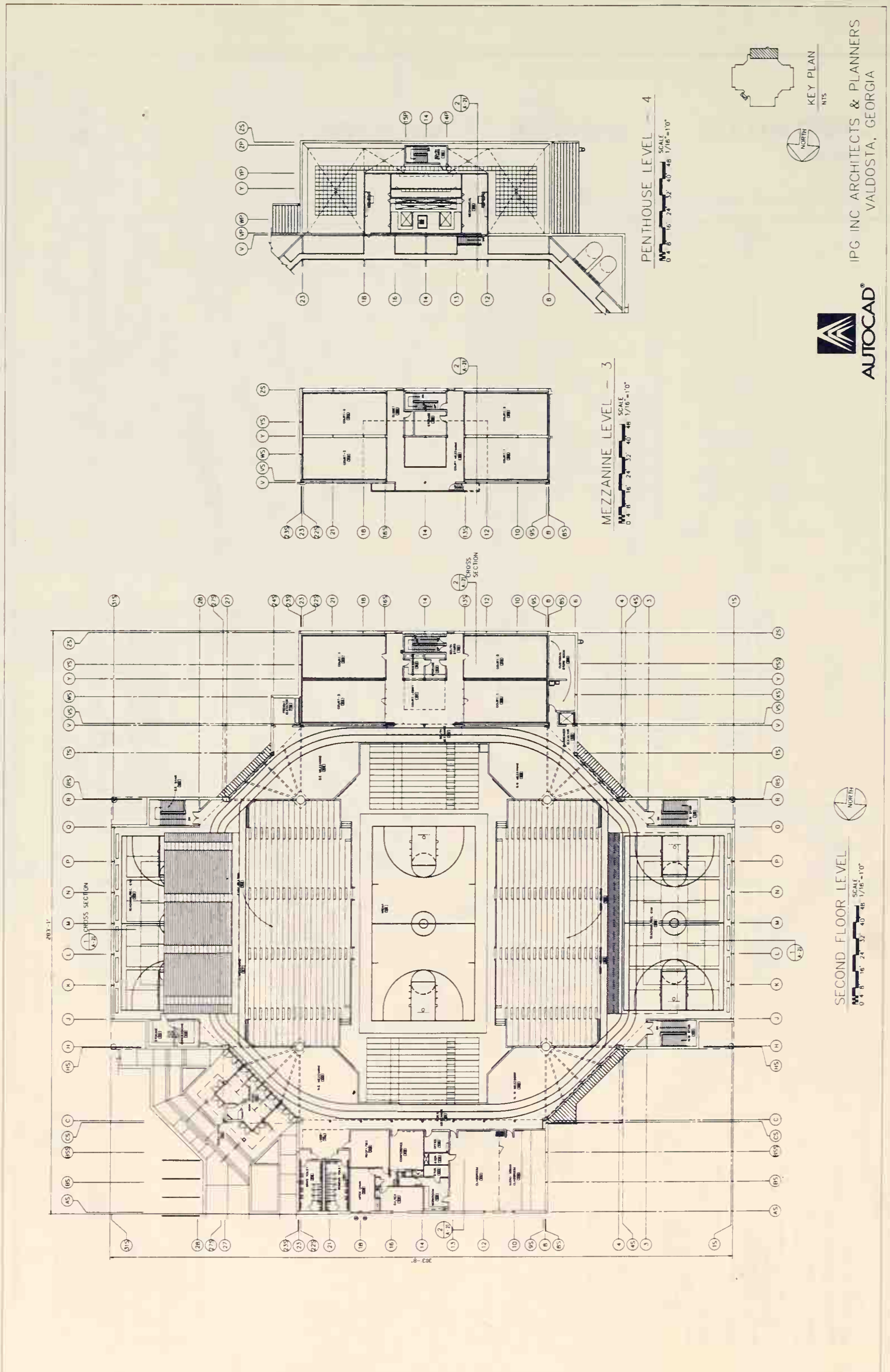


Figure 11-22 Sample CAD drawing (*Courtesy Autodesk, Inc.*)

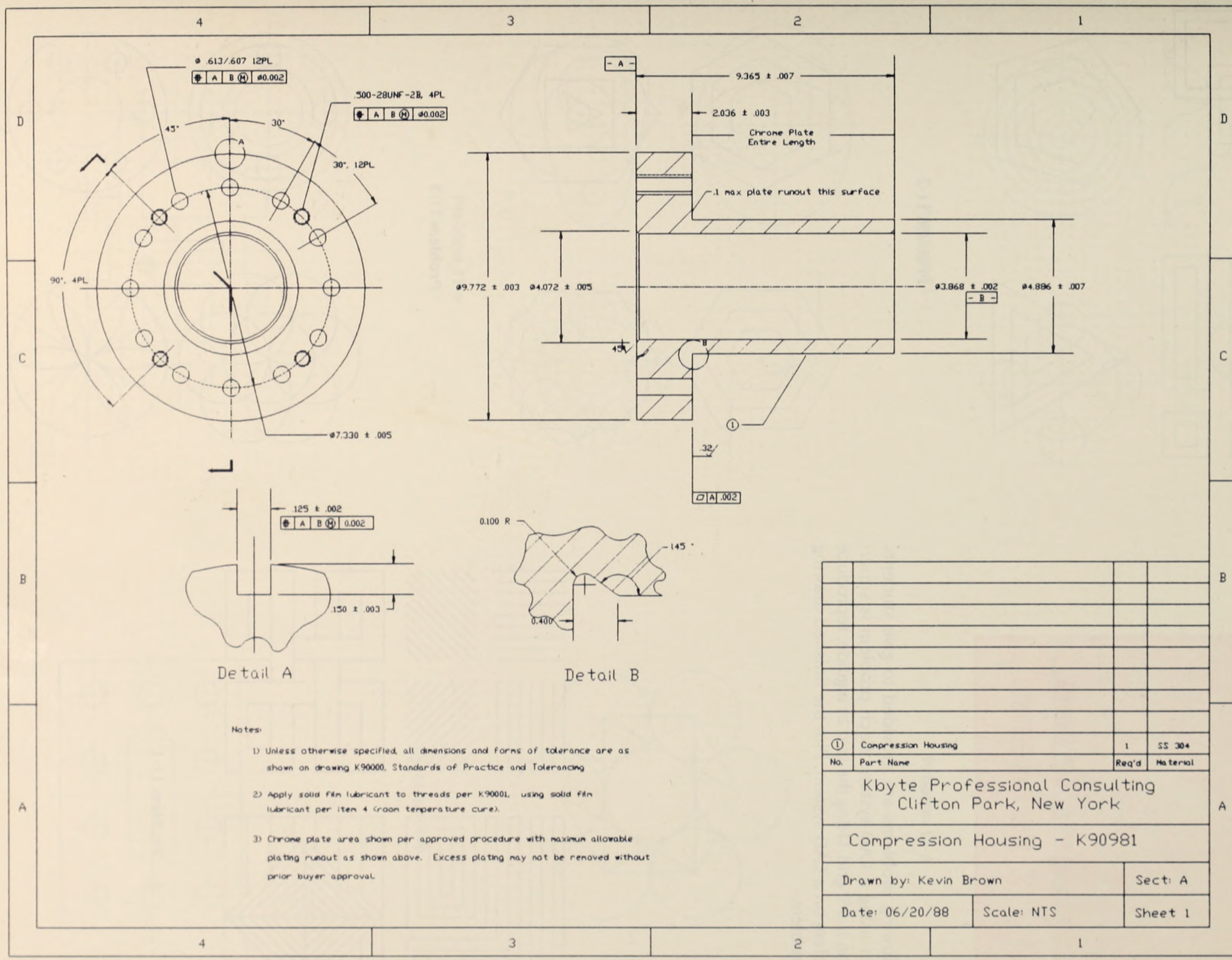
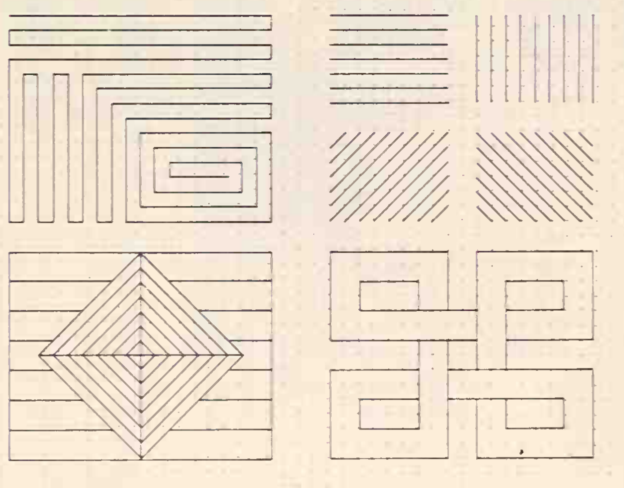


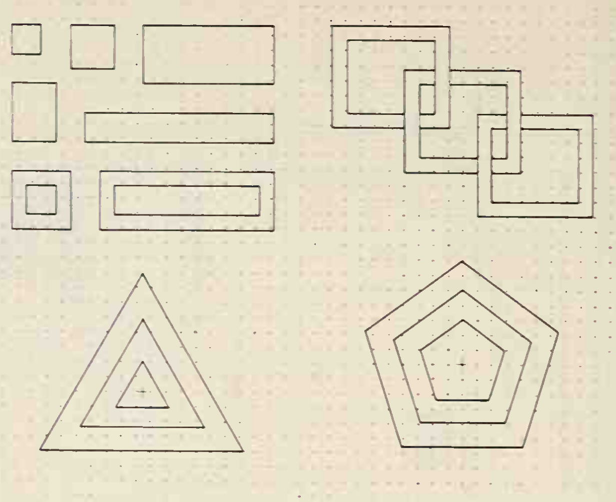
Figure 11-23 Sample CAD drawing

Chapter Eleven Problems

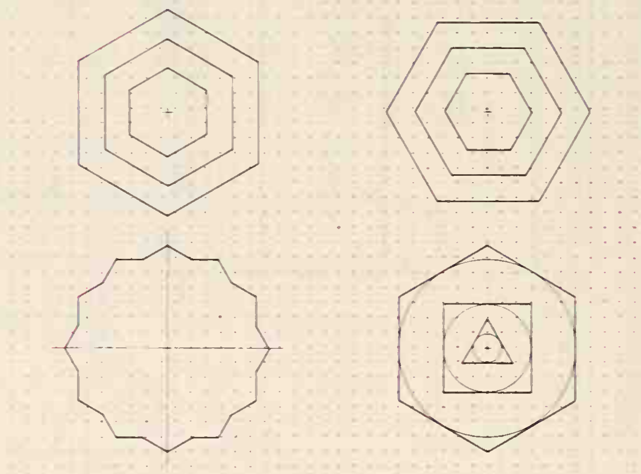
The following problems are provided to give students practice in using a CAD system. Each problem is superimposed on a .25" grid. Using the grid as a guide, reproduce each problem on a CAD system. Plot the finished drawing of each problem.



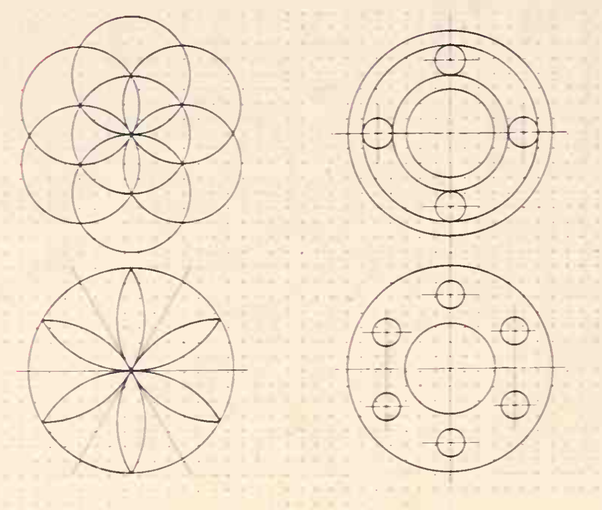
Problem 11-1



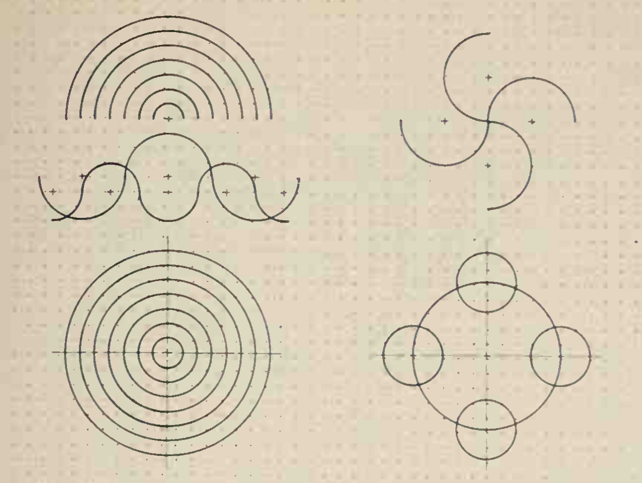
Problem 11-2



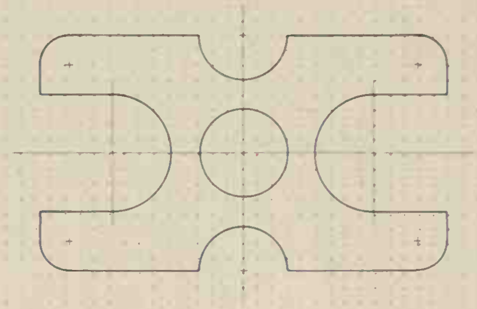
Problem 11-3



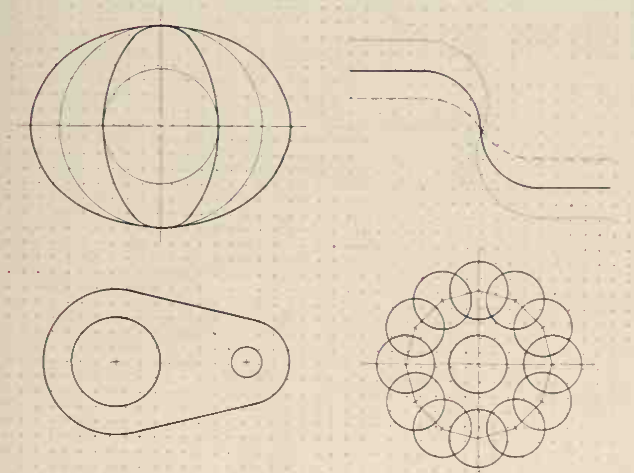
Problem 11-4



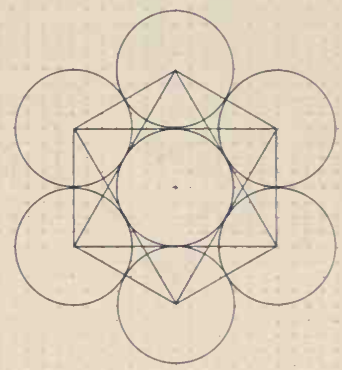
Problem 11-5



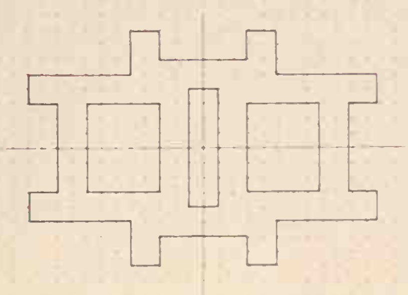
Problem 11-8



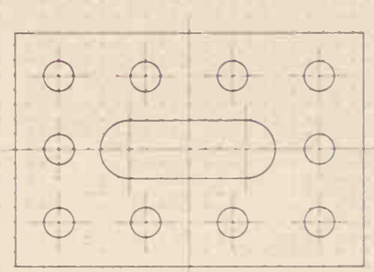
Problem 11-6



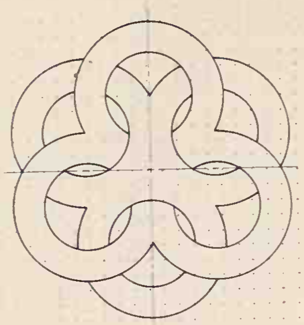
Problem 11-9



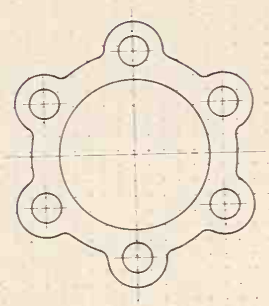
Problem 11-7



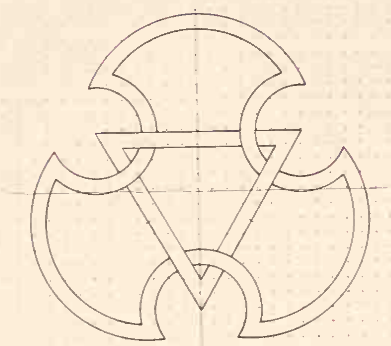
Problem 11-10



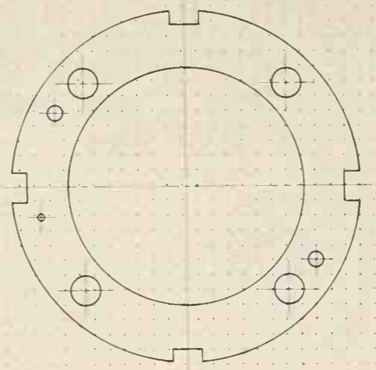
Problem 11-11



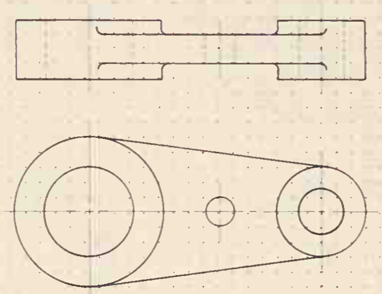
Problem 11-12



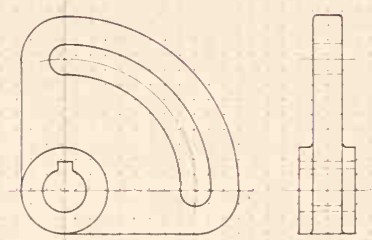
Problem 11-13



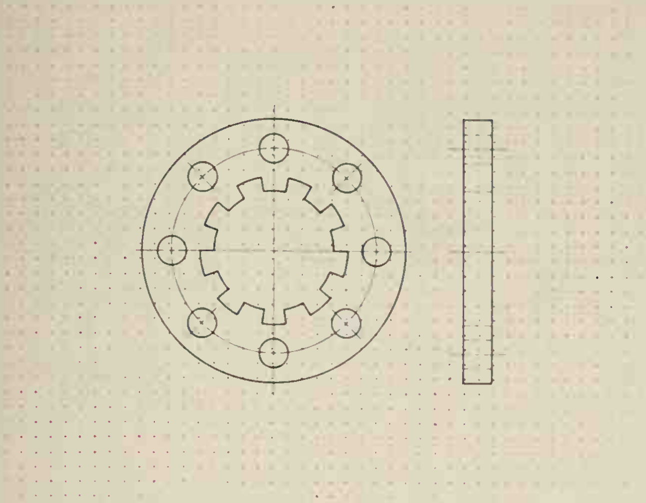
Problem 11-14



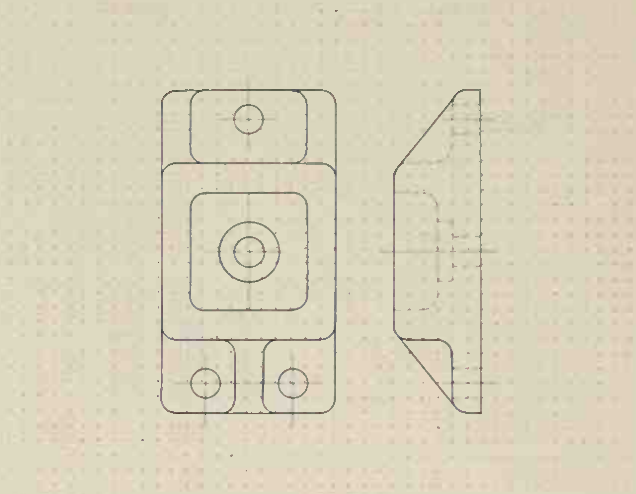
Problem 11-15



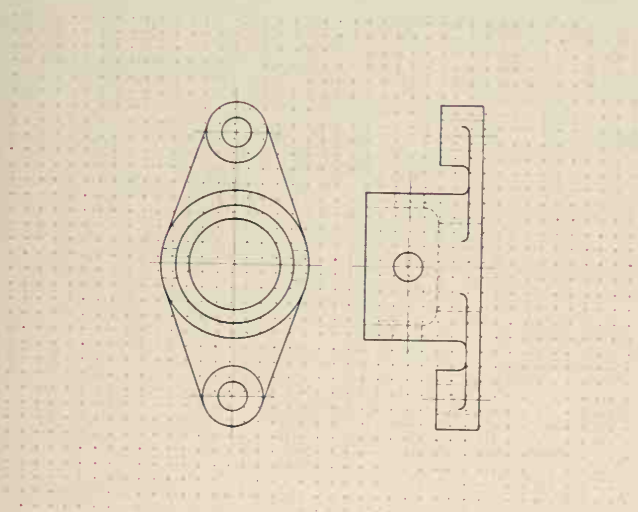
Problem 11-16



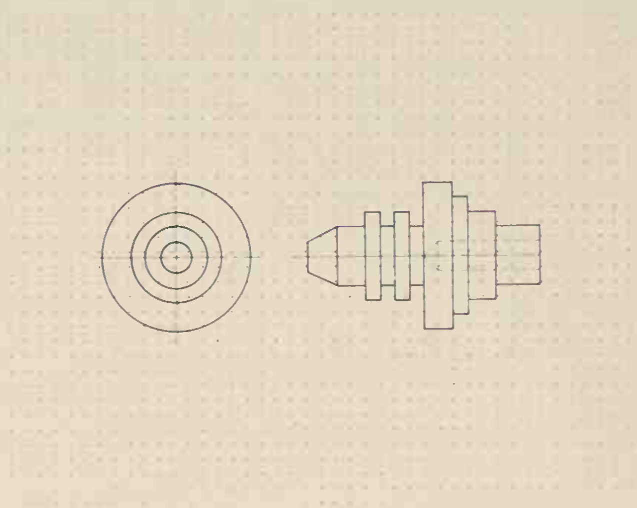
Problem 11-17



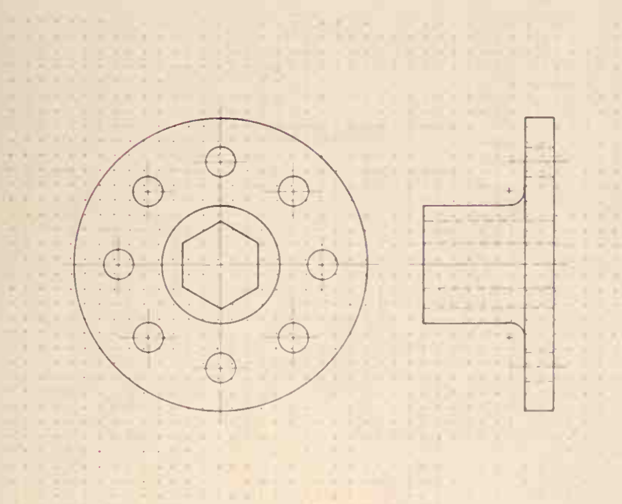
Problem 11-20



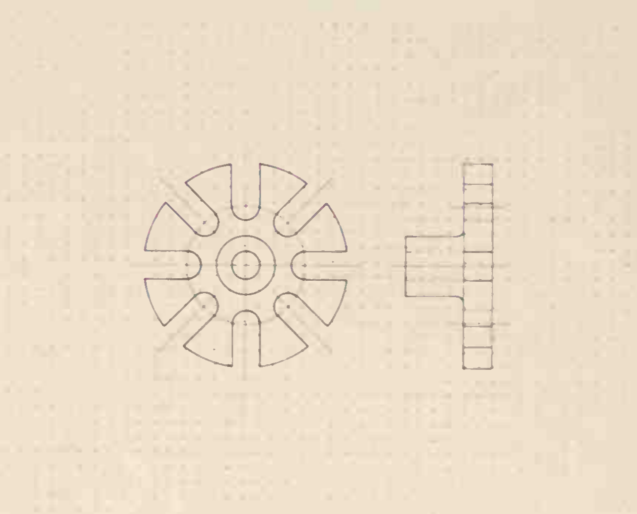
Problem 11-18



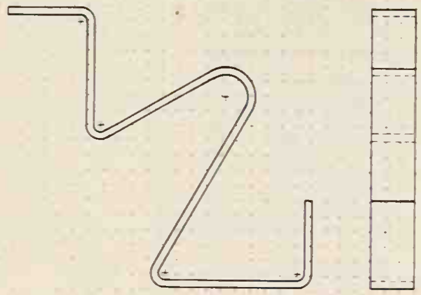
Problem 11-21



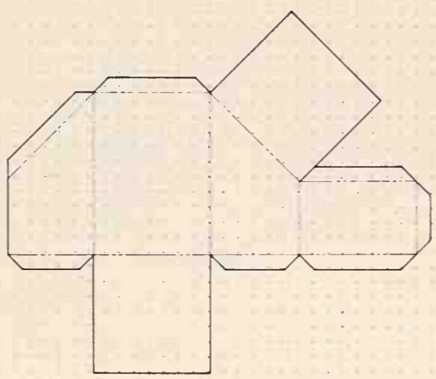
Problem 11-19



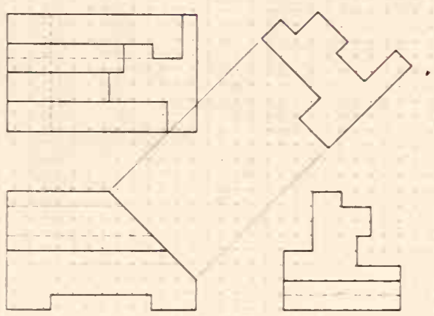
Problem 11-22



Problem 11-23



Problem 11-24



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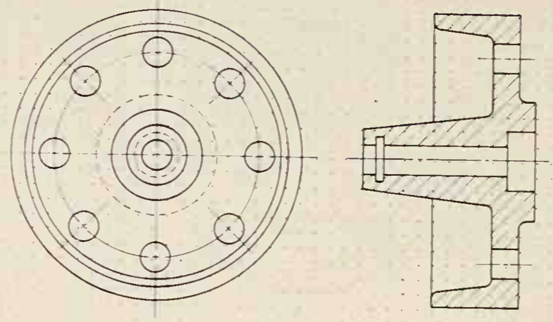

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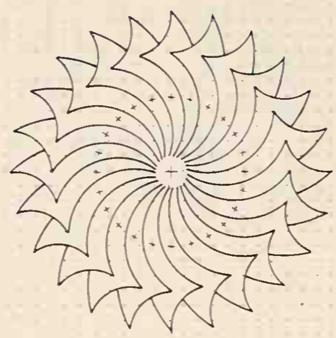

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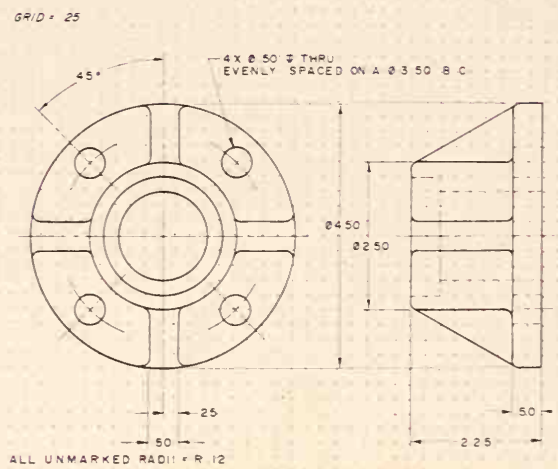

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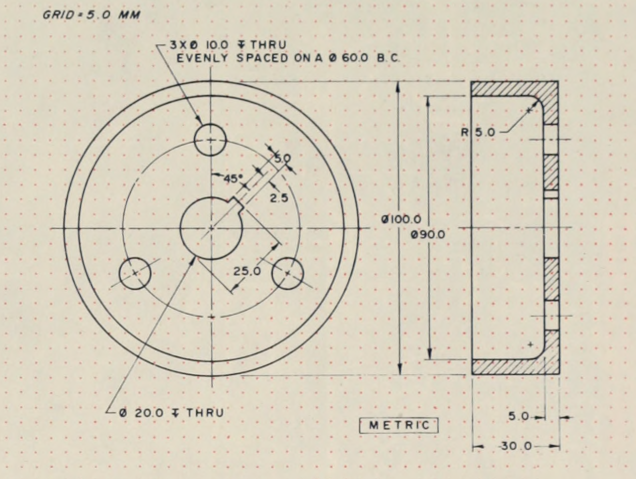

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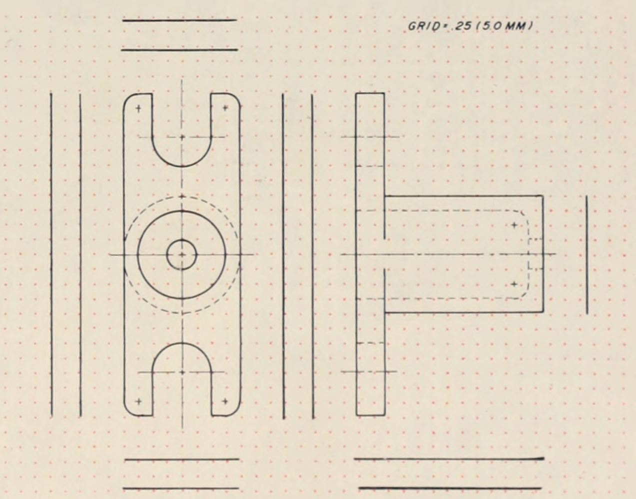

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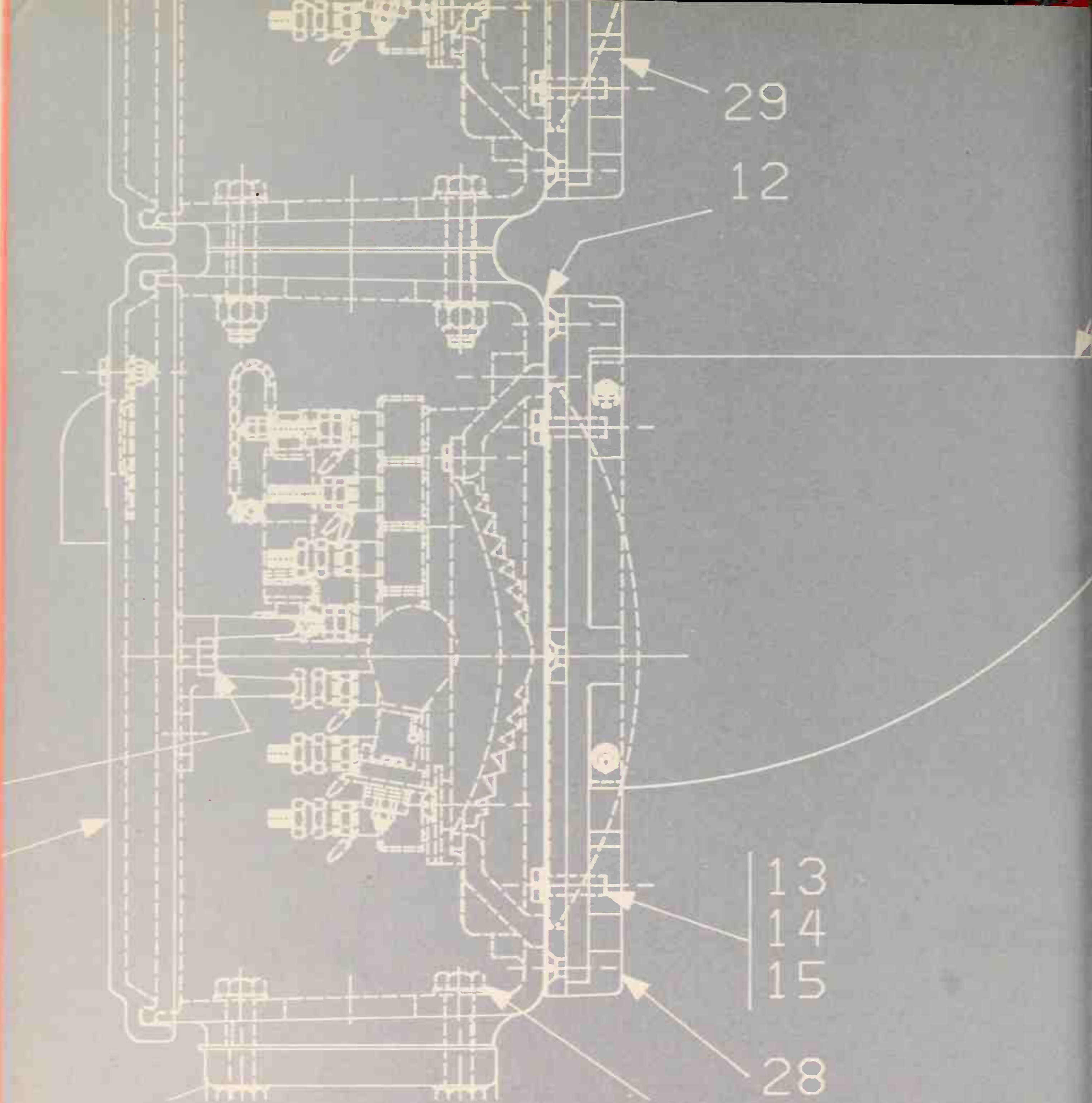
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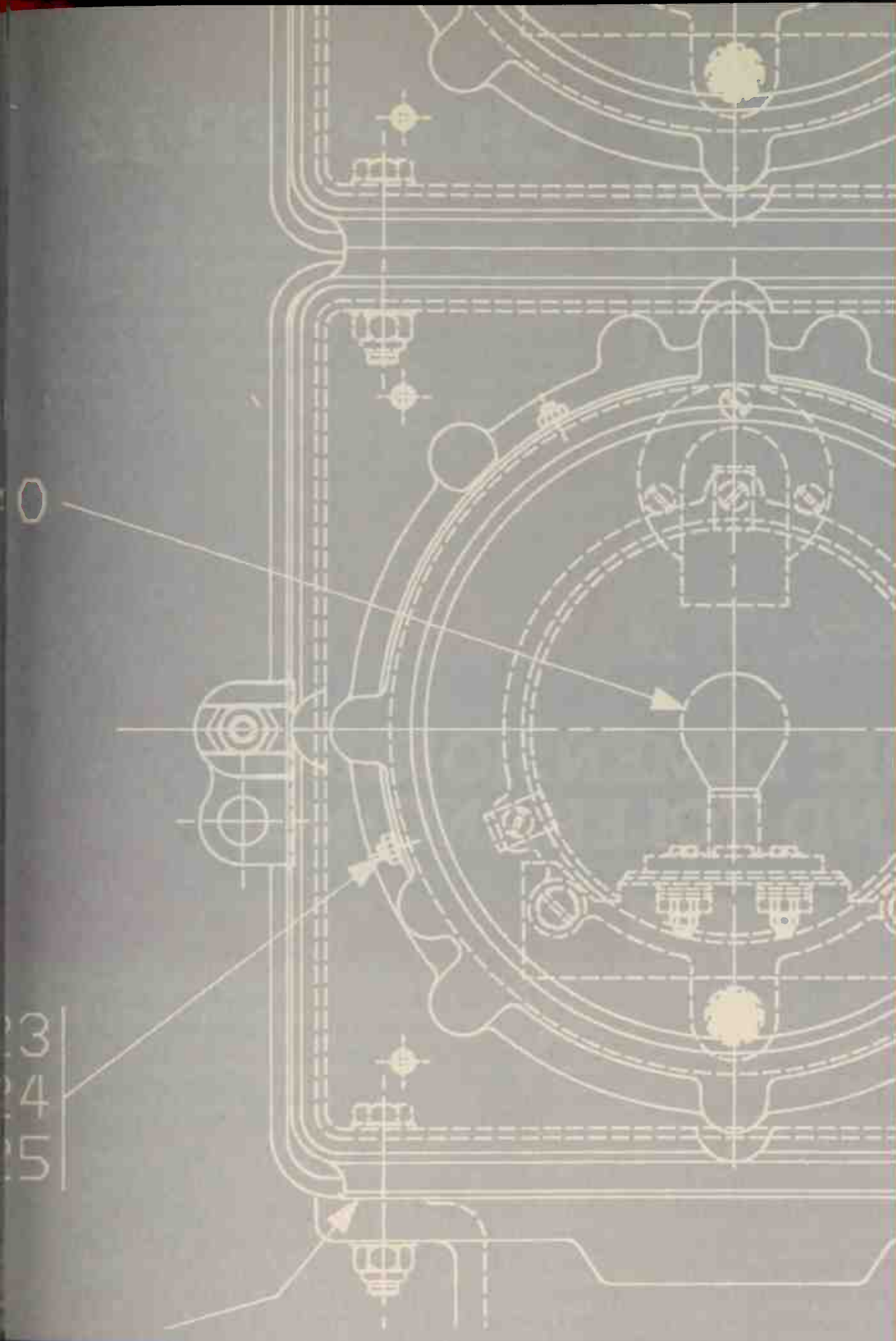
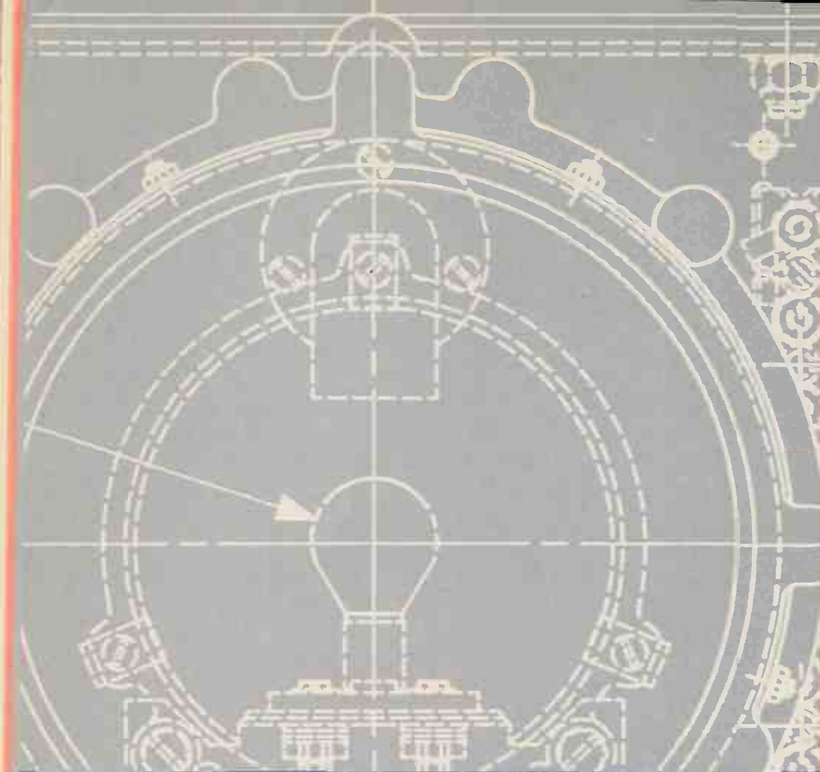
SECTION FOUR



DESIGN DRAFTING APPLICATIONS



CHAPTER 12

This chapter covers the advanced dimensioning techniques of geometric dimensioning and tolerancing according to ANSI Y14.5M-1982. Major topics covered include general tolerancing, datums, feature control symbols, true position, flatness, straightness, circularity, cylindricity, angularity, parallelism, perpendicularity, profile, and runout.

GEOMETRIC DIMENSIONING AND TOLERANCING

Summary of Geometric Dimensioning and Positional Tolerance Terms

Actual Size Actual measured size of a feature.

Angularity Tolerancing of a feature at a specified angle from another feature.

Basic Dimension A theoretically "perfect" dimension similar to a reference or nominal dimension. It is used to identify the exact location, size, or shape of a feature.

Bilateral Tolerances Tolerances that are applied to a nominal dimension in the positive and negative directions.

Circular Runout A tolerance that identifies an infinite number of elemental tolerance zones on a feature when the feature is rotated 360° for each element.

Circularity A tolerance that controls elemental tolerance zones around a circular feature that is independent of other features.

Clearance Fit A condition between mating parts in which there is always a clearance assembly.

Concentricity A tolerance in which the axis of a feature must be coaxial to a specified datum regardless of the datum's and the feature's size.

Cylindricity A tolerance that simultaneously controls the surface of revolution for straightness, parallelism, and circularity of a feature, and is independent of any other features on a part.

Datums Reference points, lines, planes, cylinders, and axes which are assumed to be exact and perfect.

Datum Feature A feature which is used to establish a datum.

Datum Identification Symbol A special rectangular box which contains the datum reference letter.

Feature A component of a part such as a hole, slot, surface, or boss.

Fit A term used to describe the range of assembly that results from tolerances on two mating parts.

Flatness A tolerance that controls the amount of variation from the perfect plane on a feature independent of any other features on the part.

Form Tolerance A tolerance that specifies the allowable variation of a feature from perfect form.

Least Material Condition (LMC) A condition of a feature in which it contains the least amount of material.
Limit Dimensions A tolerancing method showing only the maximum and minimum dimensions which establish the limits.
Limits The maximum and minimum allowable sizes of a feature.
Location Tolerance A tolerance which specifies the allowable variation from the perfect location.
Maximum Material Condition (MMC) A condition in which the feature contains the maximum amount of material.
Modifier The application of MMC or RFS to alter the normally implied interpretation of a tolerance specification.
Parallelism A tolerance that controls interdependent surfaces and axes which must be equal distance from a datum plane or axis.
Perpendicularity A tolerance that controls surfaces and axes which must be at right angles with a datum axis.
Position Tolerance A tolerance that controls the position of a feature as related to a datum or datums.
Profile of a Line A tolerance that controls the allowable variation along an elemental tolerance zone with regard to a basic profile.
Profile of a Surface A tolerance that controls the allowable variation of a surface from a basic profile or configuration.
Projected Tolerance Zone A tolerance zone that applies to the location of an axis above the surface of the feature being controlled.
Reference Dimension A non-toleranced dimension used for information purposes only which does not govern production or inspection operations.
Regardless of Feature Size (RFS) A condition of a tolerance in which the tolerance must be met regardless of the size of the feature.
Runout The composite variation from the desired form of a part surface of revolution during full rotation of the part on a datum axis.
Size Tolerance A tolerance that specifies how far individual features may vary from the desired size.
Straightness A tolerance that controls the allowable variation of a surface or an axis from a theoretically perfect plane or line.
Tolerance The variation or allowance of a dimension.
Total Runout A tolerance that simultaneously controls a surface related to a datum in all directions.
Transition Fit A condition in which two parts are toleranced so that either a clearance or an interference can result when the parts are assembled.
True Position The theoretically exact location of a feature.
Unilateral Tolerance A tolerance which allows variations in only one direction.
Virtual Condition A condition of a feature in which all tolerances of location, size, and form are considered.

General Tolerancing

The industrial revolution created a need for mass production: assembling interchangeable parts on an assembly line to turn out great quantities of a given finished product. Interchangeability of parts was the key. If a particular product was composed of 100 parts, each individual part could be produced in quantity, checked for accuracy, stored, and used as necessary.

Since it was humanly and technologically impossible to have every individual part produced exactly alike (it still is), the concept of geometric and positional tolerancing was introduced. *Tolerancing* means setting acceptable limits of deviation. For example, if a mass produced part is to be 4" in length under ideal conditions, but is acceptable as long as it is not less than 3.99" and not longer than 4.01", there is a tolerance of plus or minus .01", Figure 12-1. This type of tolerance is called a *size tolerance.*

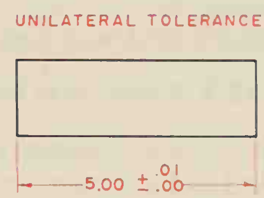


Figure 12-1 Size tolerance

There are three different types of size tolerances: unilateral and bilateral, shown in Figure 12-2, and limit dimensioning. When a *unilateral tolerance* is applied to a dimension, the tolerance applies in one direction only (for example, the object may be larger but not smaller, or it may be smaller but not larger). When a *bilateral tolerance* is applied to a dimension, the tolerance applies in both directions, but not necessarily evenly distributed. In *limit dimensioning*, the high limit is placed above the low value. When placed in a single line, the low limit precedes the high limit and the two are separated by a dash.

Tolerancing size dimensions offers a number of advantages. It allows for acceptable error without compromises in design, cuts down on unacceptable parts, decreases manufacturing time, and makes the product less expensive to produce. However, it soon became apparent that in spite of advantages gained from size tolerances, tolerancing only the size of an object was not enough. Other characteristics of objects also needed to be toleranced, such as location of features, orientation, form, runout, and profile.

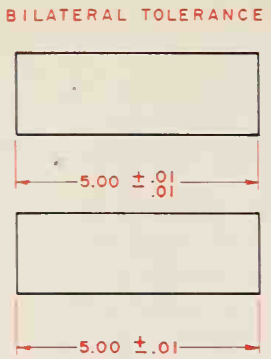


Figure 12-2 Two types of tolerances

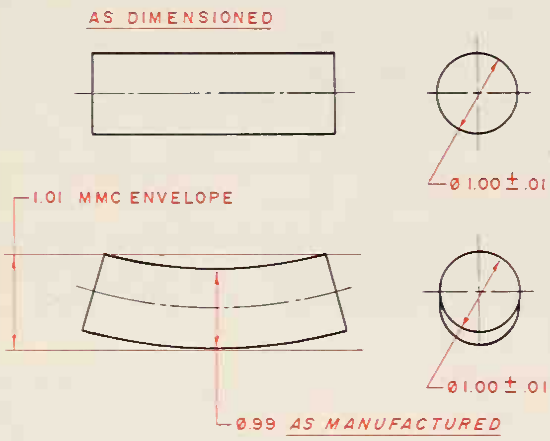


Figure 12-3 Tolerance of form

In order for parts to be acceptable, depending on their use, they need to be straight, round, cylindrical, flat, angular and so forth. This concept is illustrated in Figure 12-3. The object depicted is a shaft that is to be manufactured to within plus or minus .01 of 1.00 inch in diameter. The finished product meets the size specifications but, since it is not straight, the part might be rejected.

The need to tolerance more than just the size of objects led to the development of a more precise system of tolerancing called geometric dimensioning and positional tolerancing. This new practice improved on conventional tolerancing significantly by allowing designers to tolerance size, form, orientation, profile, location, and runout, Figure 12-4. In turn, these are the characteristics that make it possible to achieve a high degree of interchangeability.

FOR INDIVIDUAL FEATURES	FORM
FOR INDIVIDUAL RELATED FEATURES	PROFILE
FOR RELATED FEATURES	ORIENTATION LOCATION RUNOUT

Figure 12-4 Types of tolerances

Geometric Dimensioning and Positional Tolerancing Defined

Geometric dimensioning and positional tolerancing is a dimensioning practice which allows designers to set tolerance limits not just for the size of an object, but for all of the various critical characteristics of a part. In applying geometric dimensioning and tolerancing to a part, the designer must examine it in terms of its function and its relationship to mating parts.

Figure 12-5 is an example of a drawing of an object that has been geometrically dimensioned and toleranced. It is taken from ANSI Standard Y14.5M-1982, the dimensioning standards manual produced by the American National Standards Institute. This manual is a necessary reference for drafters and designers involved in geometric dimensioning and positional tolerancing.

The key to learning geometric dimensioning and positional tolerancing is to learn the various building blocks which make up the system, as well as how to properly apply them. Figure 12-6 contains a chart of the building blocks of the geometric dimensioning and tolerancing system. In addition to the standard building blocks shown in the figure, several modifying symbols are used when applying geometric tolerancing, as discussed in detail in upcoming paragraphs.

Another concept that must be understood in order to effectively apply geometric tolerancing is the concept of datums. For skilled, experienced designers, the geometric building blocks, modifiers, and datums blend together as a single concept. However, for the purpose of learning, they are dealt with separately, and undertaken step-by-step as individual concepts. They are presented now in the following order: modifiers, datums, and geometric building blocks.

Modifiers

Modifiers are symbols that can be attached to the standard geometric building blocks to alter their application or interpretation. The proper use of modifiers is fundamental to effective geometric tolerancing. Four modifiers are frequently used: maximum material condition, regardless of feature size, least material condition, and projected tolerance zone, Figure 12-7.

Maximum Material Condition

Maximum material condition, abbreviated MMC, is the condition of a characteristic when the most material exists. For example, the MMC of the external feature in Figure 12-8 is .77 inch. This is the MMC because it represents the condition where the most material exists on the part being manufactured. The MMC of the internal feature in the figure is .73 inch. This is the MMC because the most material exists when the hole is produced at the smallest allowable size.

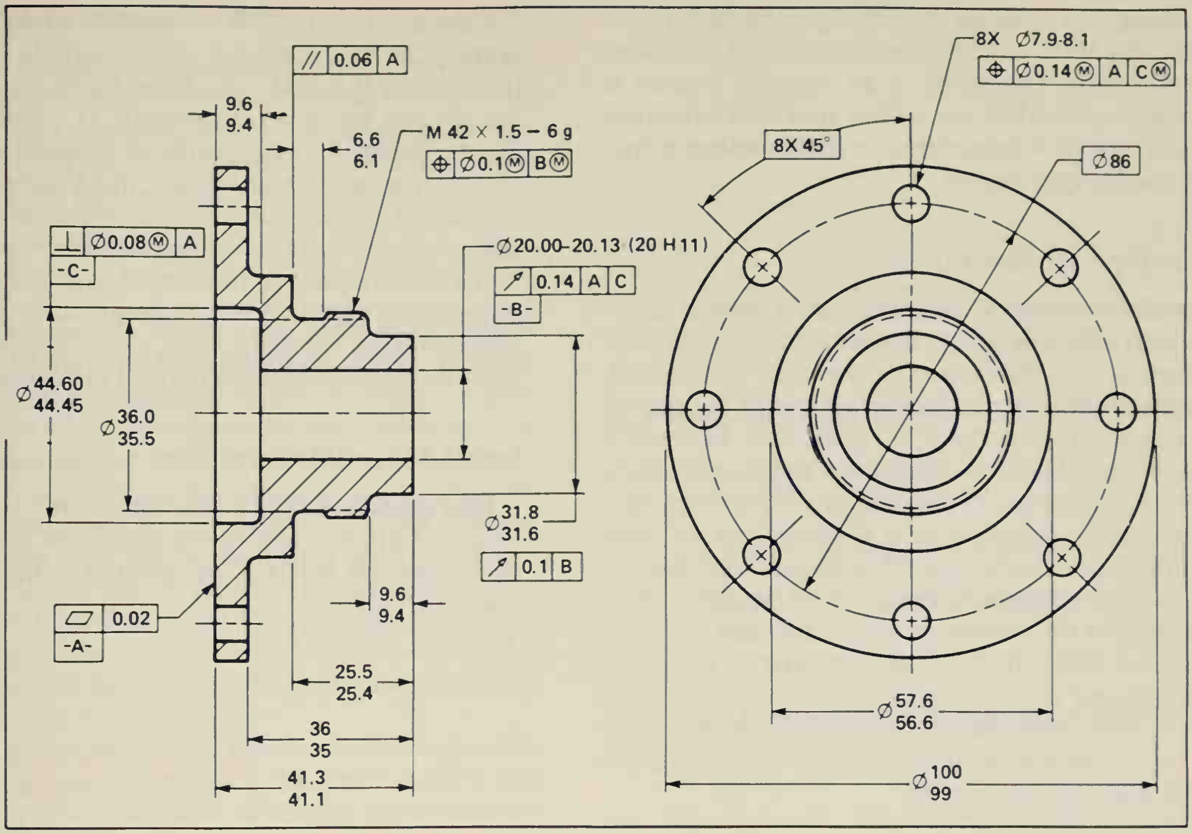


Figure 12-5 Geometrically dimensioned and toleranced drawing (*From* ANSI Y14.5M-1982)

SYMBOL	CHARACTERISTIC	GEOMETRIC TOLERANCE
—	STRAIGHTNESS	FORM
⏥	FLATNESS	
○	CIRCULARITY	
⌭	CYLINDRICITY	
⌒	PROFILE OF A LINE	PROFILE
⌓	PROFILE OF A SURFACE	
∠	ANGULARITY	ORIENTATION
⊥	PERPENDICULARITY	
//	PARALLELISM	
⌖	TRUE POSITION	LOCATION
◎	CONCENTRICITY	
⌯	SYMMETRY	
↗	CIRCULAR RUNOUT	RUNOUT
⌰	TOTAL RUNOUT	

THE SYMBOL FOR SYMMETRY IS SOMETIMES ⌖

Figure 12-6 Building blocks

Ⓜ	MAXIMUM MATERIAL CONDITION
Ⓛ	LEAST MATERIAL CONDITION
Ⓢ	REGARDLESS OF FEATURE SIZE
Ⓟ	PROJECTED TOLERANCE ZONE

Figure 12-7 Modifiers used when applying geometric tolerancing

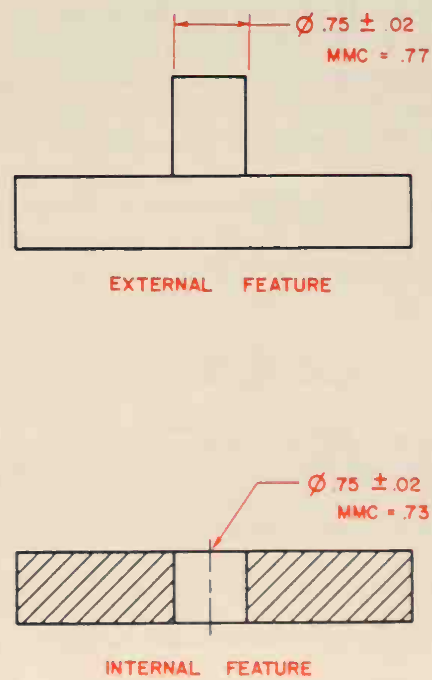


Figure 12-8 MMC of an external and an internal feature

In using this concept, the designer must remember that the MMC of an internal feature is the smallest allowable size. The MMC of an external feature is the largest allowable size within specified tolerance limits inclusive. A rule of thumb to remember is that MMC means *most material.*

Regardless of Feature Size

Regardless of feature size, abbreviated RFS, is a modifier which tells machinists that a tolerance of form or position or any characteristic must be maintained, regardless of the actual produced size of the object. This concept is illustrated in Figure 12-9. In the RFS example, the object is acceptable if produced in sizes from 1.01 inches to .99 inch inclusive. The form control is axis straightness to a tolerance of .02 inch regardless of feature size. This means that the .02 inch axis straightness tolerance must be adhered to, regardless of the produced size of the part.

Contrast this with the MMC example. In this case, the produced sizes are still 1.01 inches, 1.00 inch, and .99 inch. However, because of the MMC modifier, the .02 inch axis straightness tolerance applies only at MMC or 1.01 inches.

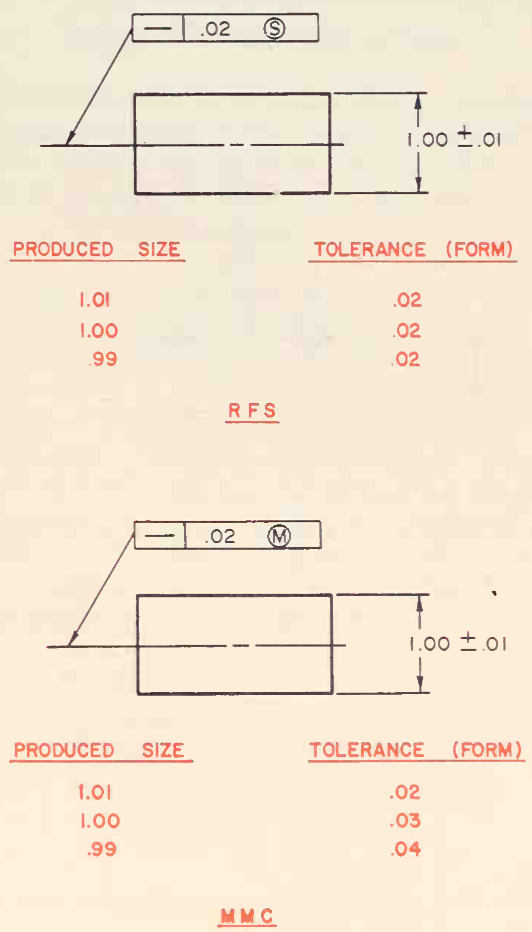


Figure 12-9 Regardless of feature size (RFS)

If the produced size is smaller, the straightness tolerance can be increased proportionally. Of course, this makes the MMC modifier more popular with machinists for several reasons: 1) it allows them greater room for error without actually increasing the tolerance, 2) it decreases the number of parts rejected, 3) it cuts down on unacceptable parts, 4) it decreases the number of inspections required, and 5) it allows the use of functional gaging. All of these advantages translate into substantial financial savings while, at the same time, making it possible to produce interchangeable parts at minimum expense.

Least Material Condition

Least material condition, abbreviated LMC, is the opposite of MMC. It refers to the condition in which the least material exists. This concept is illustrated in Figure 12-10.

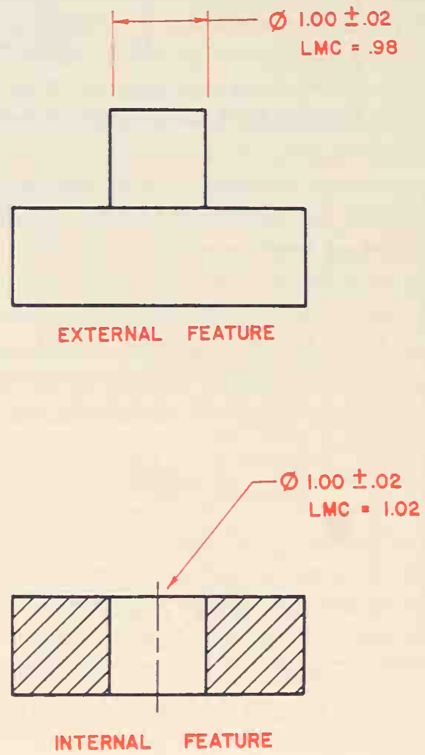


Figure 12-10 Least material condition (LMC)

In the top example, the external feature of the part is acceptable if produced in sizes ranging from .98 inch to 1.02 inches inclusive. The least material exists at .98 inch. Consequently, .98 inch is the LMC.

In the bottom example, the internal feature (hole) is acceptable if produced in sizes ranging from .98 inch to 1.02 inches inclusive. The least material exists at 1.02 inches. Consequently, 1.02 represents the LMC.

Projected Tolerance Zone

Projected tolerance zone is a modifier that allows a tolerance zone established by a locational tolerance to be extended a specified distance beyond a given surface. This concept is discussed further later in this chapter under the heading "True Position."

Datums

Datums are points, lines, axes, surfaces or planes used for referencing features of an object. Datums are identified on drawings by datum "flags" or symbols, Figure 12-11. This figure shows several ways in which datum feature symbols are placed on drawings.

In Part A of the figure, the datum symbol is attached to an extension line. In this example, DATUM A would be the plane upon which the part is resting. In Parts B, C, and D, the datum symbol is associated with a dimension by a dimension line, a leader line or by appearing under a dimension. In these cases, the symbol applies to the entire feature rather than just one surface as in object A.

Figure 12-12 shows the top, front, and right-side views of an object on which the front surface has been designated Datum A. Any depth dimension for this object can be referenced to Datum A. Figure 12-13 shows the proper method for calling out the diameter of a cylindrical object as a datum.

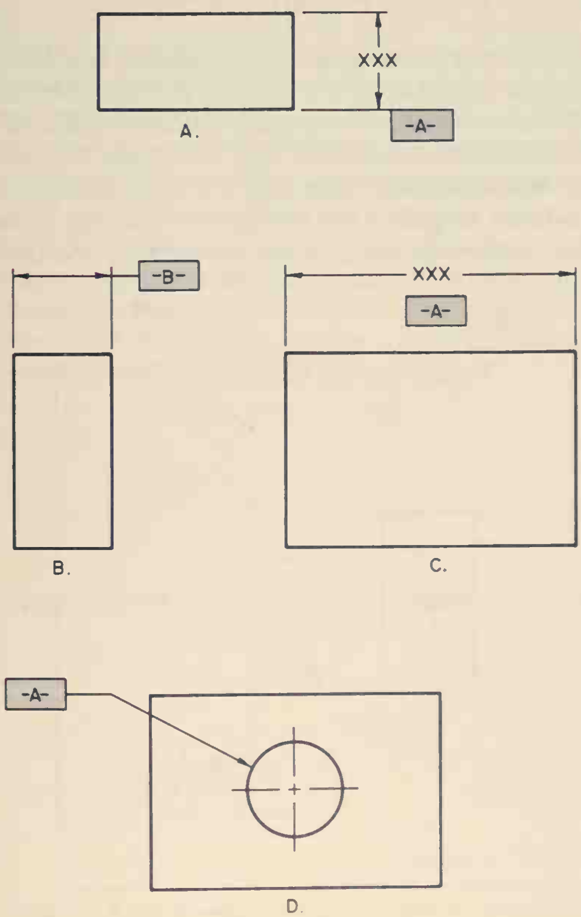


Figure 12-11 Datum flags

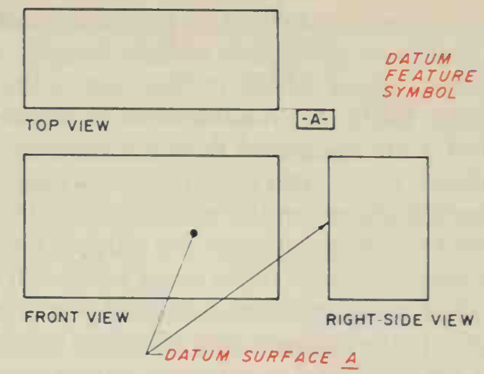


Figure 12-12 Datum callout on a flat object

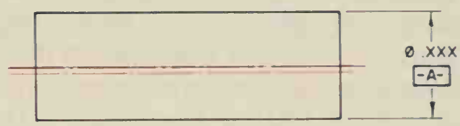


Figure 12-13 Datum callout on a diameter

Establishing Datums

In establishing datums, designers must consider the function of the part, the manufacturing processes that will be used in producing the part, how the part will be inspected, and the part's relationship to other parts after assembly. Designers and drafters must also understand the difference between a datum feature and a datum surface.

A *datum plane* is a theoretically perfect plane from which measurements are made. A *datum surface* is the inexact corresponding surface of the object. This concept is illustrated in Figure 12-14.

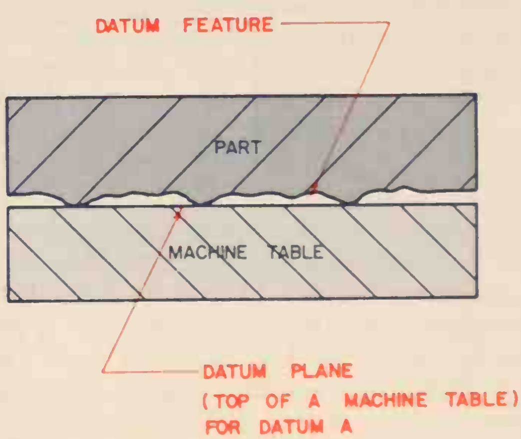


Figure 12-14 Establishing datums

Notice the irregularities on the datum surface. The high points on the datum surface actually establish the datum plane, which, in this case, is the top of a machine table. All measurements referenced to DATUM A are measured from the theoretically perfect datum plane. High point contact is used for establishing datums when the entire surface in question will be a machined surface. On rougher more irregular surfaces, such as those associated with castings, specified point contacts are used for establishing datums. In these cases, only specified points on surfaces are employed to establish datum features.

When specified point contact is used for establishing datums, a minimum of three points is required for the primary datum, a minimum of two for the secondary, and a minimum of one for the tertiary, Figure 12-15. These points are normally located with basic dimensions and identified with datum target symbols, Figure 12-16. A *basic dimension* is a theoretically exact dimension enclosed in a rectangular box.

In Figure 12-16, DATUM A is the top of the object and it is established by points A1, A2, and A3. The characters in each datum target symbol identify the datum by letter and target numbers. DATUM B is the front of the object and DATUM C is the right side.

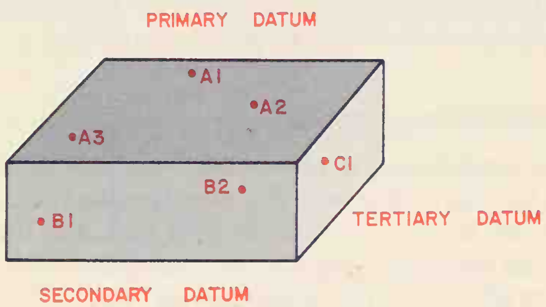


Figure 12-15 Specified point contact for establishing datums

Notice that a datum is called out on a drawing in the view where the surface in question appears as an edge. Notice also that the secondary datum must be perpendicular to the first, and the tertiary datum must be perpendicular to both the primary and secondary datums. These three datums establish what is called the datum frame. The *datum frame* is a hypothetical three-dimensional box into which the object being produced fits and from which measurements can be made.

Figure 12-17 is an example of a "basic dimension." A basic dimension is a theoretically perfect dimension, much like a nominal or design dimension, that is used to locate or specify the size of a feature. Basic dimensions are enclosed in rectangular boxes, as shown in Figure 12-17.

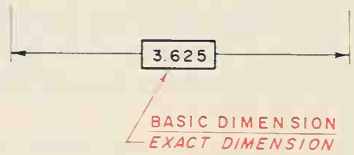


Figure 12-17 Basic dimensions

Feature Control Symbol

The *feature control symbol* is a rectangular box in which all data referring to the subject feature control are placed, including: the symbol, datum references, the feature control tolerance, and modifiers. These various feature control elements are separated by vertical lines. (Figure 12-5 contains a drawing showing how feature control symbols are actually composed.)

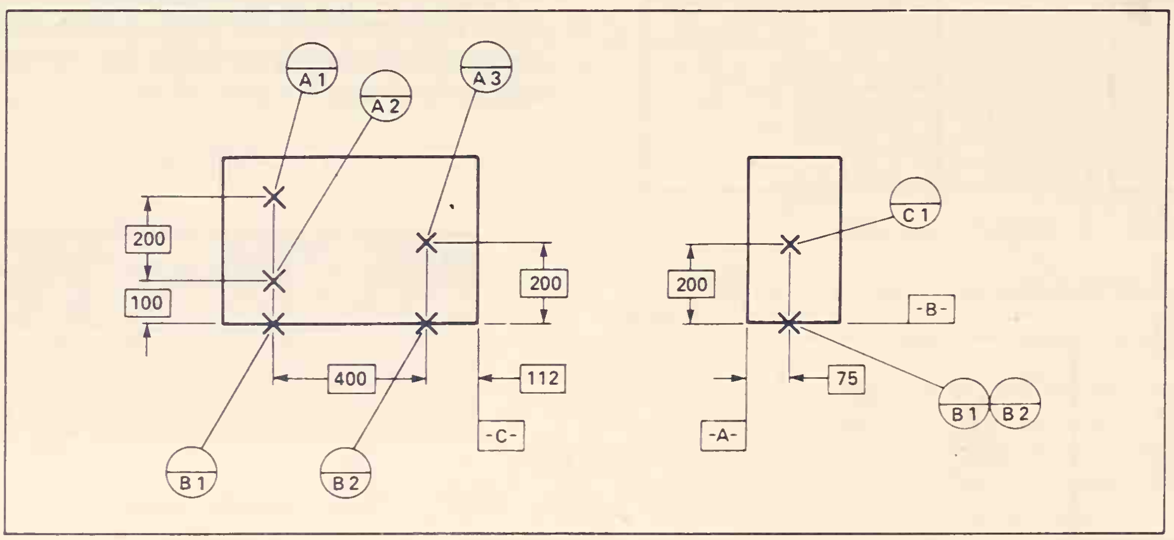


Figure 12-16 Datum target symbols with basic dimensions (*From* ANSI Y14.5M-1982)

The order of the data contained in a feature control frame is important. The first element is the feature control symbol. Next is the zone descriptor, such as a diameter symbol where applicable. Then, there is the feature control tolerance, modifiers when used, and datum references listed in order from left to right, Figure 12-18.

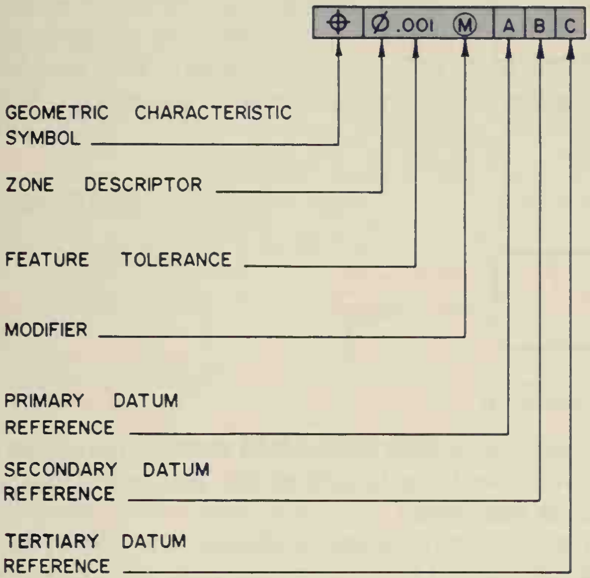


Figure 12-18 Order of elements in a feature control symbol

Figures 12-19 through 12-23 illustrate how feature control symbols are developed for a variety of design situations. Figure 12-19 is a feature control symbol which specifies a .005 tolerance for symmetry and no datum reference. Figure 12-20 specifies a tolerance of .005 for the true position of a feature relative to Datum A. Figures 12-21 and 12-22 show the proper methods for constructing feature control symbols with two and three datum references, respectively. Figure 12-23 illustrates a feature control symbol with a modifier and a controlled datum added.

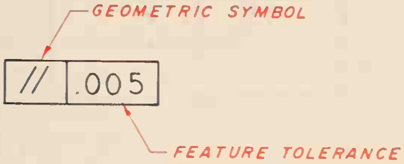


Figure 12-19 Feature control symbol with no datum reference

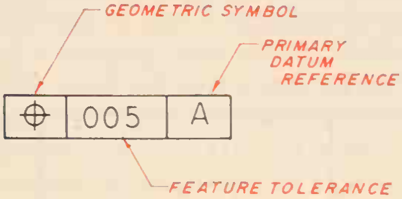


Figure 12-20 Feature control symbol with one datum reference

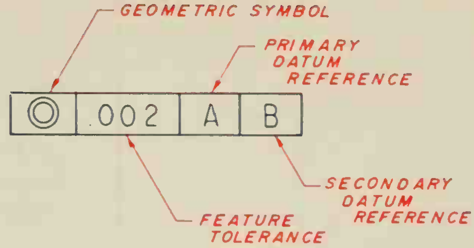


Figure 12-21 Feature control symbol with two datum references

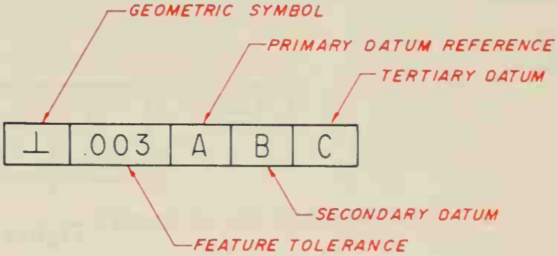


Figure 12-22 Feature control symbol with three datum references

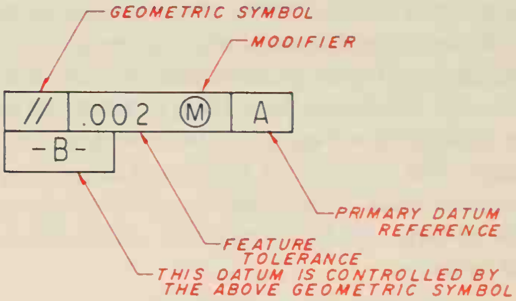


Figure 12-23 Feature control symbol with a modifier

True Position

True position is the theoretically exact location of the center line of a product feature such as a hole. The tolerance zone created by a position tolerance is an imaginary cylinder, the diameter of which is equal to the stated position tolerance. The dimensions used to locate a feature, that is to have a position tolerance, must be basic dimensions.

Figure 12-24 contains an example of a part with two holes drilled through it. The holes have a position tolerance relative to three datums: A, B, and C. The holes are located by basic dimensions. The feature control frame states that the positions of the center lines of the holes must fall within cylindrical tolerance zones having diameters of .030 inch at MMC relative to DATUMS A, B, and C. The modifier indicates that the .030 inch tolerance applies only

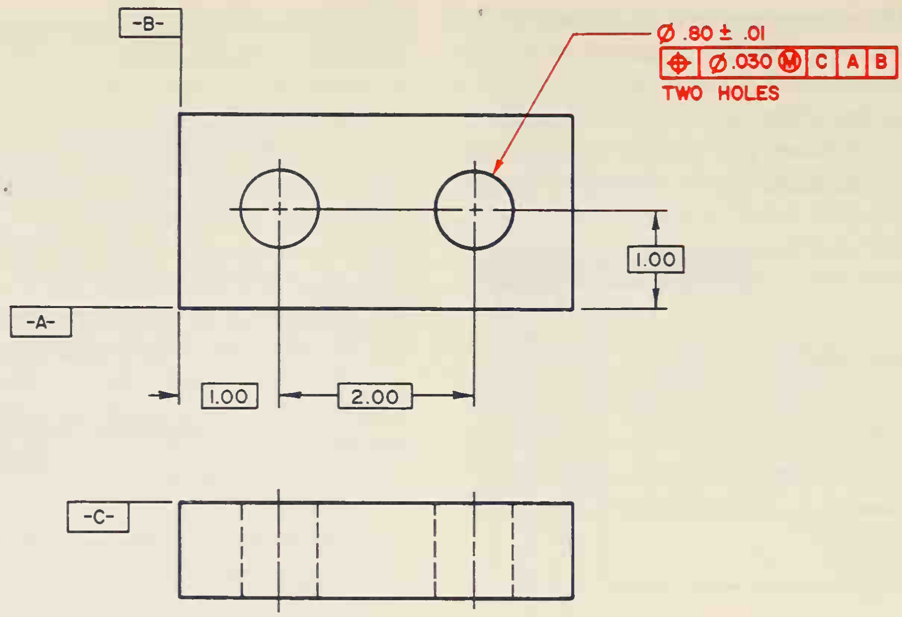


Figure 12-24 True position

at MMC. As the holes are produced larger than MMC, the diameter of the tolerance zones can be increased correspondingly.

Figure 12-25 illustrates the concept of the cylindrical tolerance zone from Figure 12-24. The feature control frame is repeated showing a .030 inch diameter tolerance zone. The broken-out section of the object from Figure 12-24 provides the interpretation. The cylindrical tolerance zone is shown in phantom lines. The center line of the hole is acceptable as long as it falls anywhere within the hypothetical cylinder.

Using the Projected Tolerance Zone Modifier

As stated previously, a *projected tolerance zone* is a tolerance zone that extends beyond the surface of a part. When a projected tolerance zone modifier is used, the surface in question must be identified as a datum and the length of the projected tolerance zone specified.

The tolerance zone illustrated in Figure 12-26 has a depth equal to that of the part through which it extends. On occasion, there is a need to extend a tolerance zone beyond the surface of a part. ANSI Y14.5M-1982 recommends the use of the projected tolerance zone concept when the variation in perpendiculars of threaded or press-fit holes could cause fasteners, such as screws, studs, or pins, to interfere with mating parts. In these cases, the projected tolerance zone concept is used.

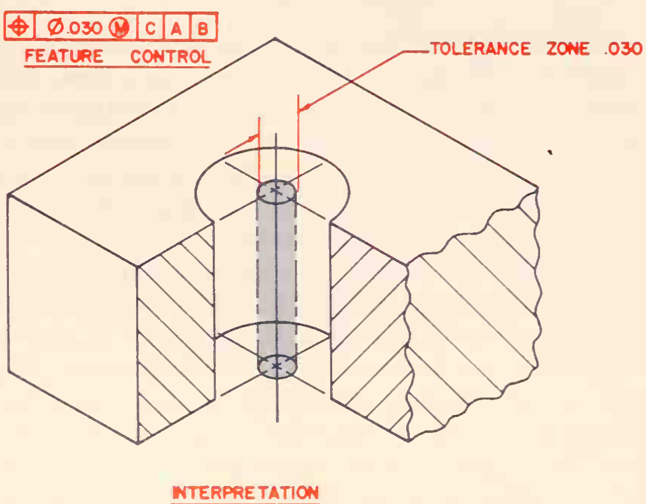


Figure 12-25 Cylindrical tolerance zone

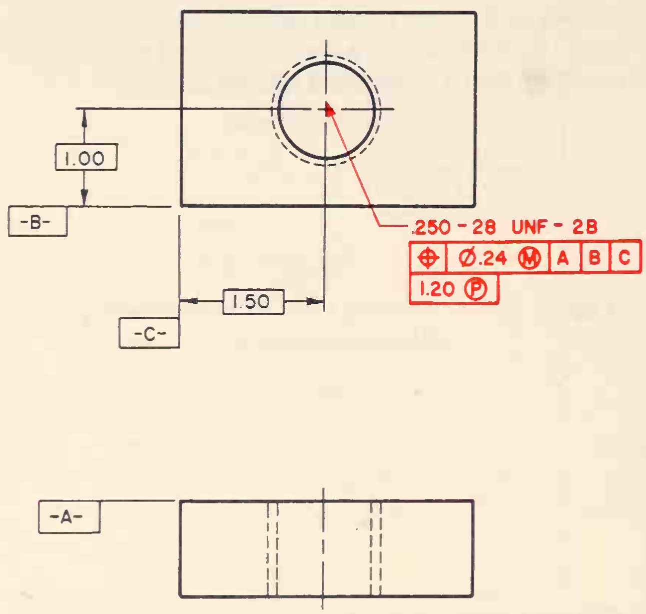


Figure 12-26 Projected tolerance zone

Flatness

Flatness is a feature control of a surface which requires all elements of the surface to lie within two hypothetical parallel planes. When flatness is the feature control, a datum reference is neither required nor proper.

Figure 12-27 shows how flatness is called out in a drawing and the effect such a callout has on the produced part. The surface indicated must be flat within a tolerance zone of .002, as shown in Figure 12-27 (right).

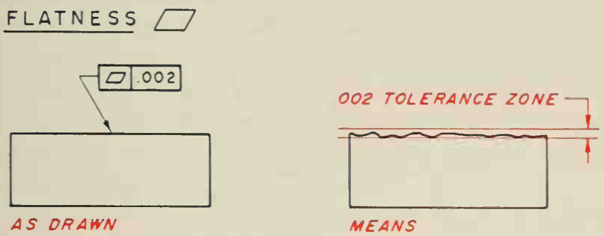


Figure 12-27 Flatness

Flatness is specified when size tolerances alone are not sufficient to control the form and quality of the surface and when a surface must be flat enough to provide a stable base or a smooth interface with a mating part.

Flatness is inspected for a full indicator movement (FIM) using a dial indicator. FIM is the newer term which has replaced the older "total indicator movement" or TIR. FIM means one full swing of the indicator needle. The dial indicator is set to run parallel to a surface table which is a theoretically perfect surface. The dial indicator is mounted on a stand or height gauge. The machined surface is run under it, allowing the dial indicator to detect irregularities that fall outside of the tolerance zone.

Straightness

Straightness is a feature control of one single element of a surface that must be a straight line to within the stated tolerance. It differs from flatness in that flatness covers an entire surface rather than just one element on a surface. A straightness tolerance yields a tolerance zone of specified width between which all points on the line in question must lie. Straightness is generally applied to longitudinal elements.

Figure 12-28 shows how a straightness tolerance is applied on a drawing. The feature control frame states that any longitudinal element of the surface in the direction indicated must lie between two parallel straight lines that are .002 inch apart.

Straightness, like flatness, does not require a datum reference. Straightness is not additive to the size tolerance and must be contained within the limits of the size tolerance.

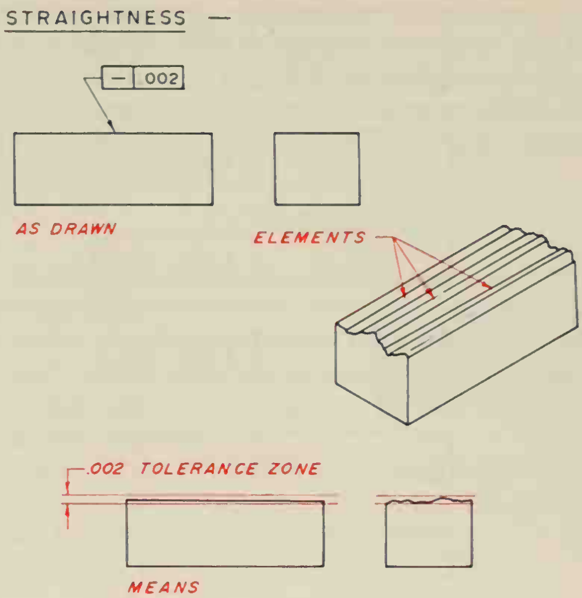


Figure 12-28 Straightness

Figure 12-29 illustrates the relationship between a straightness tolerance and a size tolerance of a part. Each element surface must stay within the specified straightness tolerance zone and within the size tolerance envelope. Straightness is effected by running the single-line elements of a surface under a dial indicator for a full indicator movement (FIM).

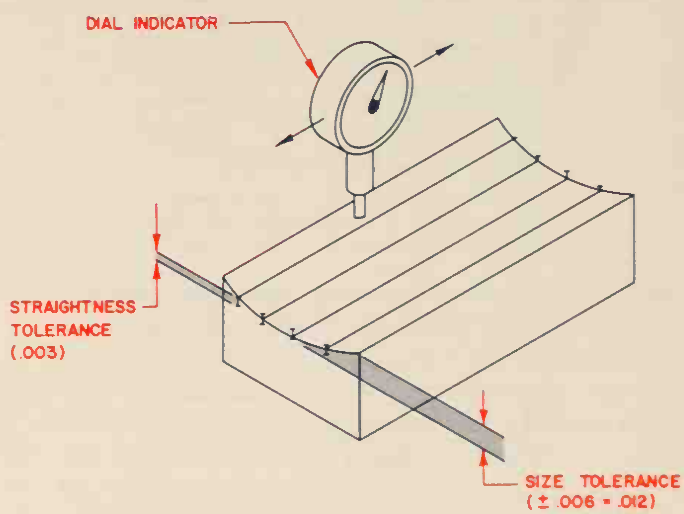


Figure 12-29 Straightness interpreted

Figures 12-30 through 12-33 further illustrate the concept of straightness. Figure 12-30 shows a part with a size tolerance, but no feature control tolerance. For each acceptable size in which the part can be produced, it must be straight. Figure 12-31 is the same part with a straightness tolerance of .002 at maximum material condition applied. The drawing at the top of the figure illustrates how the part would be drawn. The five illustrations below the part as drawn illustrate the actual shape of the object with

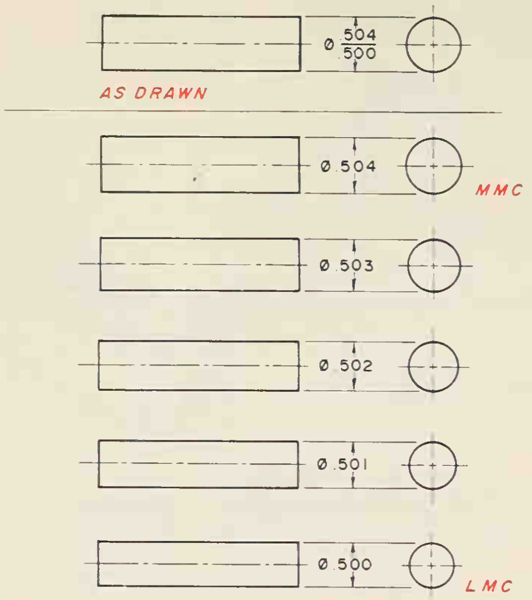
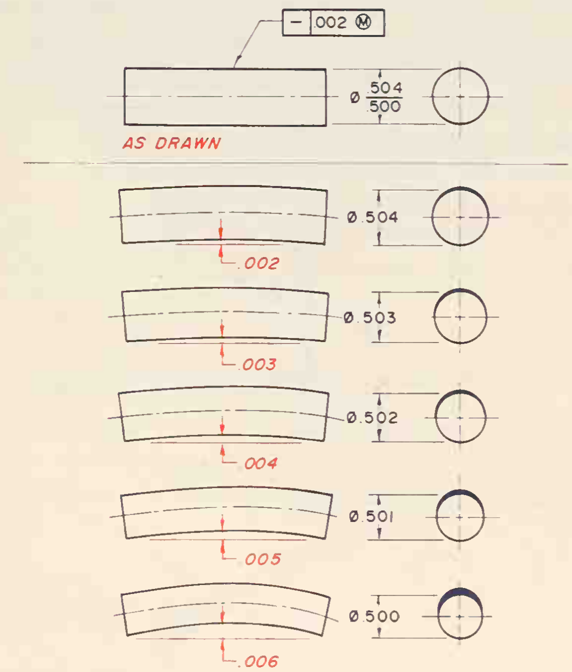


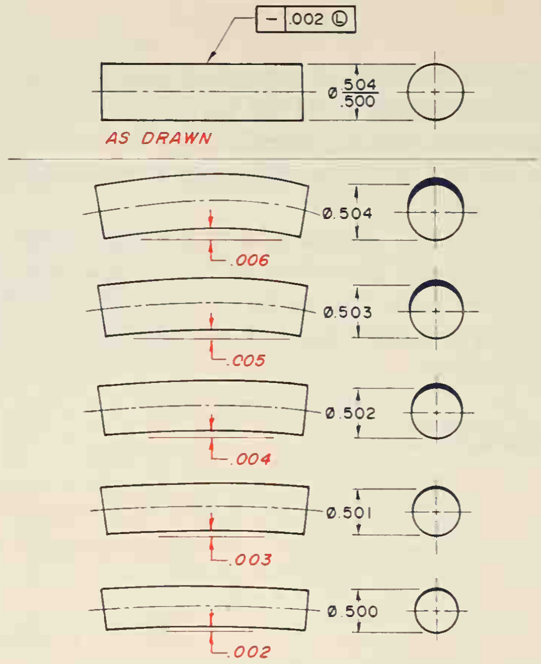
Figure 12-30 Object with no feature control symbol



MANUFACTURED SIZE	.504	.503	.502	.501	.500
OUT-OF-STRAIGHTNESS	.002	.003	.004	.005	.006

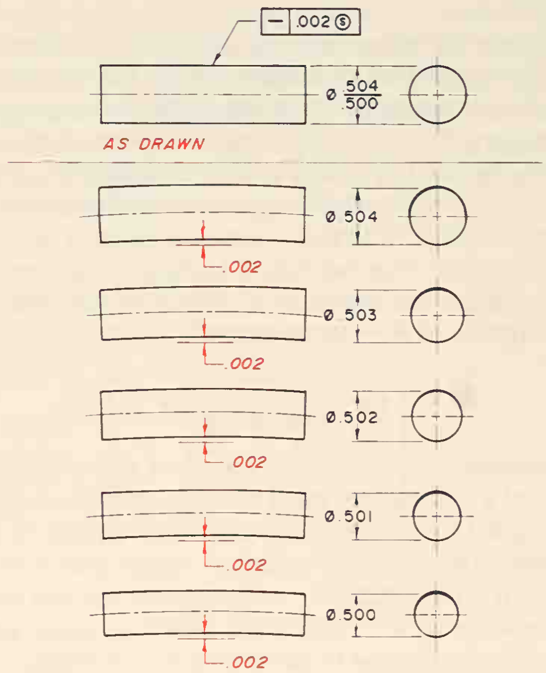
Figure 12-31 Straightness at MMC

each corresponding produced size. Since the .002 straightness tolerance applies at maximum material condition, the amount that the part can be out of straightness increases correspondingly as the produced size decreases. The table at the bottom of Figure 12-31 summarizes the manufactured sizes and the corresponding amounts that the part can be out of straightness for each side.



MANUFACTURED SIZE	504	.503	502	.501	500
OUT-OF-STRAIGHTNESS	.006	.005	.004	.003	.002

Figure 12-32 Straightness at LMC



MANUFACTURED SIZE	504	.503	.502	.501	.500
OUT-OF-STRAIGHTNESS	.002	.002	.002	.002	.002

Figure 12-33 Straightness at RFS

Figure 12-32 is an example of the same part with a .002 straightness tolerance at least material condition. This results in the opposite effect of what occurred in Figure 12-31. Notice that the .002 straightness tolerance applies at the least material condition. As the actual produced size increases, the amount of out of straightness allowed increases correspondingly.

Figure 12-33 illustrates the same part from a .002 straightness tolerance and a regardless of feature size modifier. Notice in this example that the .002 straightness tolerance applies regardless of the actual produced size of the part.

Circularity (Roundness)

Circularity, sometimes referred to as *roundness*, is a feature control for a surface of revolution (cylinder, sphere, cone, and so forth). It specifies that all points of a surface must be equidistant from the center line or axis of the object in question. The tolerance zone for circularity is formed by two concentric and coplanar circles between which all points on the surface of revolution must lie.

Figure 12-34 illustrates how circularity is called-out on a drawing and provides an interpretation of what the circularity tolerance actually means. At any selected cross section of the part, all points on the surface must fall within the zone created by the two concentric circles. At any point where circularity is measured, it must fall within the size tolerance. Notice that a circularity tolerance cannot specify a datum reference.

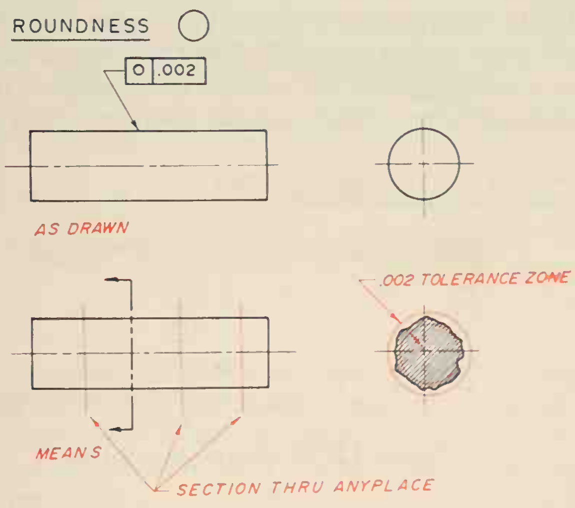


Figure 12-34 Circularity (roundness)

Circularity establishes elemental single-line tolerance zones that may be located anywhere along a surface. The tolerance zones are taken at any cross section of the feature. Therefore, the object may be spherical, cylindrical, tapered, or even hourglass shaped so long as the cross-section for inspection is taken at 90° to the nominal axis of the object. A circularity tolerance is inspected using a dial indicator and making readings relative to the axis of the feature. In measuring a circularity tolerance, the full indicator movement (FIM) of the dial indicator should not be any larger than the size tolerance, and there should be several measurements made at different points along the surface of the diameter. All measurements taken must fall within the circularity tolerance.

Cylindricity

Cylindricity is a feature control in which all elements of a surface of revolution form a cylinder. It gives the effect of circularity extended the entire length of the object, rather than just as a specified cross section. The tolerance zone is formed by two hypothetical concentric cylinders.

Figure 12-35 illustrates how cylindricity is called-out on a drawing. Notice that a cylindricity tolerance does not require a datum reference.

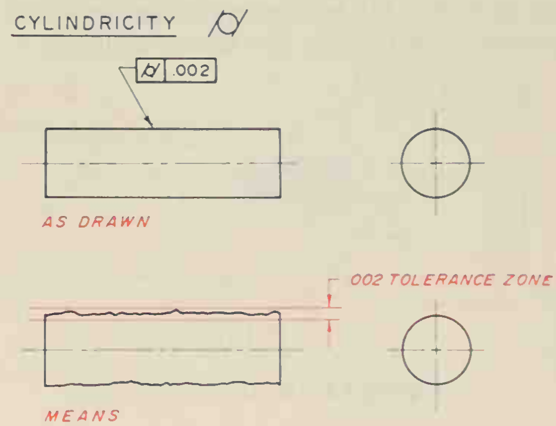


Figure 12-35 Cylindricity

Figure 12-35 also provides an illustration of what the cylindricity tolerance actually means. Two hypothetical concentric cylinders form the tolerance zone. The outside cylinder is established by the outer limits of the object at its produced size within specified size limits. The inner cylinder is smaller (on radius) by a distance equal to the cylindricity tolerance.

Cylindricity requires that all elements on the surface fall within the size tolerance and the tolerance established by the feature control.

A cylindricity tolerance must be less than the size tolerance and is not additive to the maximum material condition of the feature. Cylindricity is inspected by passing the tolerance object through a gauge. The object should pass through a gauge that is equal to or greater than the diameter of the external envelope establishing the cylindrical tolerance zone. It should not pass through a gauge that is slightly smaller than the internal envelope which establishes the cylindrical tolerance zone.

Angularity

Angularity is a feature control in which a given surface, axis, or center plane must form a specified angle with a datum other than 90°. Consequently, an angularity tolerance requires a datum reference. The tolerance zone formed by an angularity callout consists of two hypothetical parallel planes which form the specified angle with the datum. All points on the angular surface or along the angular axis must lie between these parallel planes.

Figure 12-36 illustrates how an angularity tolerance is called out on a drawing. Notice that the specified angle is enclosed in a BASIC box. This is required when applying an angularity tolerance. Figure 12-36 also provides an interpretation of what the angularity tolerance actually means. Notice that the outside plane of the tolerance zone is established by the outermost extremities of the angular surface. The inner plane is measured in a distance equal to the angularity tolerance. All elements of the toleranced surface must lie within the size tolerance limits.

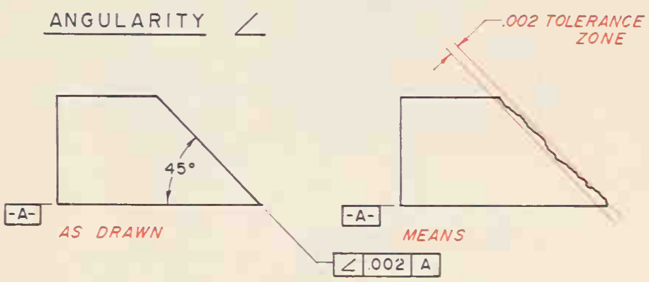


Figure 12-36 Angularity

Parallelism

Parallelism is a feature control that specifies that all points on a surface, center plane, axis or line must be equidistant from a datum. Consequently, a parallelism tolerance must have a datum reference. A parallelism tolerance zone is formed by two hypothetical planes that are parallel to a specified datum. They are spaced apart at a distance equal to the parallelism tolerance.

Figure 12-37 illustrates how a parallelism is called-out on a drawing and provides an interpretation of what the parallelism tolerance actually means. Notice that all elements of the toleranced surface must fall within the size limits.

Notice in Figure 12-37 that the .002 parallelism tolerance is called out relative to Datum A. You must specify a datum when calling out a parallelism tolerance. Parallelism should be specified when features such as surfaces, axes, and planes are required to lie in a common orientation. Parallelism is inspected by placing the part on an inspection table and running a dial indicator a full indicator movement across the surface of the part.

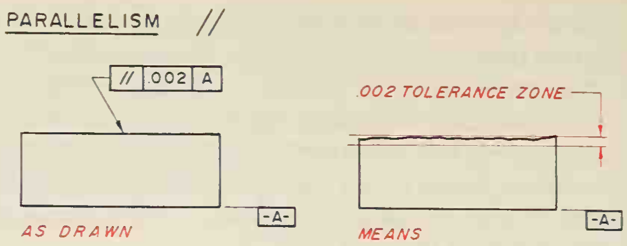


Figure 12-37 Parallelism

Perpendicularity

Perpendicularity is a feature control which specifies that all elements of a surface, axis, center plane, or line form a 90° angle with a datum. Consequently, a perpendicularity tolerance requires a datum reference. A perpendicularity tolerance is formed by two hypothetical parallel planes.

Figure 12-38 illustrates how a perpendicularity tolerance is called-out on a drawing and provides an interpretation of what the perpendicularity tolerance actually means. The elements of the toleranced surface must fall within the size limits and between two hypothetical parallel planes that are a distance apart equal to the perpendicularity tolerance.

The perpendicularity of a part such as the one shown in Figure 12-38 could be inspected by clamping the part to an inspection angle. The datum surface should rest against the inspection angle. Then a dial indicator should be passed over the entire surface for a full indicator movement to determine if the perpendicularity tolerance has been complied with.

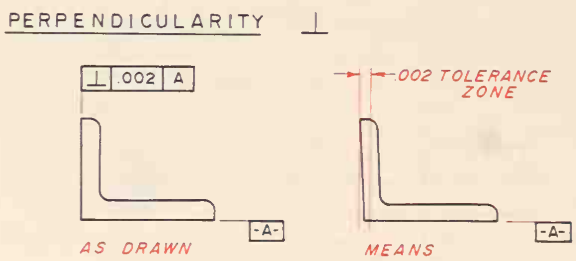


Figure 12-38 Perpendicularity

Profile

Profile is a feature control that specifies the amount of allowance variance of a surface or line elements on a surface. There are three different variations of the profile tolerance: bilateral, unilateral up, and unilateral down, Figures 12-39, 12-40, and 12-41. A profile tolerance is normally used for controlling arcs, curves, and other unusual profiles not covered by the other feature controls. It is a valuable feature control for use on objects that are so irregular that other feature controls do not easily apply.

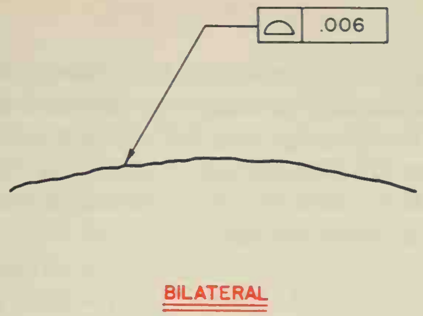


Figure 12-39 Bilateral profile tolerance

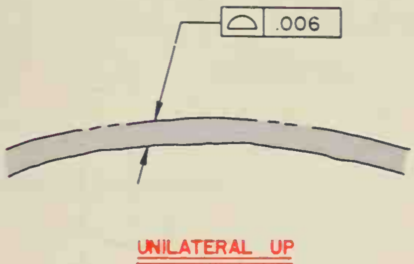


Figure 12-40 Unilateral up profile

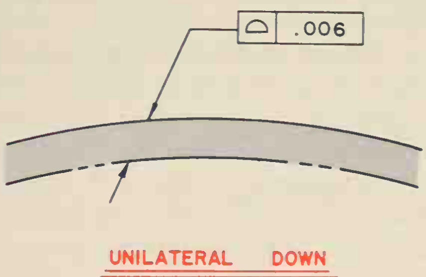


Figure 12-41 Unilateral down profile

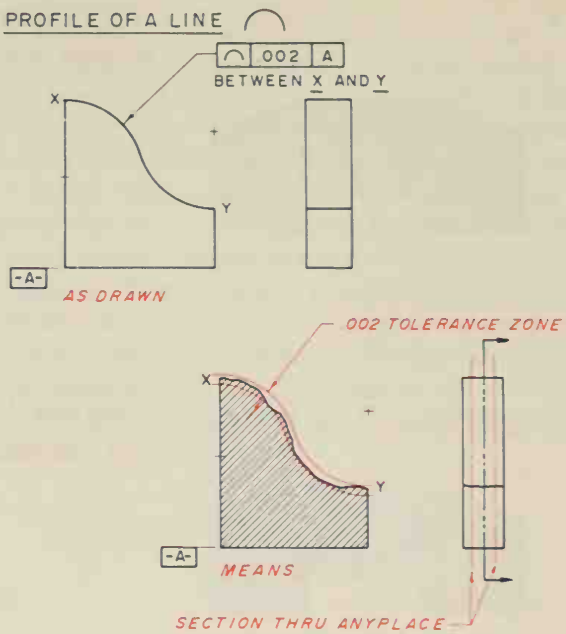


Figure 12-42 Profile of a line

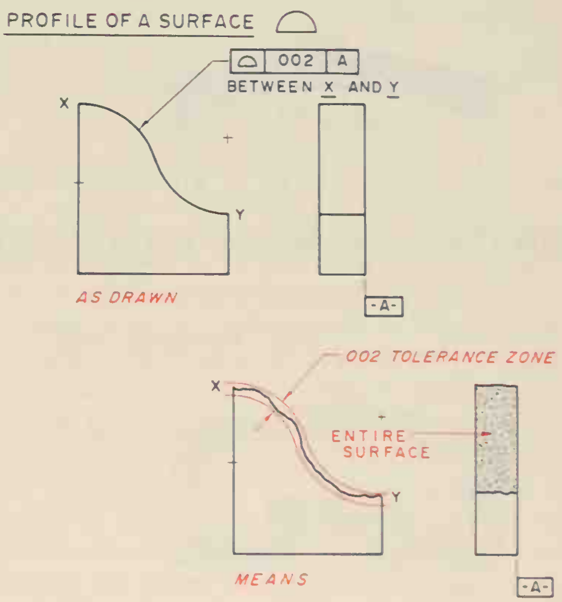


Figure 12-43 Profile of a surface

When applying a profile tolerance, the symbol used indicates whether the designer intends profile of a line or profile of a surface, Figures 12-42 and 12-43. *Profile of a line* establishes a tolerance for a given single element of a surface. *Profile of a surface* applies to the entire surface. The difference between profile of a line and profile of a surface is similar to the difference between circularity and cylindricity.

When using a profile tolerance, drafters and designers should remember to use phantom lines to indicate whether the tolerance is applied unilaterally up or unilaterally down. A bilateral profile tolerance requires no phantom lines. An ALL AROUND symbol should also be placed on the leader line of the feature control frame to specify whether the tolerance applies ALL AROUND or between specific points on the object, Figure 12-44.

Figure 12-45 provides an interpretation of what the BETWEEN A & B profile tolerance in Figure 12-44 actually means. The rounded top surface, and only the top surface, of the object must fall within the specified tolerance zone. Figure 12-46 provides an interpretation of what the ALL AROUND profile tolerance in Figure 12-44 actually means. The entire surface of the object, all around the object, must fall within the specified tolerance zone.

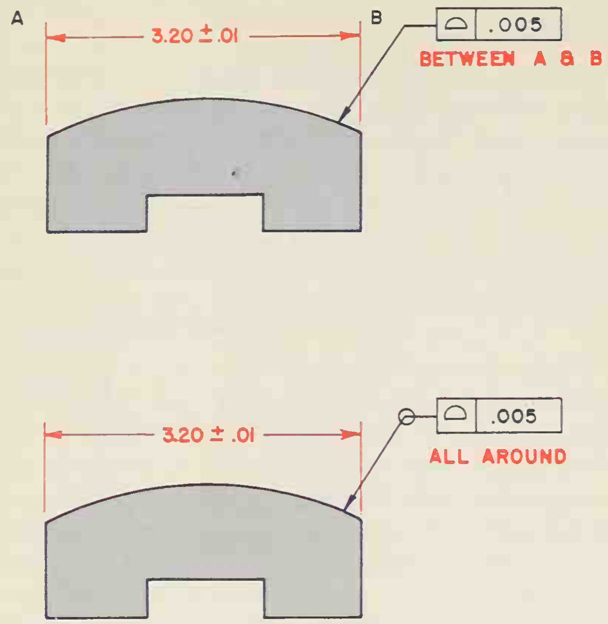


Figure 12-44 Profile "ALL AROUND"

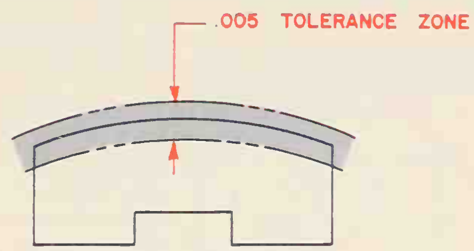


Figure 12-45 Interpretation of "BETWEEN A & B"

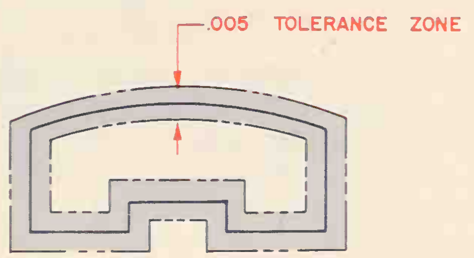


Figure 12-46 Interpretation of "ALL AROUND"

Profile tolerances may be inspected using a dial indicator. However, because the tolerance zone must be measured at right angles to the basic true profile and perpendicular to the datum, the dial indicator must be set up to move and read in both directions. Other methods of inspecting profile tolerances are becoming more popular, however. Optical comparators are becoming widely used for inspecting profile tolerances. An optical comparator magnifies the silhouette of the part and projects it onto a screen where it is compared to a calibrated grid or template so that the profile and size tolerances may be inspected visually.

Runout

R*unout* is a feature control that limits the amount of deviation from perfect form allowed on surfaces or rotation through one full rotation of the object about its axis. Revolution of the object is around a datum axis. Consequently, a runout tolerance does require a datum reference.

Runout is most frequently used on objects consisting of a series of concentric cylinders and other shapes of revolution that have circular cross sections; usually, the types of objects manufactured on lathes, Figures 12-47 and 12-48.

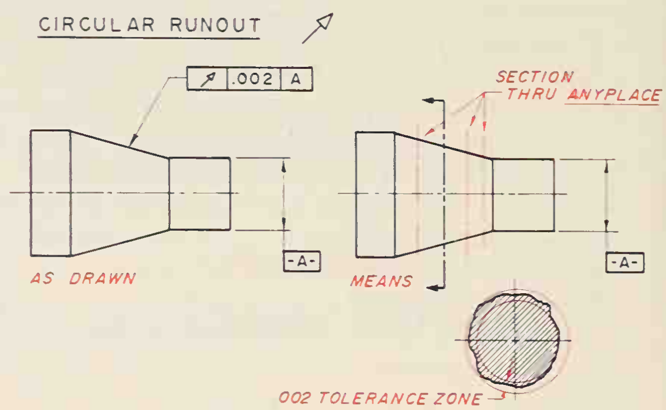


Figure 12-47 Circular runout

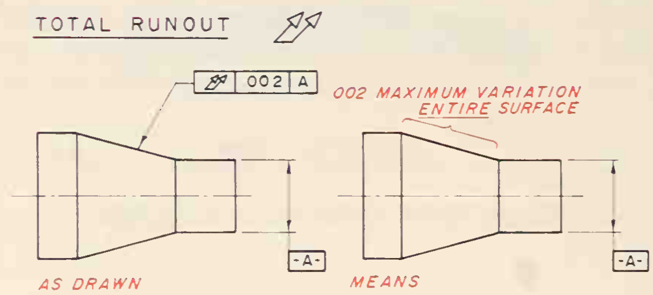


Figure 12-48 Total runout

Notice in Figures 12-47 and 12-48 that there are two types of runout: circular runout and total runout. The circular runout tolerance applies at any single-line element through which a section passes. The total runout tolerance applies along an entire surface, as illustrated in Figure 12-48. Runout is most frequently used when the actual produced size of the feature is not as important as the form, and the quality of the feature must be related to some other feature. Circular runout is inspected using a dial indicator along a single fixed position so that errors are read only along a single line. Total runout requires that the dial indicator move in both directions along the entire surface being toleranced.

Concentricity

It is not uncommon in manufacturing to have a part made up of several subparts all sharing the same center line or axis. Such a part is illustrated in Figure 12-49. In such a part it is critical that the center line for each subsequent subpart be concentric with the center lines of the other subparts. When this is the case, a concentricity tolerance is applied. A concentricity tolerance locates the axis of a feature relative to the axis of a datum. A concentricity tolerance deals only with the center-line relationship. It does not affect the size, form, or surface quality of the part. Concentricity deals only with axial relationships. Regardless of how large or small the various subparts of an overall part are, only their axes are required to be concentric. A concentricity tolerance creates a cylindrical tolerance zone in which all center lines for each successive subpart of an overall part must fall. This concept is illustrated in Figure 12-50. A concentricity tolerance is inspected by a full indicator movement of a dial indicator.

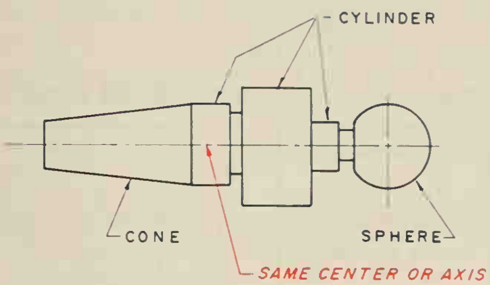


Figure 12-49 Part with concentric subparts

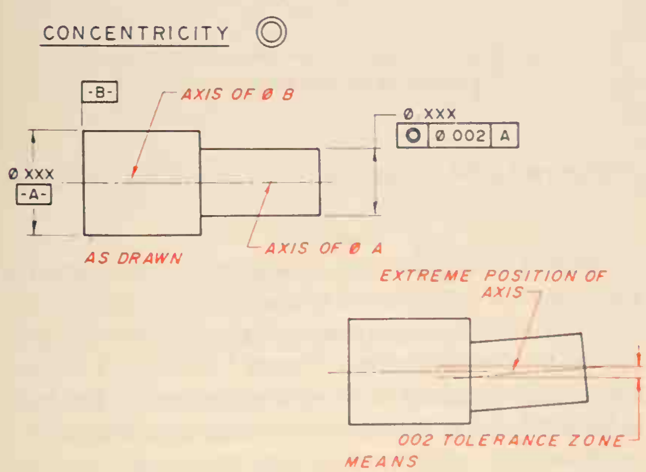


Figure 12-50 Concentricity

Symmetry

Parts that are symmetrically disposed about the center plane of a datum feature are common in manufacturing settings. If it is necessary that a feature be located symmetrically with regard to the center plane of a datum feature, a symmetry tolerance may be applied, Figure 12-51. The part in Figure 12-51 is symmetrical about a center plane that is perpendicular to Datum A. To ensure that the part is located symmetrically with respect to the center plane, a .002 symmetry tolerance is applied. This creates a .002 tolerance zone within which the center plane in question must fall, as illustrated on the right-hand side of Figure 12-51.

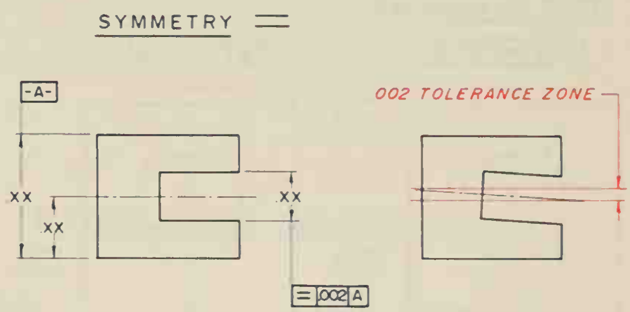


Figure 12-51 Symmetry

True Positioning

True position tolerancing is used to locate features of parts that are to be assembled and mated. True position is symbolized by a circle overlaid by a large plus sign or cross. This symbol is followed by the tolerance, a modifier when appropriate, and a reference datum, Figure 12-52. Figures 12-53 and 12-54 illustrate the difference between conventional and true position dimensioning. The tolerance dimensions shown in Figure 12-53 create a square tolerance zone. This means that the zone within which the center line being located by the dimensions must fall takes the shape of a square. As you can see in Figure 12-54, the tolerance zone is round when true position dimensioning is used. The effect of this on manufacturing is that the round tolerancing zone with true position dimensioning increases the size of the tolerance zone by 57%, Figure 12-55. This means that for the same tolerance the machinist has 57% more room for error without producing an out-of-tolerance part.

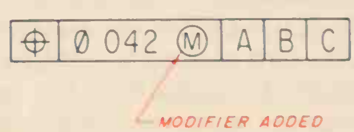


Figure 12-52 True position symbology

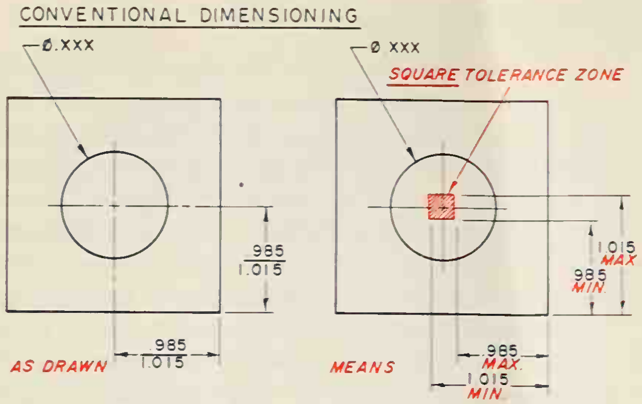


Figure 12-53 Conventional dimensioning

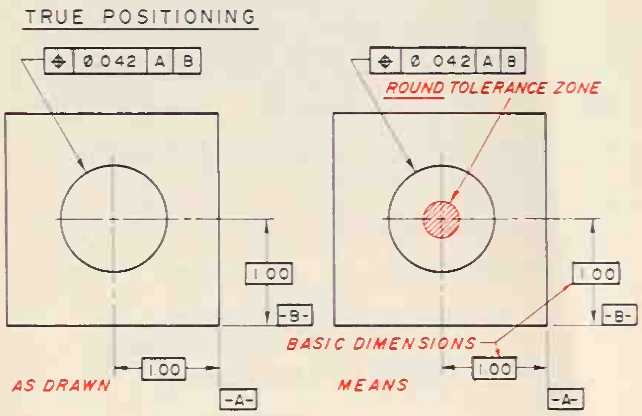


Figure 12-54 True position dimensioning

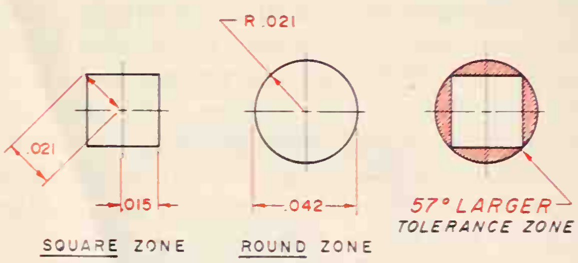


Figure 12-55 Comparison of tolerance zones

When using true position dimensioning, the tolerance is assumed to apply regardless of the feature size unless modified otherwise. Figure 12-56 illustrates the effect of modifying a true position tolerance with a maximum material condition modifier. In this example, a hole is to be drilled through a plate. The maximum diameter is 0.254 and the minimum diameter is 0.250. Therefore, the maximum material condition of the part occurs when the hole is drilled to a diameter of .250. Notice from this example that as the hole size decreases, the positional tolerance increases. At least material condition (.254 diameter), the tolerance zone has a diameter of .042. At

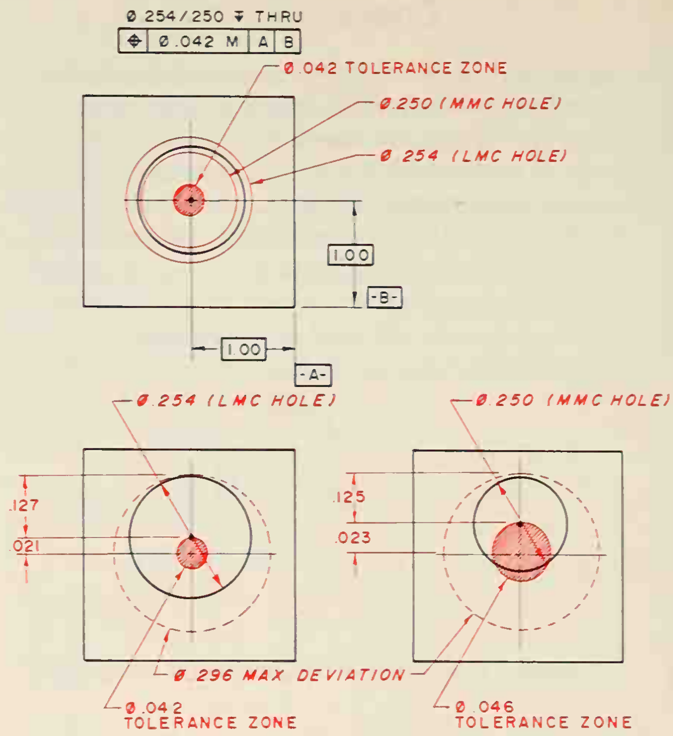


Figure 12-56 True positioning at MMC

maximum material condition (.250 diameter), the tolerance zone increases to .046 diameter. The tolerance zone diameter increases correspondingly as the hole size decreases.

Projected Tolerance Zone

Occasionally when working with mating parts it becomes necessary to control the perpendicularity of a surface of a part to ensure ease of assembly. When this is the case, a designer can specify a projected tolerance zone. This means that the tolerance zone is projected above the surface for a specified distance. Figure 12-57 illustrates the symbol used for specifying a projected tolerance zone.

Figure 12-57 Projected tolerance zone symbol

Figure 12-58 illustrates how a projected tolerance zone symbol is attatched to a normal feature control box and what doing so means for manufacturing personnel. In the example in Figure 12-58, a .25 diameter threaded hole is to be placed in a part. The hole is located using true position dimensioning with a positional tolerance of .042 at maximum material condition. The designer has specified that the tolerance zone is to project above the surface of the part

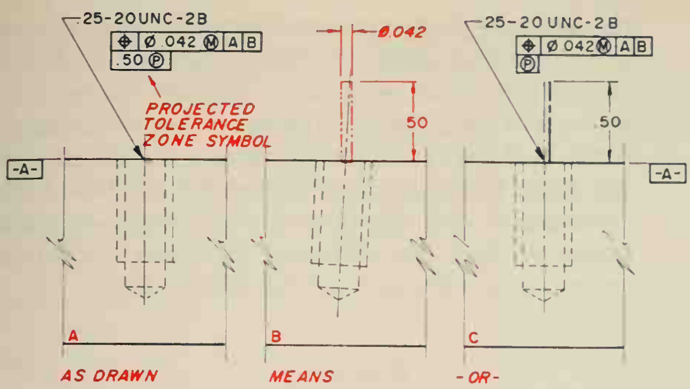


Figure 12-58 Projected tolerance zone

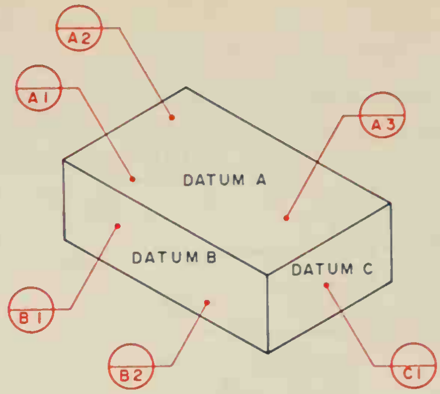


Figure 12-60 Establishing datums

for a distance of .50 of an inch. This is illustrated in Figure A. Figures B and C illustrate what such a callout actually means.

Review of Datums

Fundamental to an understanding of geometric dimensioning and tolerancing is an understanding of datums. Since many engineering and drafting students find the concept of datums difficult to understand, this section will review the concept in depth. It is important to understand datums because they represent the starting point for referencing dimensions to various features on parts and for making calculations relative to those dimensions. Datums are usually physical components. However, they can also be invisible lines, planes, axes, or points that are located by calculations or as they relate to other features. Features such as diameters, widths, holes, and slots, are frequently specified as datum features.

Datums are classified as being a primary, secondary, or tertiary datum, Figure 12-59. Three points are

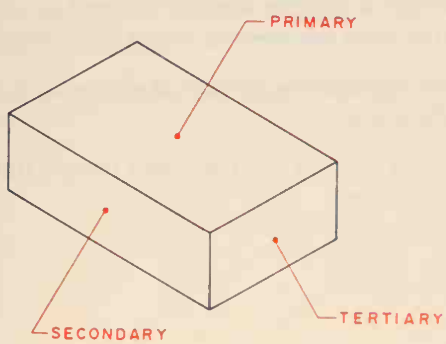


Figure 12-59 Datums

required to establish a primary datum. Two points are required to establish a secondary datum. One point is required to establish a tertiary datum, Figure 12-60. Each point used to establish a datum is called off by a datum target symbol, Figure 12-61.

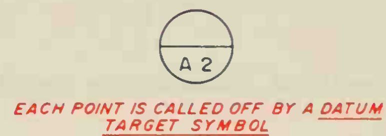


Figure 12-61 Datum target symbol

The letter designation in the datum target symbol is the datum identifier. For example, the letter A in Figure 12-62 is the datum designator for Datum A. The number 2 in Figure 12-63 is the point designator for Point 2. Therefore, the complete designation of "A2" means Datum A-Point 2.

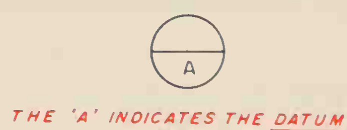


Figure 12-62 Datum designation

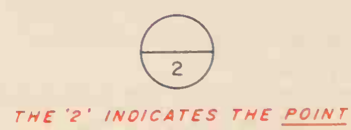


Figure 12-63 Point designator

Figure 12-64 illustrates how the points which establish datums should be dimensioned on a drawing. In this illustration, the three points which establish Datum A are dimensioned in the top view and labeled using the datum target symbol. The two points that establish Datum B are dimensioned in the front view. The one point that establishes Datum C is dimensioned in the right-side view. Figure 12-65 illustrates the concept of datum plane and datum surface. The

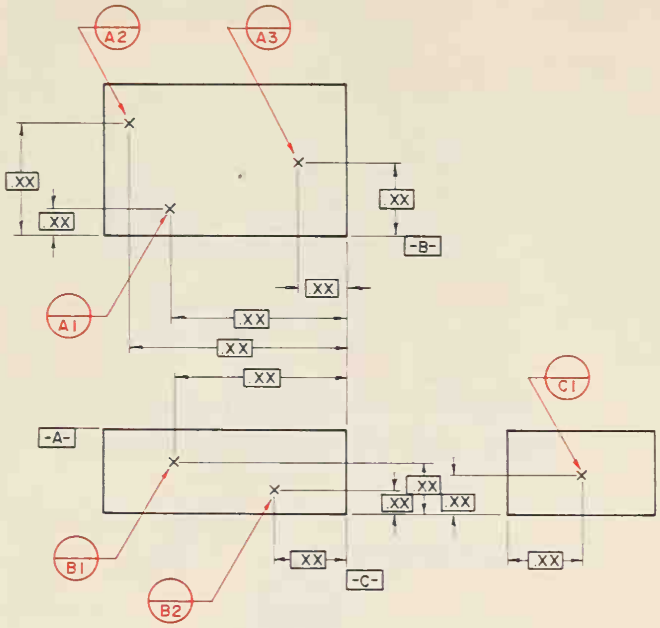


Figure 12-64 Dimensioning datum points

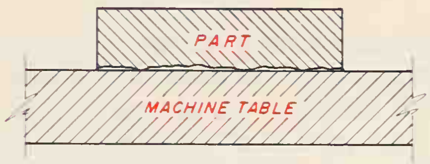


Figure 12-65 Datum plane versus datum surface

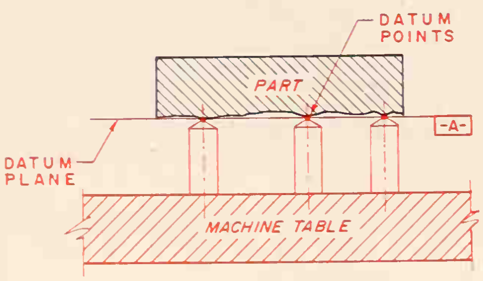


Figure 12-66 Reconciling the datum surface to the datum plane

theoretically perfect plane is represented by the top of the machine table. The less perfect actual datum surface is the bottom surface of the part. Figure 12-66 shows how the differences between the perfect datum plane and the actual datum surface are reconciled. The three points protruding from the machine table correspond with the three points which establish Datum A. Once this difference has been reconciled, inspections of the part can be carried out.

Review

1. Define the term *tolerancing*.
2. What are the two types of size tolerances?
3. What led to the development of geometric dimensioning and tolerancing?
4. Define the term *geometric dimensioning and tolerancing*.
5. Identify the ANSI standard that pertains to geometric dimensioning and tolerancing.
6. Sketch the symbols for the following:
   a. Flatness
   b. Circularity
   c. Straightness
   d. True position
   e. Perpendicularity
   f. Parallelism
   g. Angularity
7. Explain the term *maximum material condition*.
8. Explain the term *regardless of feature size*.
9. Explain the term *least material condition*.
10. What is a datum?
11. How is a datum established on a machined surface?
12. How is a datum established on a cast surface?
13. Sketch a sample feature control symbol that illustrates the proper order of elements.
14. Which feature controls *do not* require a datum reference?
15. Which feature controls *must* have a datum reference?

Chapter Twelve Problems

The following problems are intended to give beginning drafters practice in applying the principles of geometric dimensioning and tolerancing.

The steps to follow in completing the problems are:

Step 1. Study the problem carefully.

Step 2. Make a checklist of tasks you will need to complete.

Step 3. Center the required view or views in the work area.

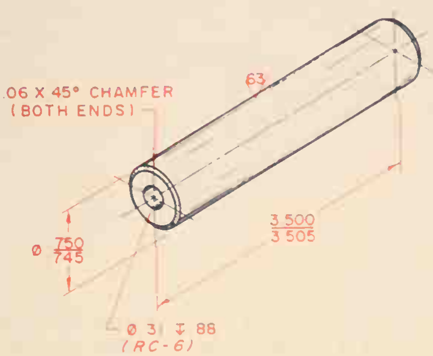
Step 4. Include all dimensions according to ANSI Y14.5M-1982.

Step 5. Re-check all work. If it's correct, neatly fill out the title block using light guidelines and freehand lettering.

Note: These problems do not follow current drafting standards. You are to use the information shown here to develop properly drawn, dimensioned, and toleranced drawings.

Problem 12-1

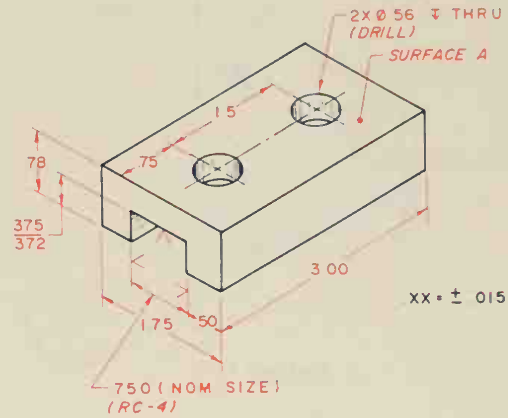
Apply tolerances so that this part is straight to within .004 at MMZ.



Problem 12-1

Problem 12-2

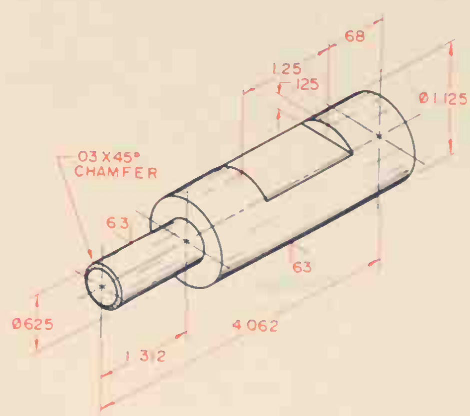
Apply tolerances so that the top surface of this part is flat to within .001 and the two sides of the slot are parallel to each other within .002 RFS.



Problem 12-2

Problem 12-3

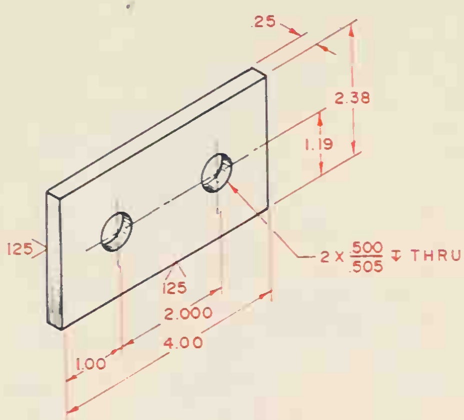
Apply tolerances so that the smaller diameter has a cylindricity tolerance of .005 and the smaller diameter is concentric to the larger diameter to within .002. The shoulder must be perpendicular to the axis of the part to within .002.



Problem 12-3

Problem 12-4

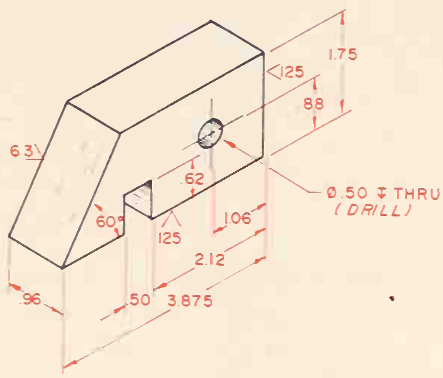
Apply tolerances to locate the holes using true position and basic dimensions relative to datums A-B-C.



Problem 12-4

Problem 12-5

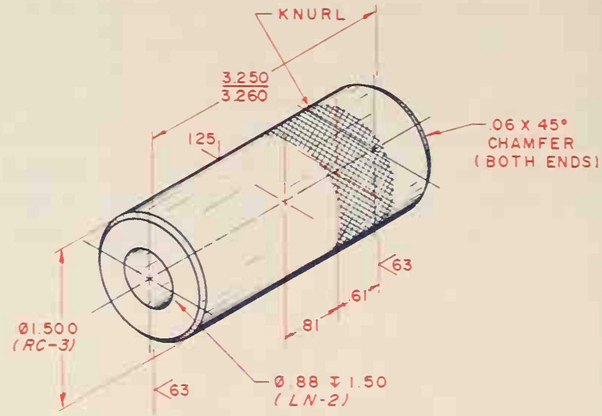
Apply angularity, true position, and parallelism tolerances of .001 to this part. Select the appropriate datums. The parallelism tolerances should be applied to the sides of the slot.



Problem 12-5

Problem 12-6

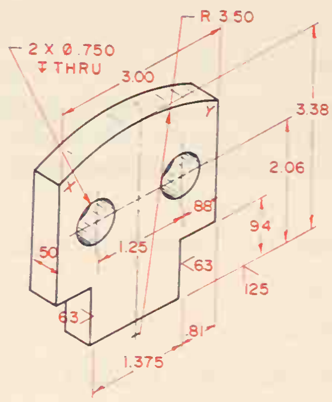
Apply tolerances so that the outside diameter of the part is round to within .004 and the ends are parallel to within .001 at maximum material condition.



Problem 12-6

Problem 12-7

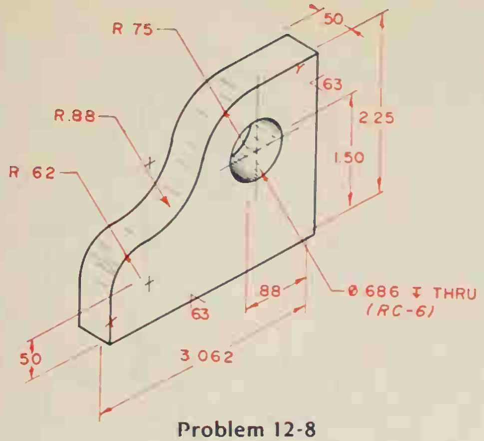
Apply a line profile tolerance to the top of the part between points X and Y of .004. Apply true position tolerances to the holes of .021, and parallelism tolerances of .001 to the two finished sides.



Problem 12-7

Problem 12-8

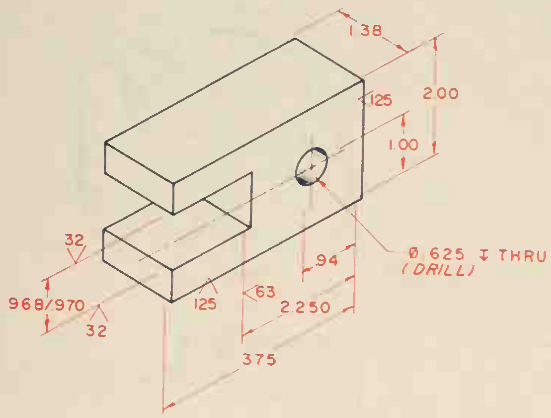
Use the bottom of the part as datum A and the right side of the part as datum B. Apply surface profile tolerances of .001 to the top of the part between points X and Y.



Problem 12-8

Problem 12-9

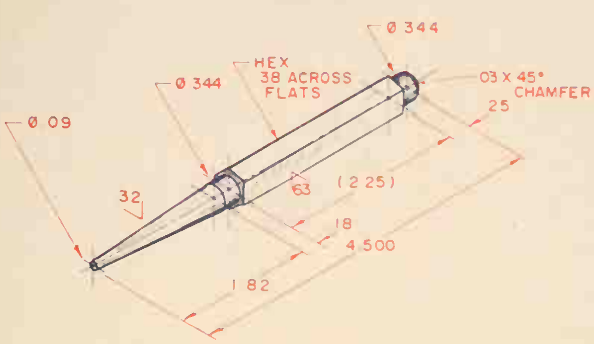
Select datums and apply tolerances in such a way as to ensure that the slot is symmetrical to within .002 with the .50 diameter hole, and the bottom surface is parallel to the top surface to within .004.



Problem 12-9

Problem 12-10

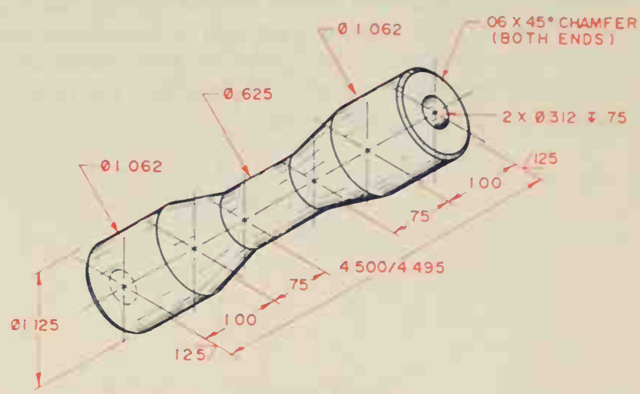
Apply tolerances to this part so that the tapered end has a total runout of .002.



Problem 12-10

Problem 12-11

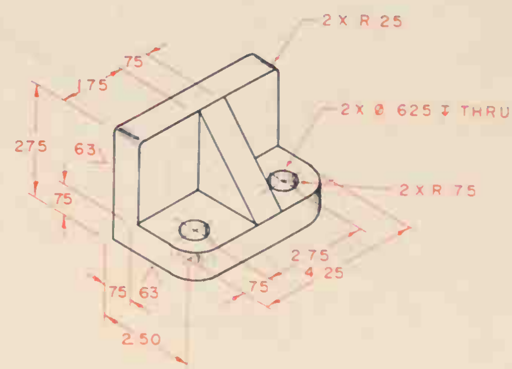
Apply tolerances to this part so that diameters X and Z have a total runout of .02 relative to datum A (the large diameter of the part) and line runout of .004 to the two tapered surfaces.



Problem 12-11

Problem 12-12

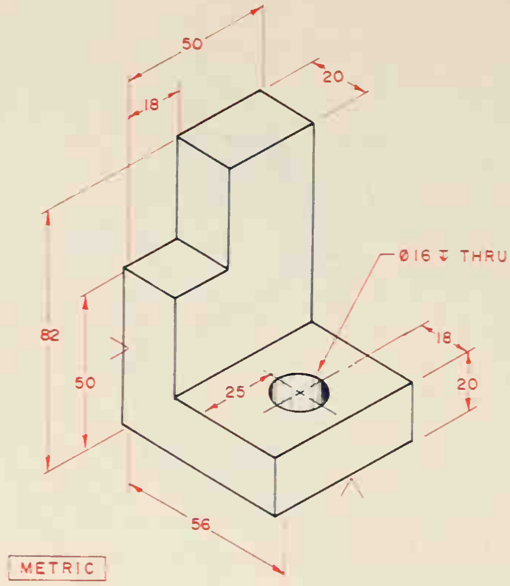
Select datums and apply a true position tolerance of .001 at MMC to the holes, and a perpendicularity tolerance of .003 to the vertical leg of the angle.



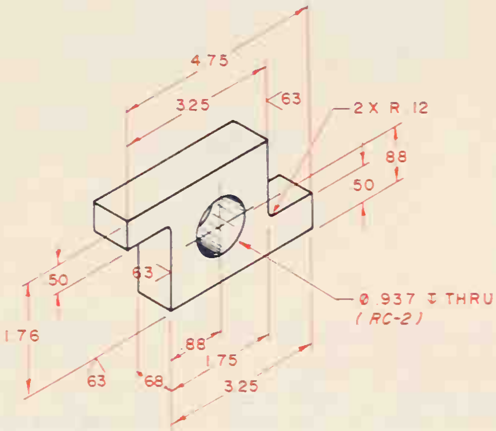
Problem 12-12

Problems 12-13 through 12-30

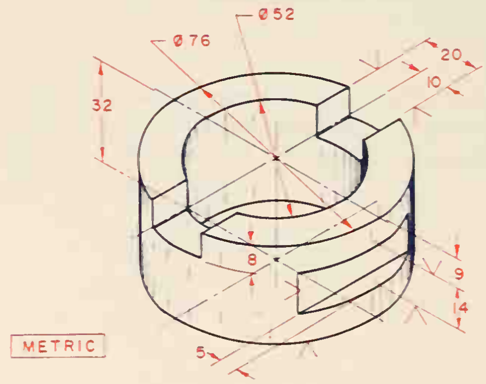
For each of the remaining geometric dimensioning and tolerancing problems, examine the problem closely with an eye to the purpose that will be served by the part. Then select datums, tolerances, and feature controls as appropriate, and apply them properly to the parts. In this way you will begin to develop the skills required of a mechanical designer. Do not overdesign. Remember, the closer the tolerances, and the more feature control applied, the more expensive the part. Try to use the rule of thumb that says: "Apply only as many feature controls and tolerances as absolutely necessary to ensure that the part will properly serve its purpose after assembly."



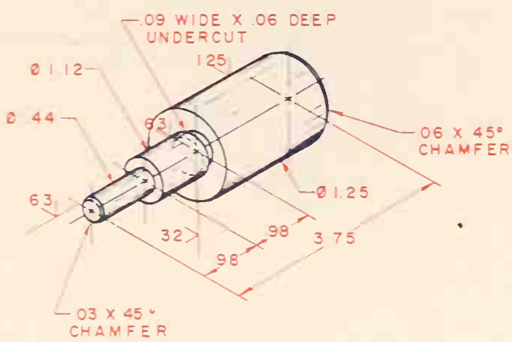
Problem 12-15



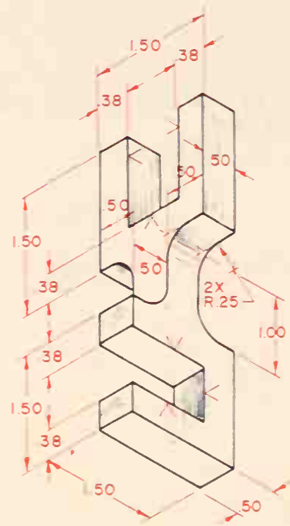
Problem 12-13



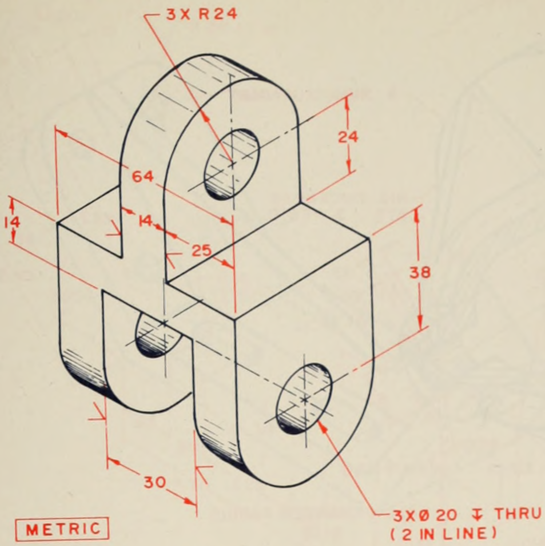
Problem 12-16



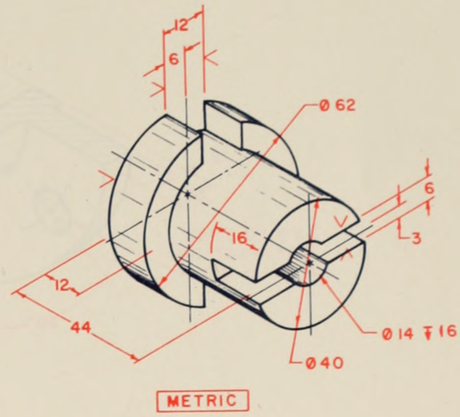
Problem 12-14



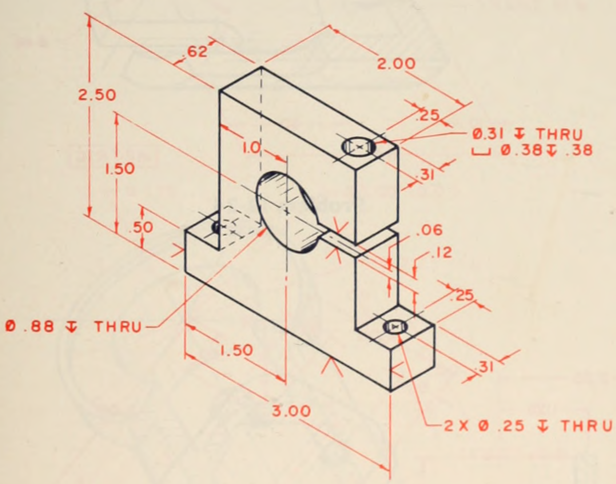
Problem 12-17



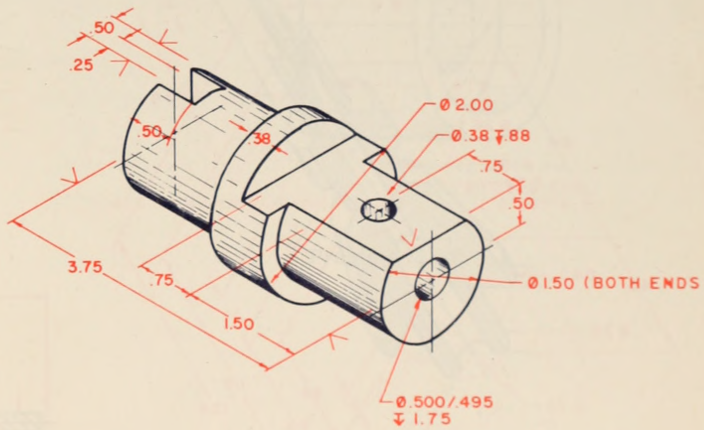
Problem 12-18



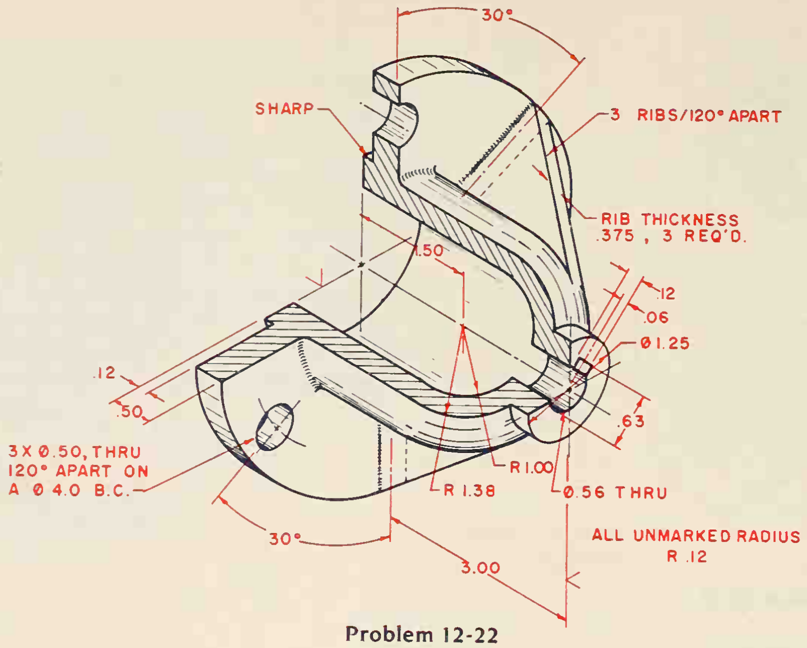
Problem 12-20



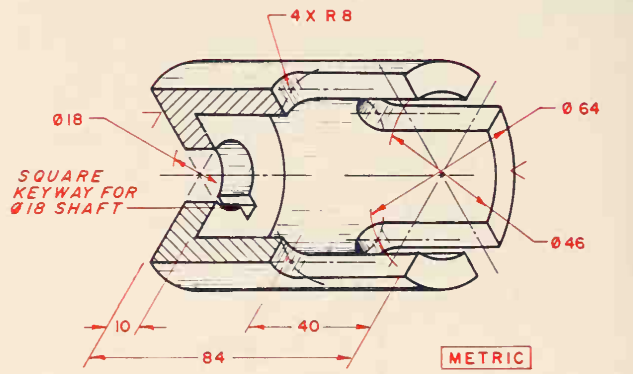
Problem 12-19



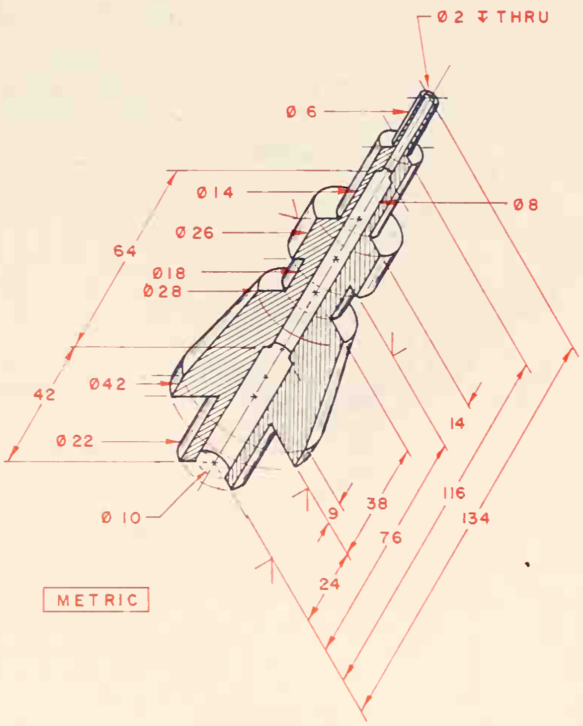
Problem 12-21



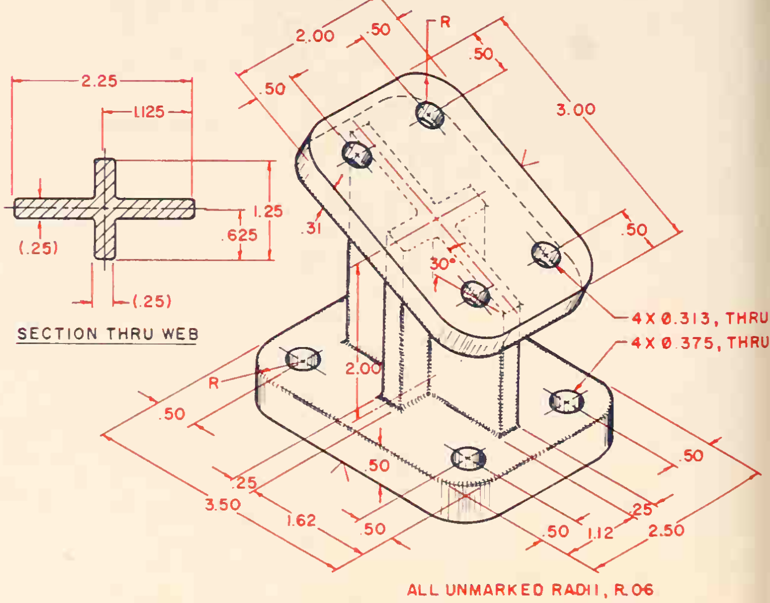
Problem 12-22



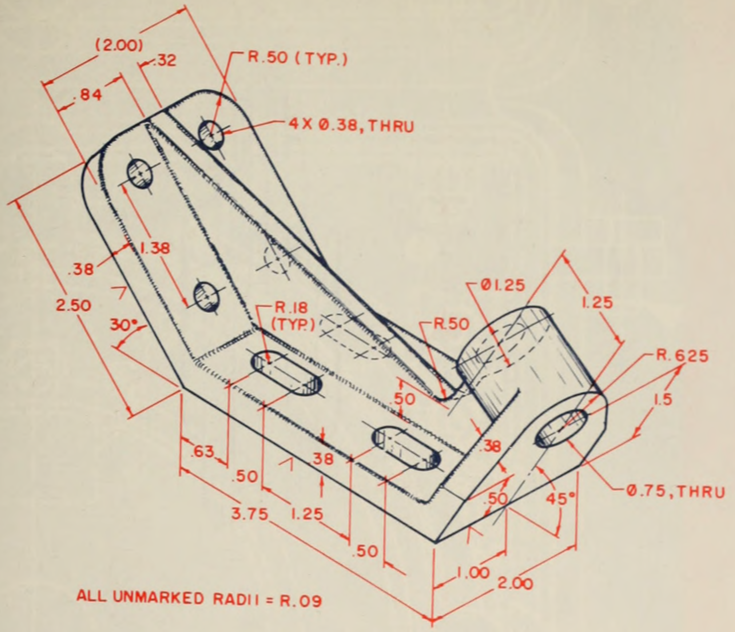
Problem 12-24



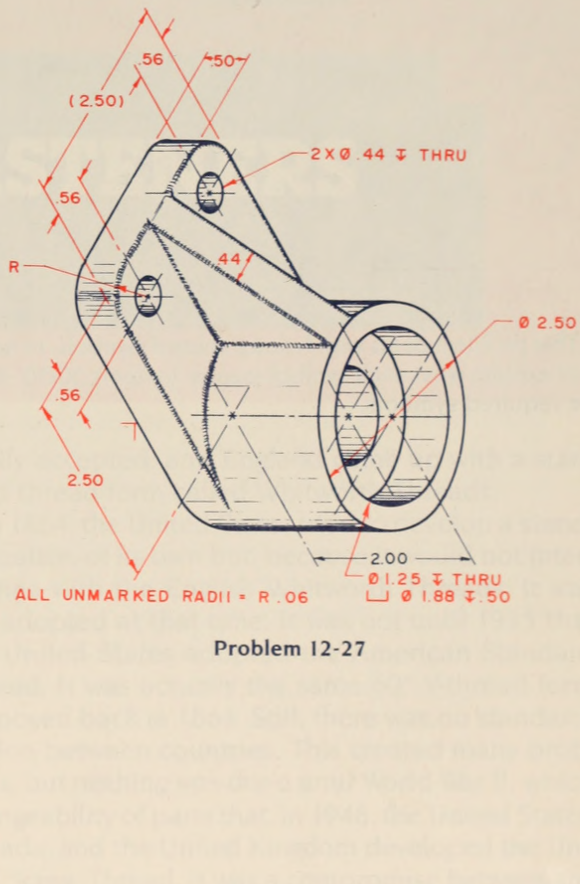
Problem 12-23



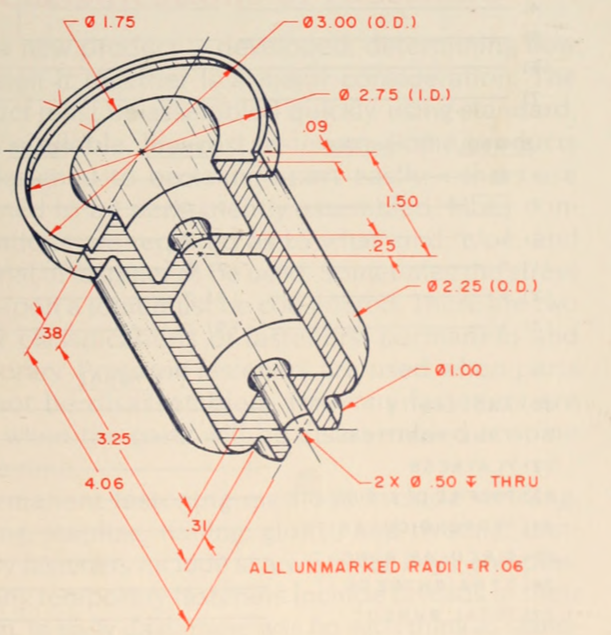
Problem 12-25



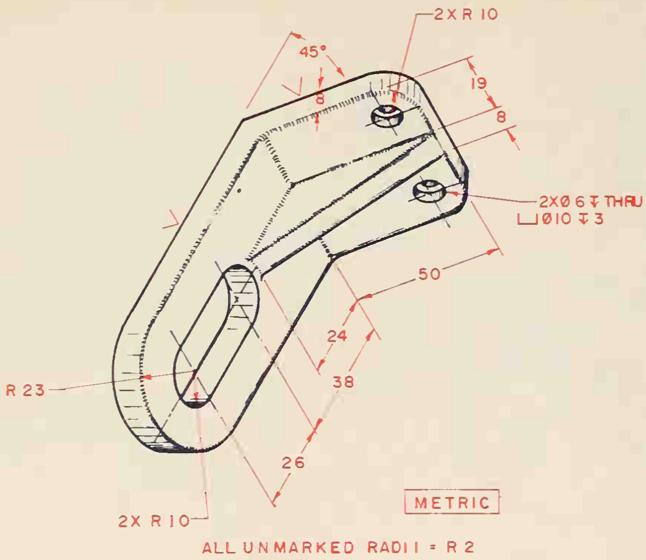
Problem 12-26



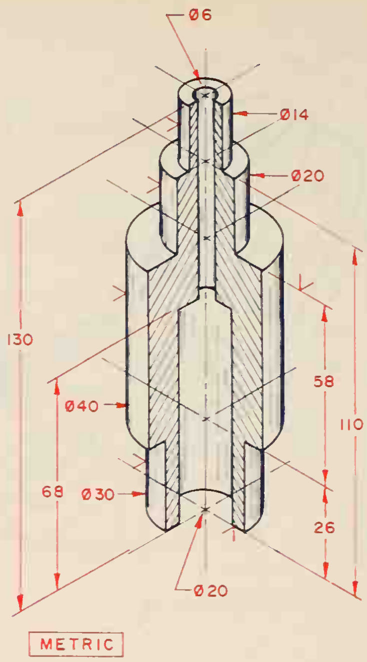
Problem 12-27



Problem 12-28



Problem 12-29



Problem 12-30

Problem 12-31

This problem deals with feature control symbols. In items 1-19 explain what each symbol means. In items 20-30, draw the required symbols.

MEANS

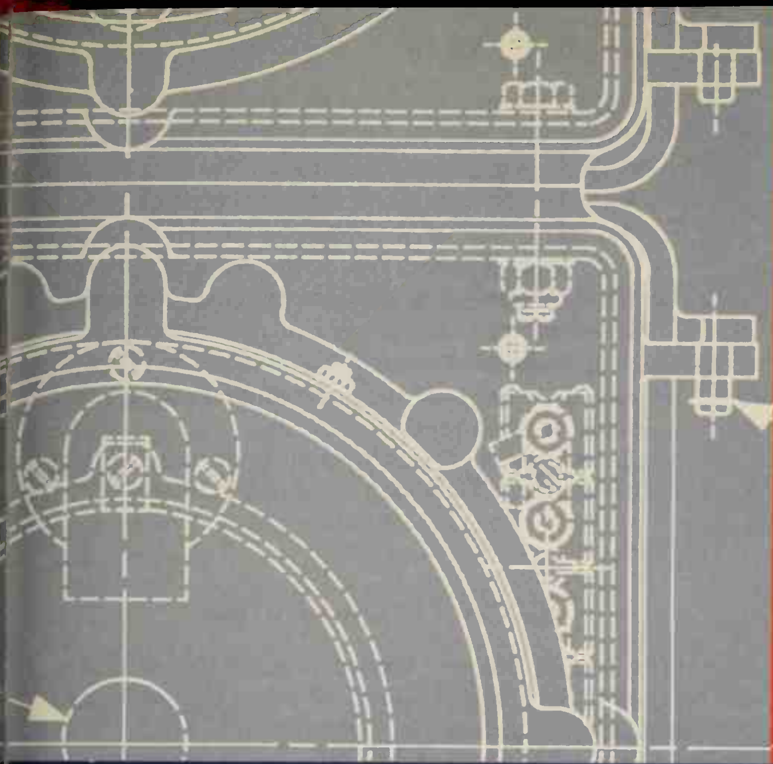
⊥	.005 Ⓜ	A	B	C Ⓜ

1) ______
2) ______
3) ______
4) ______
5) ______
6) ______
7) ______

SYMBOL	MEANS	SYMBOL	MEANS
8) Ⓜ	______	14) ○	______
9) [-A-]	______	15) ⌭	______
10) ( )	______	16) ⌖	______
11) R	______	17) Ⓢ	______
12) ↧	______	18) Ø	______
13) ∨	______	19) ⌓	______

	SYMBOL
20) ANGULARITY	______
21) TRUE POSITION	______
22) FLATNESS	______
23) PROFILE OF A SURFACE	______
24) PERPENDICULARITY	______
25) CIRCULAR RUNOUT	______
26) STRAIGHTNESS	______
27) TOTAL RUNOUT	______
28) PROFILE OF A LINE	______
29) CYLINDRICITY	______
30) CIRCULARITY	______

Problem 12-31



CHAPTER 13

This chapter covers all terminology associated with the major kinds of fasteners, and illustrates the fasteners used in industry today. How to interpret and draw tabulated fastener standard-size drawings is covered. In-depth study is devoted to where to use groove pins and retaining rings, and how to design them into existing assemblies.

FASTENERS

Classifications of Fasteners

As a new product is developed, determining how to fasten it together is a major consideration. The product must be assembled quickly, using standard, easily available, low-cost fasteners. Some products are designed to be taken apart easily—others are designed to be permanently assembled. Many considerations are required as to what kind, type, and material of fastener to be used. Sometimes the stress load upon a joint must be considered. There are two major classifications of fasteners: permanent and temporary. *Permanent* fasteners are used when parts will not be disassembled. *Temporary* fasteners are used when the parts will be disassembled at some future time.

Permanent fastening methods include welding, brazing, stapling, nailing, gluing, and riveting. Temporary fasteners include screws, bolts, keys, and pins.

Many temporary fasteners include threads in their design. In early days, there was no such thing as standardization. Nuts and bolts from one company would not fit nuts and bolts from another company. In 1841, Sir Joseph Whitworth worked toward some kind of standardization through England. His efforts were finally accepted, and England came up with a standard thread form called Whitworth Threads.

In 1864, the United States tried to develop a standardization of its own but, because it would not interchange with the English Whitworth Threads, it was not adopted at that time. It was not until 1935 that the United States adopted the American Standard Thread. It was actually the same 60° V-thread form proposed back in 1864. Still, there was no standardization between countries. This created many problems, but nothing was done until World War II, which changeability of parts that, in 1948, the United States, Canada, and the United Kingdom developed the Unified Screw Thread. It was a compromise between the newer American Standard Thread and the old Whitworth Threads.

Today, with the changeover to the metric system, new standards are being developed. The International Organization for Standardization (ISO) was formed to develop a single international system using metric screw threads. This new ISO standard will be united with the American National Standards Institute (ANSI) standards. At the present time, we are in a transitional period and a combination of both systems is still being used.

Threads

Threads are used for four basic applications:

1. to fasten parts together, such as a nut and a bolt.
2. for fine adjustment between parts in relation to each other, such as the fine adjusting screw on a surveyor's transit.
3. for fine measurement, such as a micrometer.
4. to transmit motion or power, such as an automatic screw threading attachment on a lathe or a house jack.

There are many types and sizes of fasteners, each designed for a particular function. Permanently fastening parts together by welding or brazing is discussed in Chapter 19. Although screw threads have other important uses, such as adjusting parts and measuring and transmitting power, only their use as a fastener and only the most used kinds of fasteners are discussed in this chapter.

Thread Terms

Refer to Figure 13-1 for the following terms.

- *External thread*—Threads located on the outside of a part, such as those on a bolt.
- *Internal thread*—Threads located on the inside of a part, such as those on a nut.
- *Axis*—A longitudinal center line of the thread.
- *Major diameter*—The largest diameter of a screw thread, both external and internal.
- *Minor diameter*—The smallest diameter of a screw thread, both external and internal.
- *Pitch diameter*—The diameter of an imaginary diameter centrally located between the major diameter and the minor diameter.
- *Pitch*—The distance from a point on a screw thread to a corresponding point on the next thread, as measured parallel to the axis.
- *Root*—The bottom point joining the sides of a thread.
- *Crest*—The top point joining the sides of a thread.
- *Depth of thread*—The distance between the crest and the root of the thread, as measured at a right angle to the axis.
- *Angle of thread*—The included angle between the sides of the thread.
- *Series of thread*—A standard number of threads per inch (TPI) for each standard diameter.

Screw Thread Forms

The *form* of a screw thread is actually its profile shape. There are many kinds of screw thread forms. Seven major kinds are discussed next.

Unified National Thread Form

The Unified National thread form has been the standard thread used in the United States, Canada, and the United Kingdom since 1948, Figure 13-2A. This thread form is used mostly for fasteners and adjustments.

ISO Metric Thread Form

The ISO metric thread form is the new standard to be used throughout the world. Its form or profile is very similar to that of the Unified National thread, except that the thread depth is slightly less, Figure 13-2B. This thread form is used mostly for fasteners and adjustments.

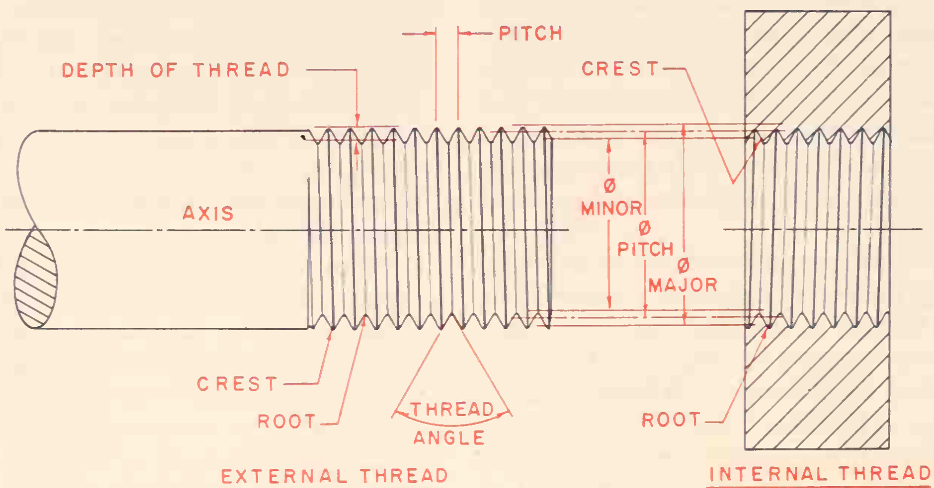


Figure 13-1 Thread terms

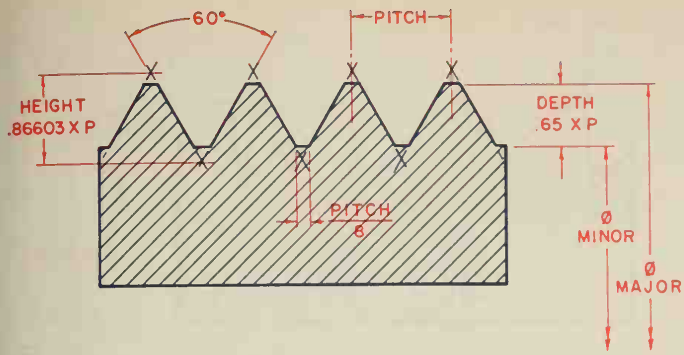


Figure 13-2A Unified national thread form (UN)

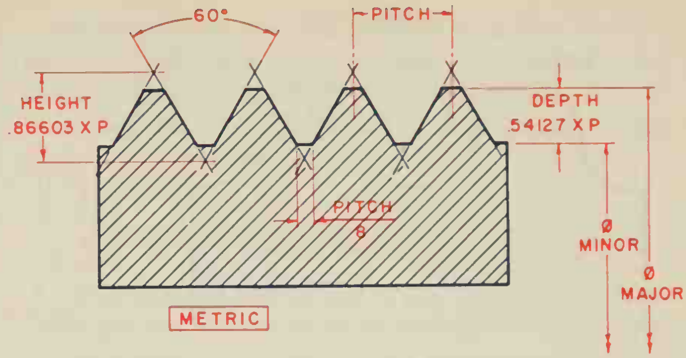


Figure 13-2B ISO metric thread form

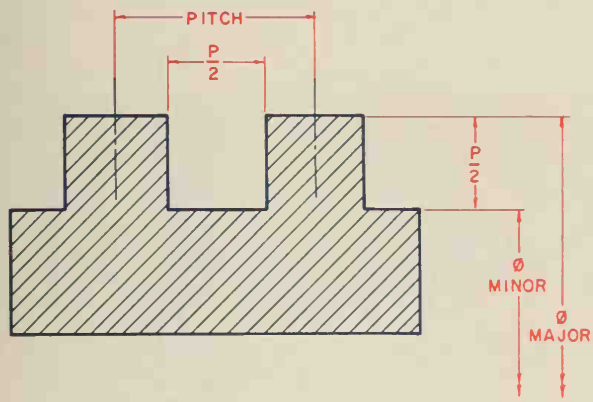


Figure 13-2C Square thread form

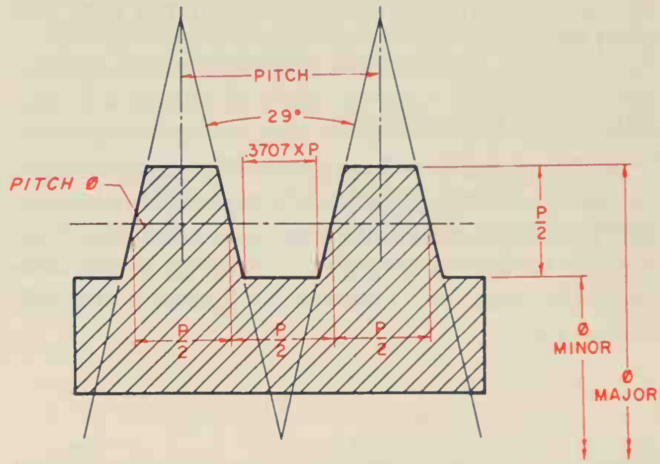


Figure 13-2D Acme thread form

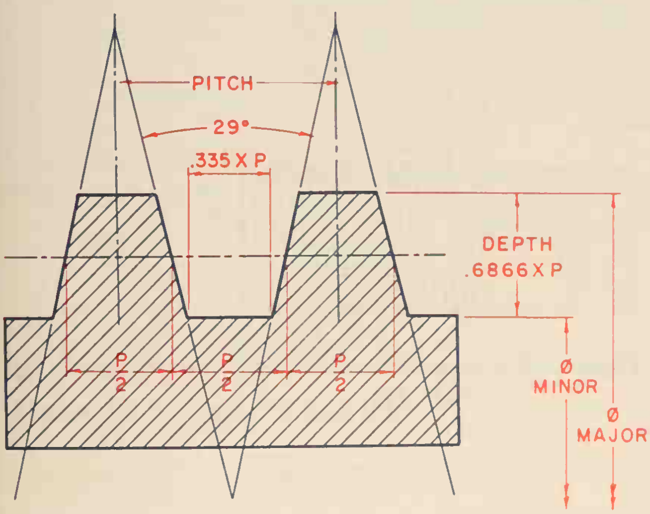


Figure 13-2E Worm thread form

Square Thread Form

The square thread's profile is exactly as its name implies: that is, square. The faces of the teeth are at right angles to the axis and, theoretically, this is the best thread to transmit power, Figure 13-2C. Because this thread is difficult to manufacture, it is being replaced by the Acme thread.

Acme Thread Form

The Acme thread is a slight modification of the square thread. It is easier to manufacture and is actually stronger than the square thread, Figure 13-2D. It, too, is used to transmit power.

Worm Thread Form

The worm thread is similar to the Acme thread, and is used primarily to transmit power, Figure 13-2E.

Knuckle Thread Form

The knuckle thread is usually rolled from sheet metal and is used, slightly modified, in electric light

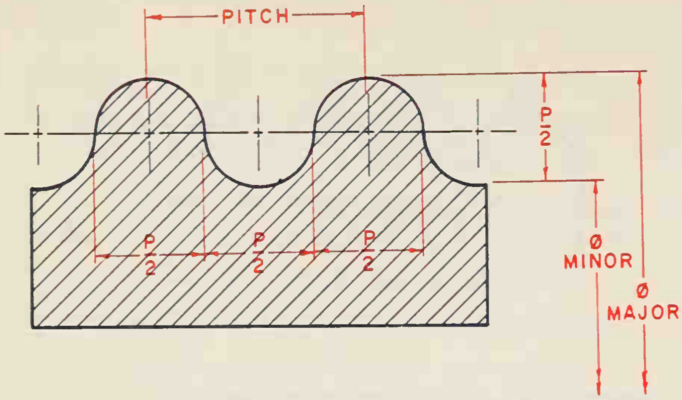


Figure 13-2F Knuckle thread form

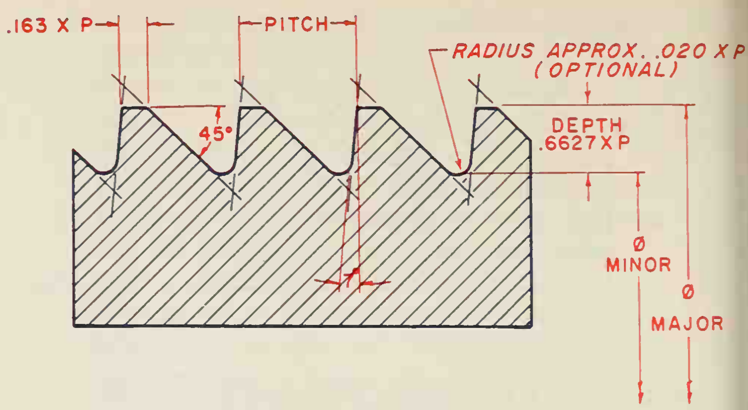


Figure 13-2G Buttress thread form

bulbs, electric light sockets, and sometimes for bottle tops. The knuckle thread is sometimes cast, Figure 13-2F.

Buttress Thread Form

The buttress thread has certain advantages in applications involving exceptionally high stress along its axis in *one* direction only. Examples of applications are the breech assemblies of large guns, airplane propeller hubs, and columns for hydraulic presses, Figure 13-2G.

Tap and Die

Various methods are used to produce inside and outside threads. The simplest method uses thread-cutting tools called taps and dies. The *tap* cuts internal threads; the *die* cuts external threads, Figure 13-3. In making an internal threaded hole, a tap-drilled hole must be drilled first. This hole is approximately the same diameter as the minor diameter of the threads.

Notice how the tap is tapered at the end; this taper allows the tap to start into the tap-drilled hole. This tapered area contains only partial threads.

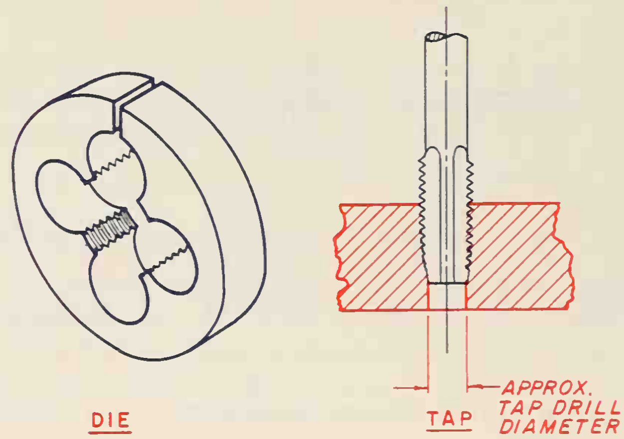


Figure 13-3 Tap and die

Threads per Inch (TPI)

One method of measuring threads per inch (TPI) is to place a standard scale on the crests of the threads, parallel to the axis, and count the number of full threads within one inch of the scale, Figure 13-4. If only part of an inch of stock is threaded, count the number of full threads in one half inch and multiply by two to determine TPI.

A simple, more accurate method of determining threads per inch is to use a screw thread gage, Figure 13-5. By trial and error, the various fingers or leaves of the gage are placed over the threads until one is found that fits exactly into all the threads. Threads per inch are then read directly on each leaf of the gage, Figure 13-6.

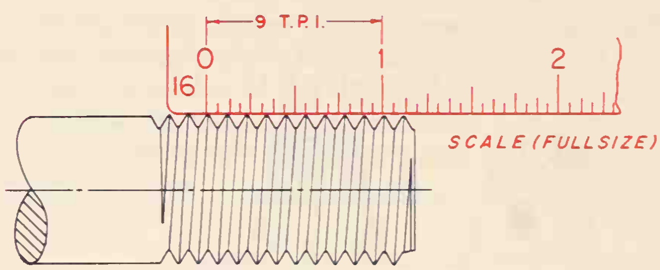


Figure 13-4 Use of a scale to calculate threads per inch (TPI)

Pitch

The *pitch* of any thread, regardless of its thread form or profile, is the distance from one point on a thread to the corresponding point on the adjacent thread as measured parallel to its axis, Figure 13-7. Pitch is found by dividing the TPI into one inch.

In this example, a coarse thread pitch, there are 10 threads in one measured inch; 10 TPI divided into one inch equals a pitch of 10. In a fine thread of the same diameter there are 20 threads in one measured inch; 20 TPI divided into one inch equals a pitch of 20, Figure 13-8.

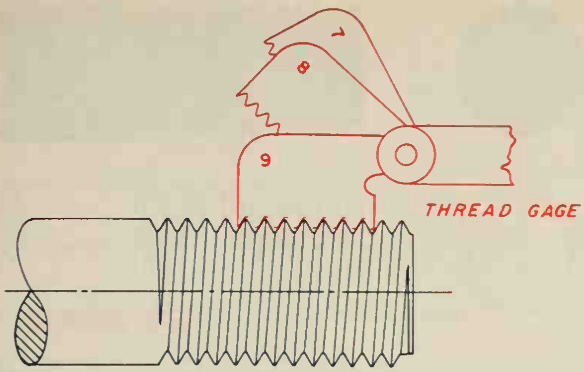


Figure 13-5 Use of a screw thread gage

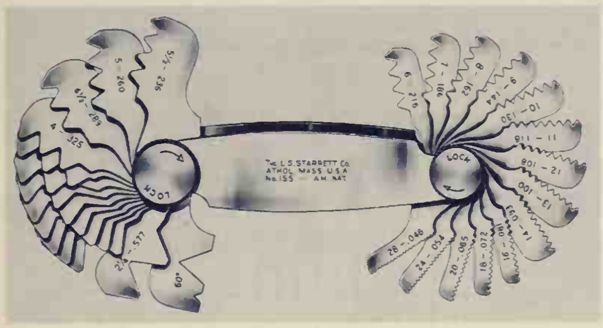


Figure 13-6 Reading screw thread gage (*Courtesy The L.S. Starrett Co.*)

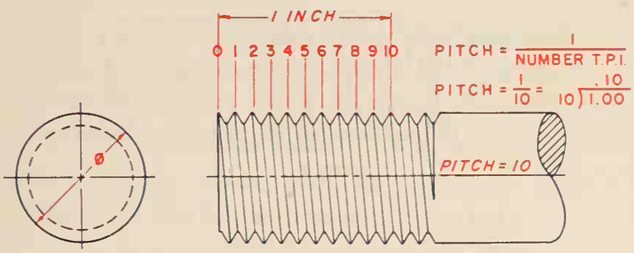


Figure 13-7 Coarse thread pitch

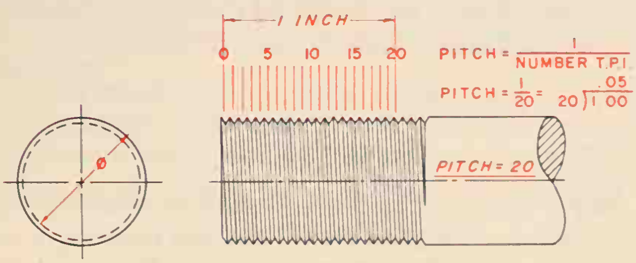


Figure 13-8 Fine thread pitch

For metric threads, the pitch is specified in millimetres. Pitch for a metric thread is included in its call-off designation. For example: M10 × 1.5. The 1.5 indicates the pitch; therefore, it does not as a rule have to be calculated.

Single and Multiple Threads

A *single thread* is composed of one continuous ridge. The lead of a single thread is equal to the pitch. *Lead* is the distance a screw thread advances axially in one full turn. Most threads are single threads.

Multiple threads are made up of two or more continuous ridges following side-by-side. The lead of a double thread is equal to twice the pitch. The lead of a triple thread is equal to three times the pitch, Figure 13-9.

Multiple threads are used when speed or travel distance is an important design factor. A good example of a double or triple thread is found in an inexpensive ball-point pen. Take a ball-point pen apart and study the end of the external threads. There will probably be two or three ridges starting at the end of the threads. Notice how fast the parts screw together. This speed, not power, is the characteristic of multiple threads.

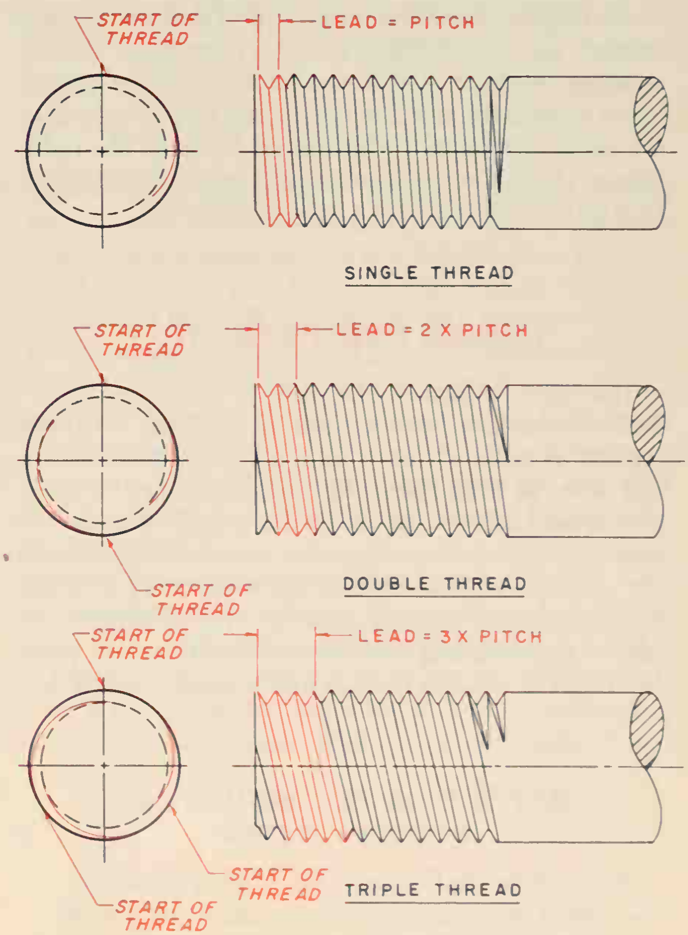


Figure 13-9 Single and multiple threads

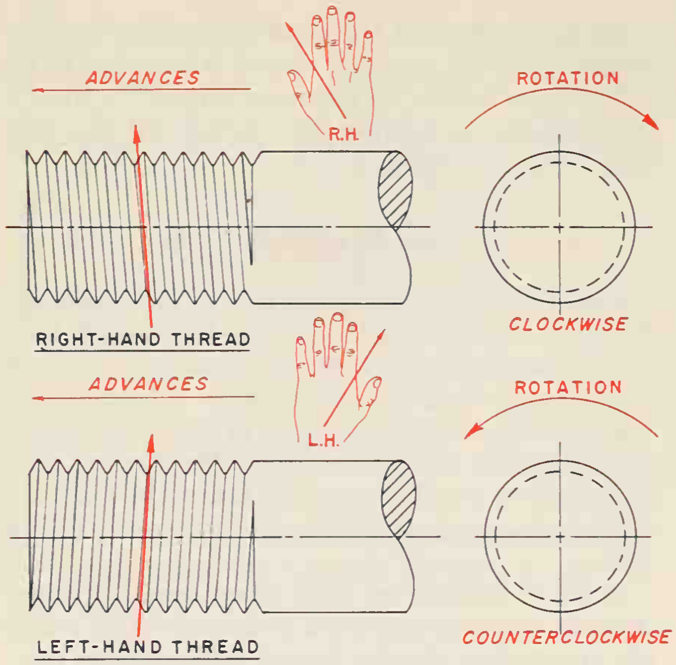


Figure 13-10 Right-hand and left-hand threads

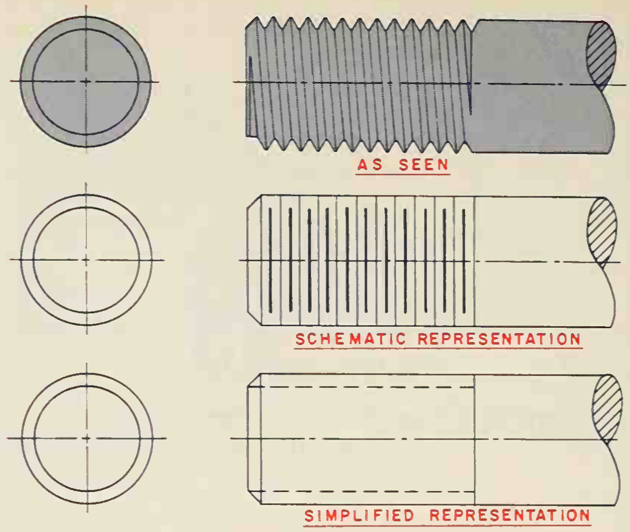


Figure 13-11 Thread representation

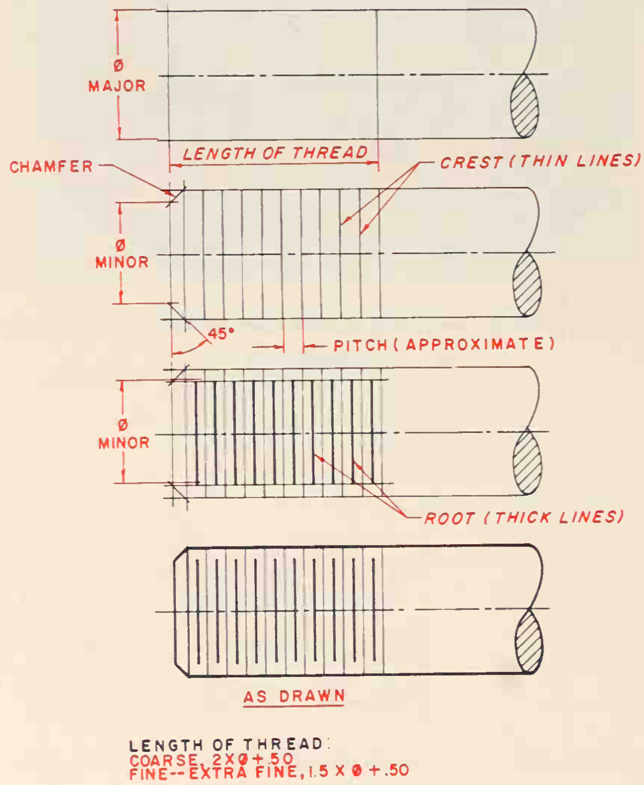


Figure 13-12 How to draw threads using the schematic system

Right-Hand and Left-Hand Threads

Threads can be either right-handed or left-handed. To distinguish between a right-hand and a left-hand thread, use this simple trick. A right-hand thread winding tends to lean toward the left. If the thread leans toward the left, the right-hand thumb points in the same direction. If the thread leans to the right, Figure 13-10, the left-hand thumb leans in that direction indicating that it is a left-hand thread.

Thread Representation

The top illustration of Figure 13-11 shows a normal view of an external thread. To draw a thread exactly as it will actually look takes too much drafting time. To help speed up the drawing of threads, one of two basic systems is used and each is described and illustrated. The schematic system of representing threads was developed approximately in 1940, and is still used somewhat today. The simplified system of representing threads was developed 15 years later, and is actually quicker and in greater use today.

How To Draw Threads Using the Schematic System

Step 1. Refer to Figure 13-12. Lightly draw the major diameter, and locate the approximate length of full threads.

Step 2. Lightly locate the minor diameter and draw the 45° chamfered ends as illustrated. Draw lines to represent the crest of the threads spaced approximately equal to the pitch.

Step 3. Draw slightly thicker lines centered between the crest lines to the minor diameter. These lines represent the root of the threads.

Step 4. Check all work and darken in. Notice the crest lines are *thin* black lines and the root lines are *thick* black lines.

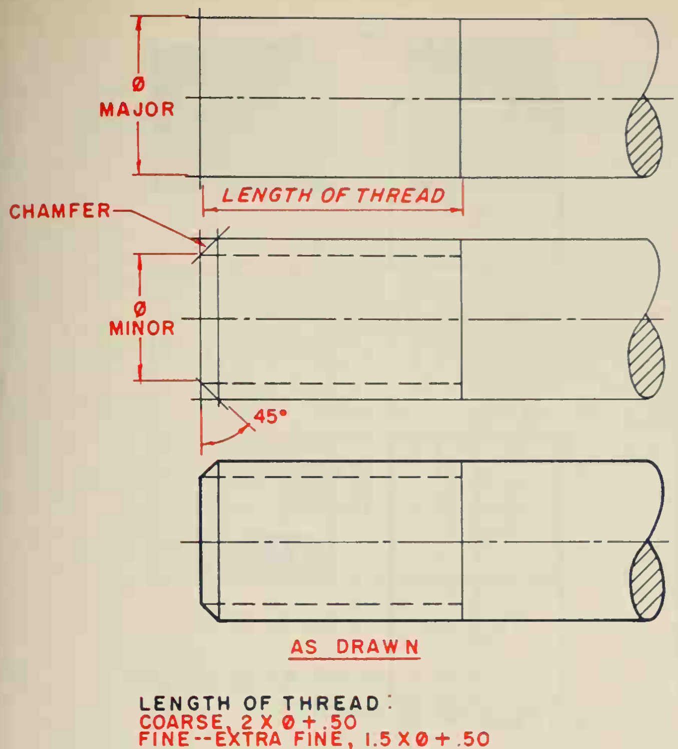


Figure 13-13 How to draw threads using the simplified system

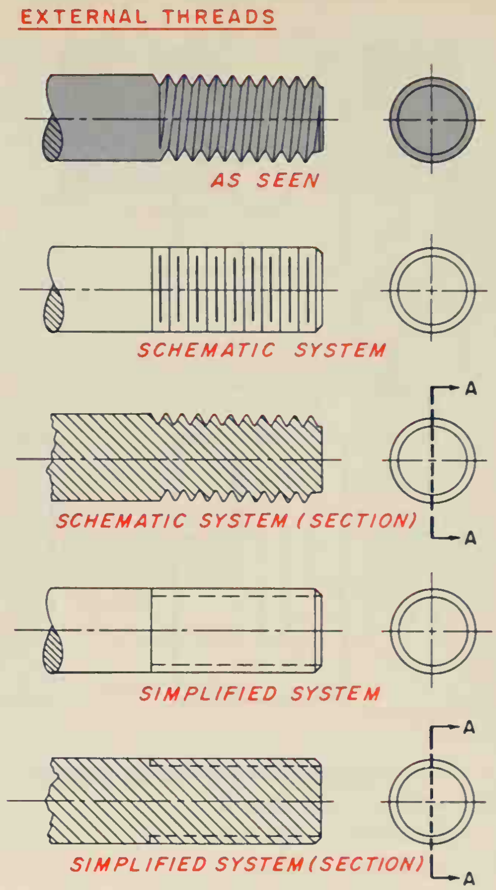


Figure 13-14 Standard external thread representation

How To Draw Threads Using the Simplified System

Step 1. Refer to Figure 13-13. Lightly draw the major diameter and locate the approximate length of full threads.

Step 2. Lightly locate the minor diameter and draw the 45° chamfered ends as illustrated. Draw dash lines along the minor diameter. This represents the root of the threads.

Step 3. Check all work and darken in. The dash lines are *thin* black lines.

Standard External Thread Representation

The most recent standard to illustrate external threads using either the schematic or simplified system is illustrated in Figure 13-14. Note how section views are illustrated using schematic and simplified systems.

Standard Internal Thread Representation

There are two major kinds of interior holes: through holes and blind holes. A *through hole*, as its name implies, goes completely through an object. A *blind hole* is a hole that does *not* go completely through an object. In the manufacture of a blind hole, a tap drill must be drilled into the part first, Figure 13-15. To illustrate a tap drill, use the 30°-60° triangle. This is *not* the actual angle of a drill point but is close enough for illustration. The tap is now turned into the tap drill hole. Because of the taper on the tap, *full* threads do not extend to the bottom of the hole (refer back to Figure 13-3). The drafter illustrates the tap drill and the full threaded section as shown to the right in Figure 13-15.

Using the schematic system to represent a through hole is illustrated in Figure 13-16. A blind hole and a section view are drawn as illustrated in Figure 13-17.

Using the simplified system to represent a through hole is illustrated in Figure 13-18. A blind hole and a section view are drawn as illustrated in Figure 13-19.

Thread Relief (Undercut)

On exterior threads, it is impossible to make perfectly uniform threads up to a shoulder; thus, the

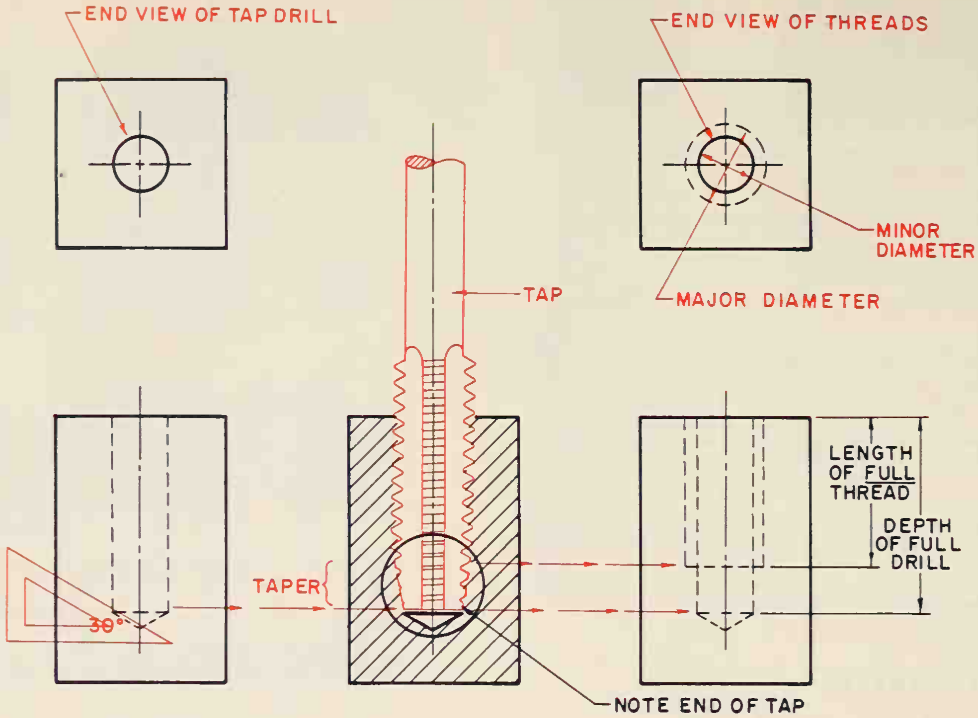


Figure 13-15 Standard internal thread representation

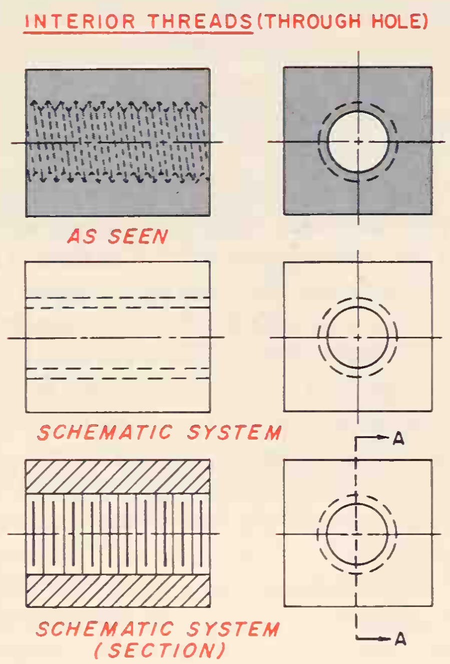


Figure 13-16 Standard internal thread representation for a through hole (schematic system)

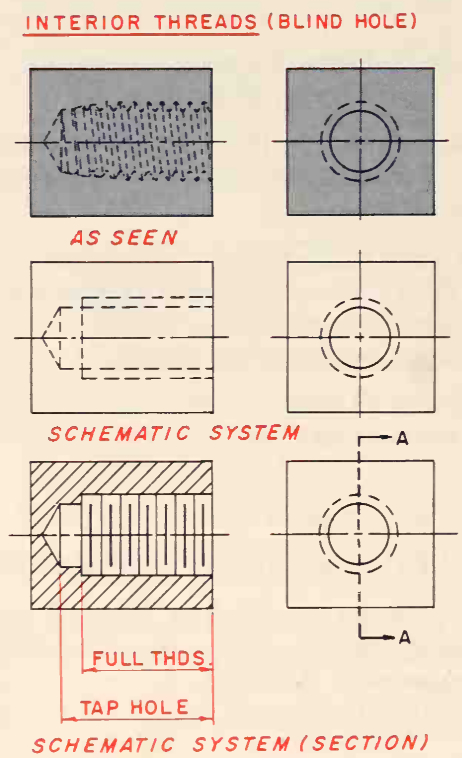


Figure 13-17 Standard internal thread representation for a blind hold (schematic system)

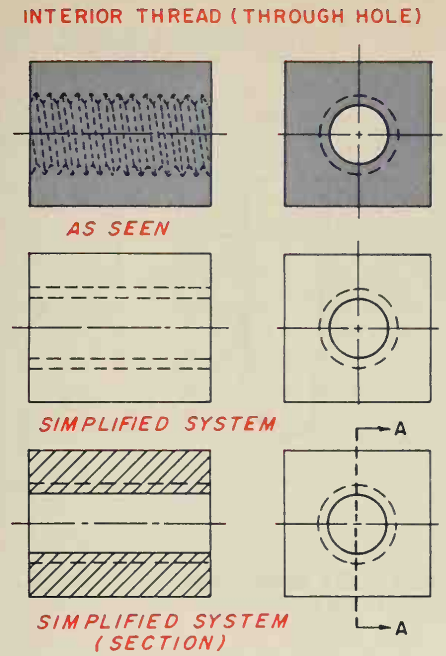


Figure 13-18 Standard internal thread representation for a through hole (simplified system)

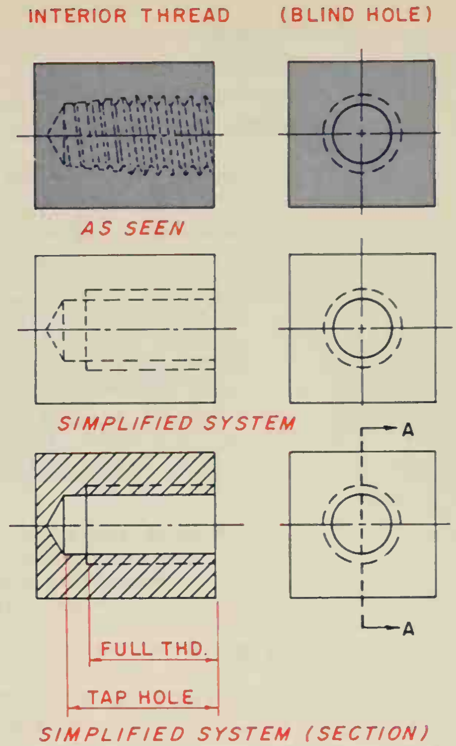


Figure 13-19 Standard internal thread representation for a blind hold (simplified system)

threads tend to run out, as illustrated in Figure 13-20. Where mating parts must be held tightly against the shoulder, the last one or two threads must be removed or *relieved*. This is usually done no farther than to the depth of the threads so as not to weaken the fastener. The simplified system of thread representation is illustrated at the bottom of Figure 13-20.

Full interior threads cannot be manufactured to the end of a blind hole. One way to eliminate this problem is to call-off a thread relief or undercut, as illustrated in Figure 13-21. The bottom illustration is as it would be drawn by the drafter.

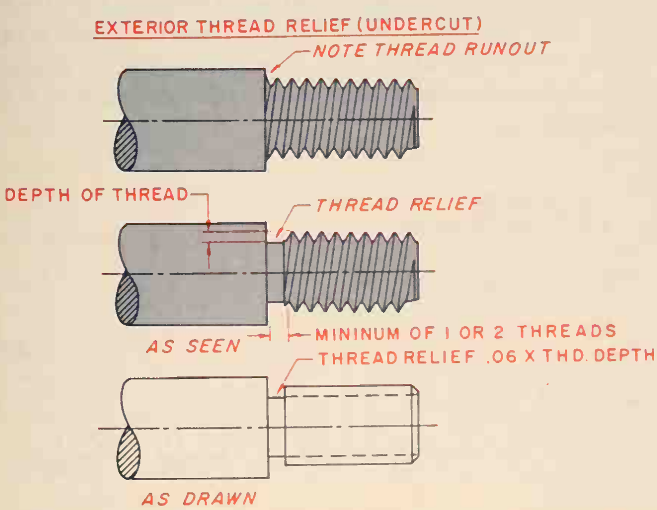


Figure 13-20 External thread relief (undercut)

Screw, Bolt, and Stud

Figure 13-22 illustrates and describes a screw, a bolt, and a stud. A *screw* is a fastener that does not use a nut and is screwed directly into a part.

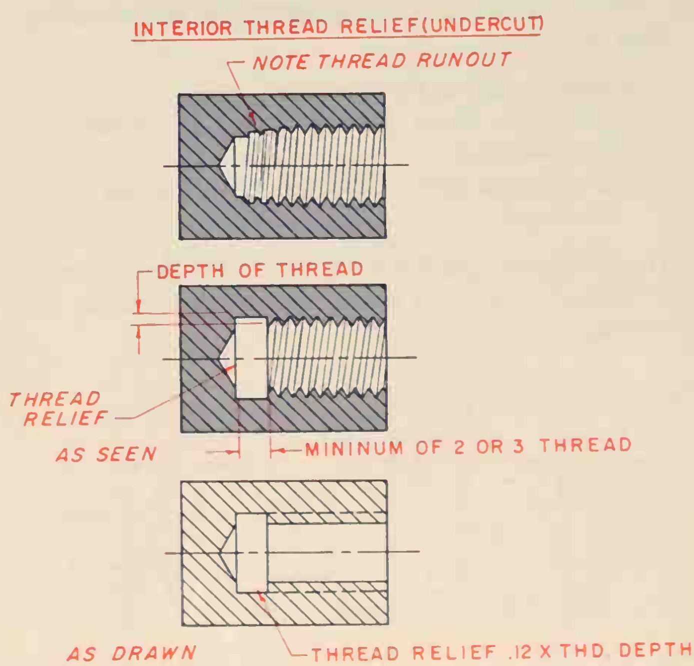
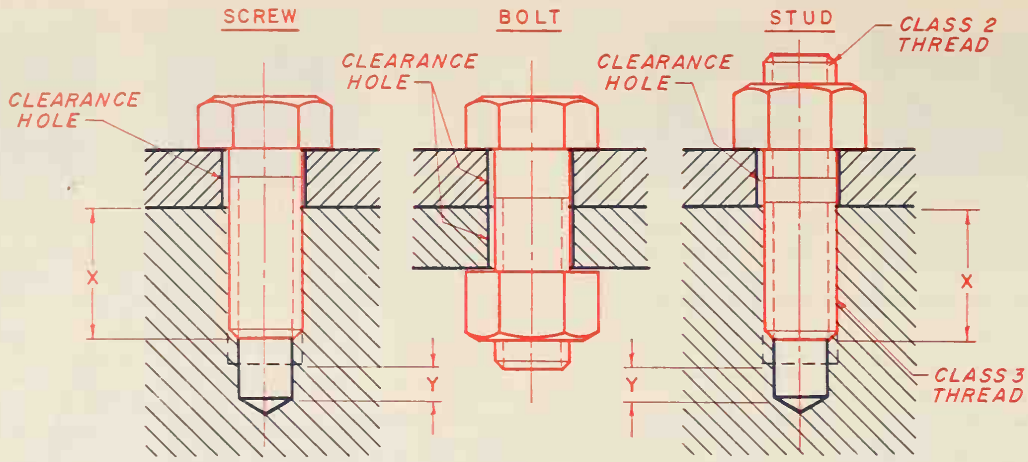


Figure 13-21 Internal thread relief (undercut)



X = MINIMUM THREADS REQUIRED:
STEEL, X = OUTSIDE DIAMETER
CAST IRON/BRASS/BRONZE, X = 1.5 X OUTSIDE DIAMETER
ALUMINUM/ZINC/PLASTIC, X = 2 X OUTSIDE DIAMETER

Y = MINIMUM SPACE = 2X PITCH LENGTH

CLEARANCE HOLE: 0 TO .375 (9) = .03 (1) LARGER THAN OUTSIDE DIAMETER
.375 (9) UP = .06 (2) LARGER THAN OUTSIDE DIAMETER

Figure 13-22 Screw, bolt and stud

A *bolt* is a fastener that passes directly through parts to hold them together, and uses a nut to tighten or hold the parts together.

A *stud* is a fastener that is a steel rod with threads at both ends. It is screwed into a blind hole and holds other parts together by a nut on its free end. In general practice, a stud has either fine threads at one end and coarse threads at the other, or Class 3-fit threads at one end and Class 2-fit threads at the other end. Class of fit is fully explained later in this chapter under "Classes of Fit."

The minimum full thread length for a screw or a stud is:

In steel: equal to the diameter.
In cast iron, brass, bronze: equal to 1.5 times the diameter.
In aluminum, zinc, plastic: equal to 2 times the diameter.

The clearance hole for holes up to .375 (9) diameter is approximately .03 oversize; for larger holes, .06 oversize.

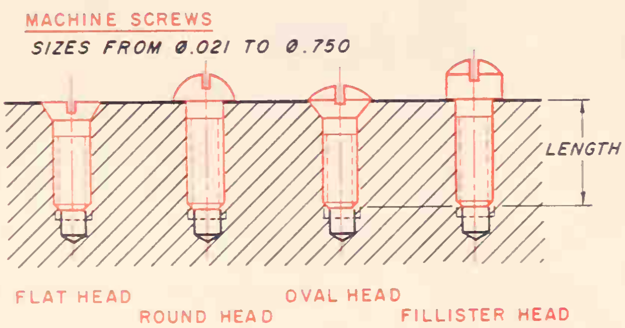


Figure 13-23 Machine screws

Machine Screws

Machine screw sizes run from .021 (.3) to .750 (20) in diameter. There are eight standard head forms. Four major kinds are illustrated in Figure 13-23. *Machine screws* are used for screwing into thin materials. Most machine screws are threaded within a thread or two to the head. Although these are screws, machine screws sometimes incorporate a hex-head nut to fasten parts together.

The length of a machine screw is measured from the top surface to the part to be held together to the end of the screw (refer again to Figure 13-23).

Cap Screws

Cap screw sizes run from .250 (6) and up. There are five standard head forms, Figure 13-24. A *cap screw* is usually used as a true screw, and it passes through a clearance hole in one part and screws into another part.

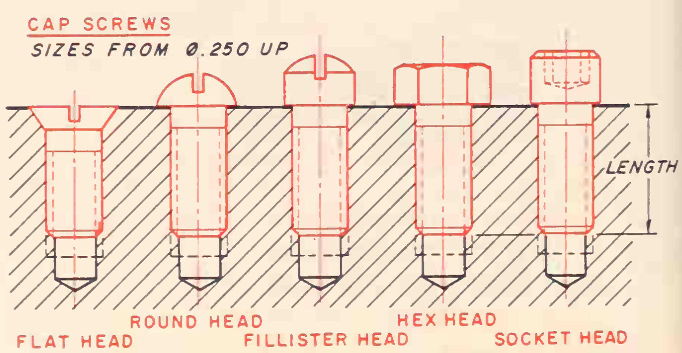


Figure 13-24 Cap screws

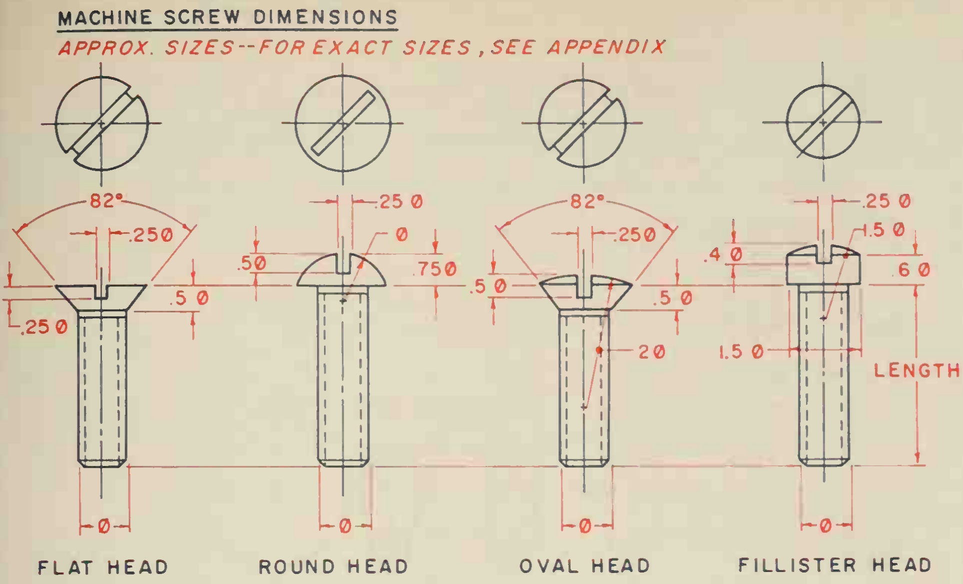


Figure 13-25 Approximate sizes for machine screws or cap screws

How To Draw a Machine Screw or Cap Screw

The exact dimensions of machine screws and cap screws are given in the Appendix of the text but, in actual practice, they are seldom used for drawing purposes. See Figures 13-25 and 13-26, which show the various sizes as they are proportioned in regard to the diameter of the fastener. Various fastener templates are now available to further speed up drafting time.

Set Screws

A *set screw* is used to prevent motion between mating parts, such as the hub of a pulley on a shaft. The set screw is screwed into and through one part so that it applies pressure against another part, thus preventing motion. Set screws are usually manufactured of steel, and are hardened to make them stronger than the average fastener.

Set screws have various kinds of heads and many kinds of points. Figure 13-27 illustrates a few of the more common kinds of set screws. Set screws are manufactured in many standard lengths of very small increments, so almost any required length is probably "standard." Exact sizes and lengths can be found in the Appendix. As with machine screws and cap screws, in actual practice, the actual drawing of set screws is done using their proportions in relationship to their diameters.

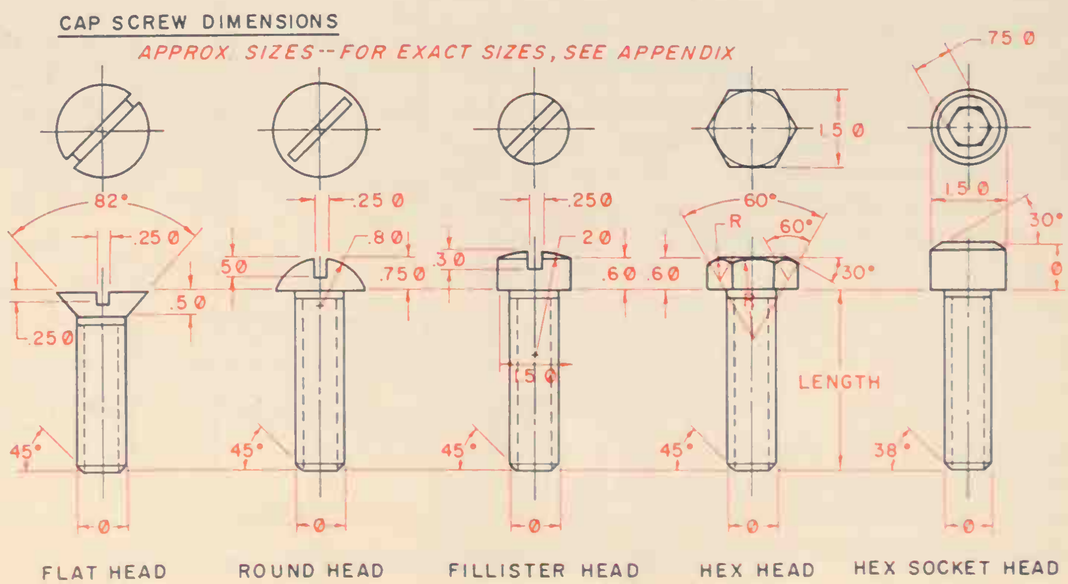


Figure 13-26 Approximate sizes for machine screws or cap screws

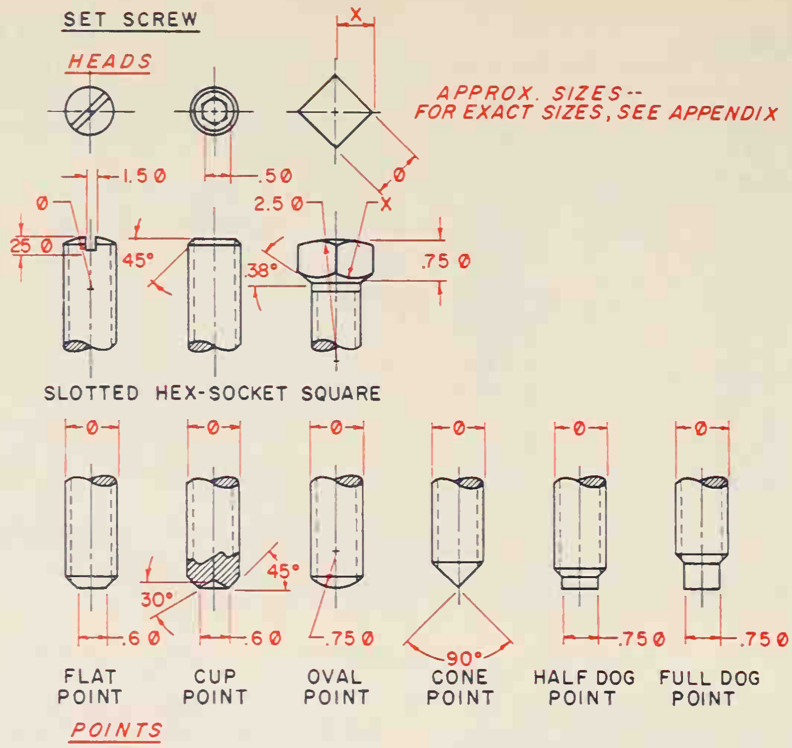


Figure 13-27 Approximate sizes for set screws and set screw points

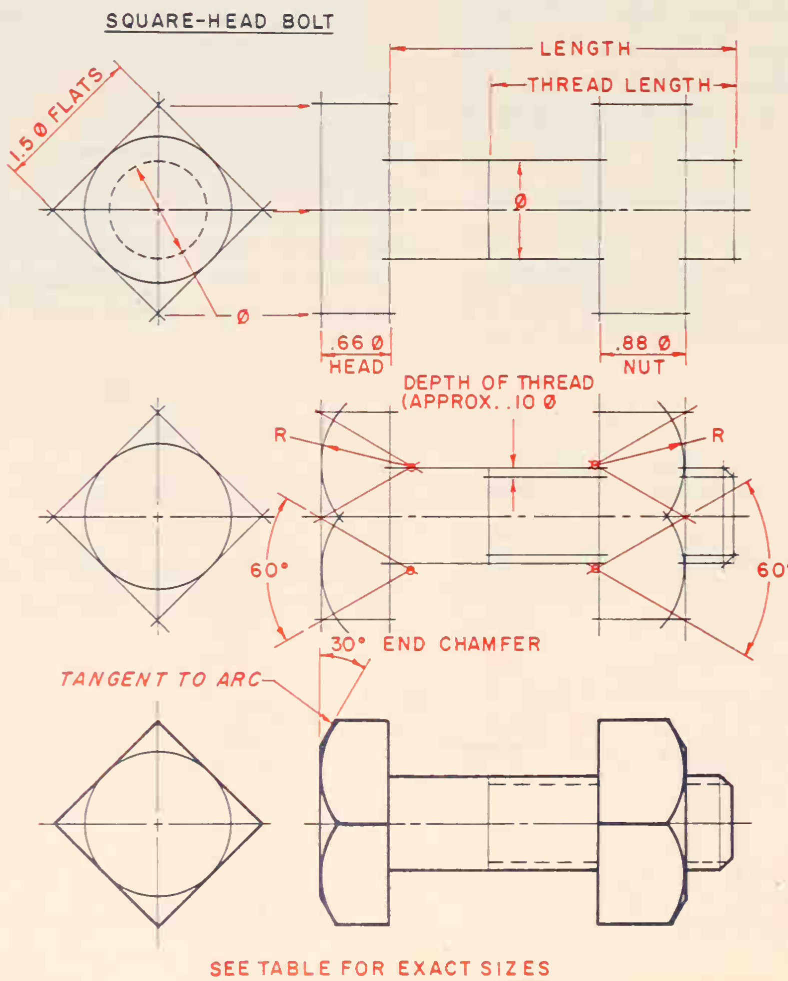


Figure 13-28 Approximate sizes for a square-head bolt

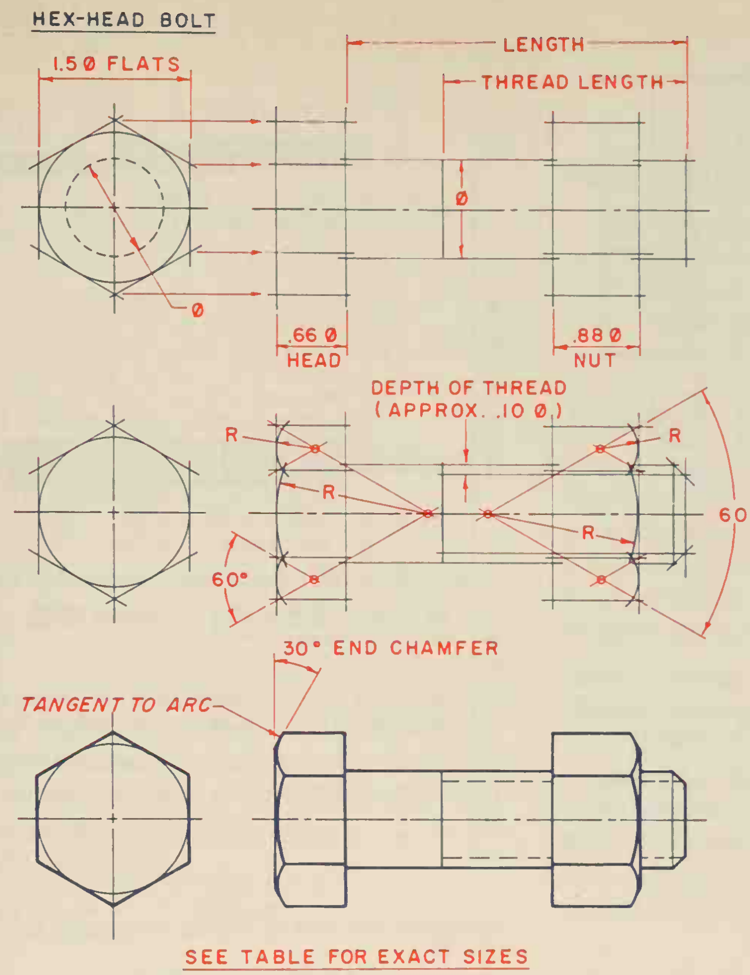


Figure 13-29 Approximate size for a hex-head bolt

How To Draw Square- and Hex-Head Bolts

Exact dimensions for square- and hex-head bolts are given in the Appendix of the text, but, in actual practice, they are drawn using the proportions as given in Figures 13-28 and 13-29. Notice that the heads are shown in the profile so three surfaces are seen in the front view. In the event a square- or hex-head bolt must be illustrated 90°, the proportions as illustrated in Figure 13-30 are used.

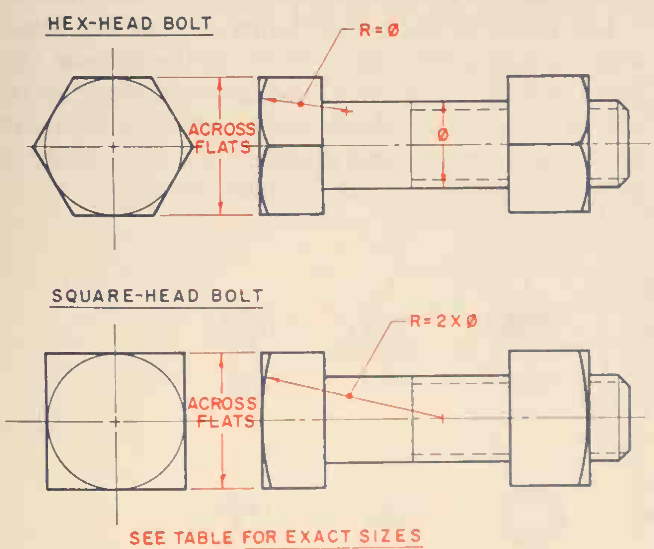


Figure 13-30 Side view of hex- and square-head bolts

Nuts, Bolts, and Other Fasteners in Section

If the cutting plane passes through the axis of any fastener, the fastener is *not* sectioned. It is treated exactly as a shaft and drawn exactly as it is viewed. Refer to Figure 13-31. The illustration at the left is drawn correctly. The figure at the right is drawn incorrectly (notice how difficult it is to understand, especially the nut).

Thread Call-offs

Although not all companies use the exact same call-offs for various fasteners, it is important that all drafters within one company use the same method. One method used to call-off fasteners is illustrated

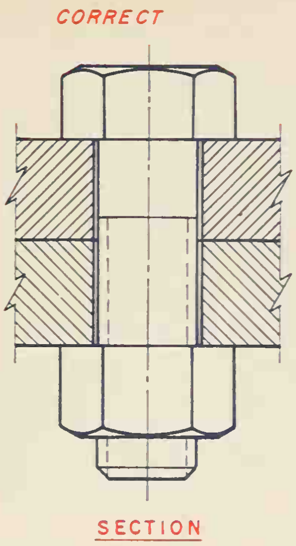


Figure 13-31 Fasteners in section

in Figure 13-32. Regardless of which system is used, the first line contains the fastener's general identification, type of head, and classification. The second line contains all exact detailed information. All threads are assumed to be right hand (R.H.), unless otherwise noted. If a thread is to be left hand (L.H.), it is noted at the end of the second line.

Various Kinds of Heads

Many different kinds of screw heads are used today. Figure 13-33 illustrates a few of the standard heads.

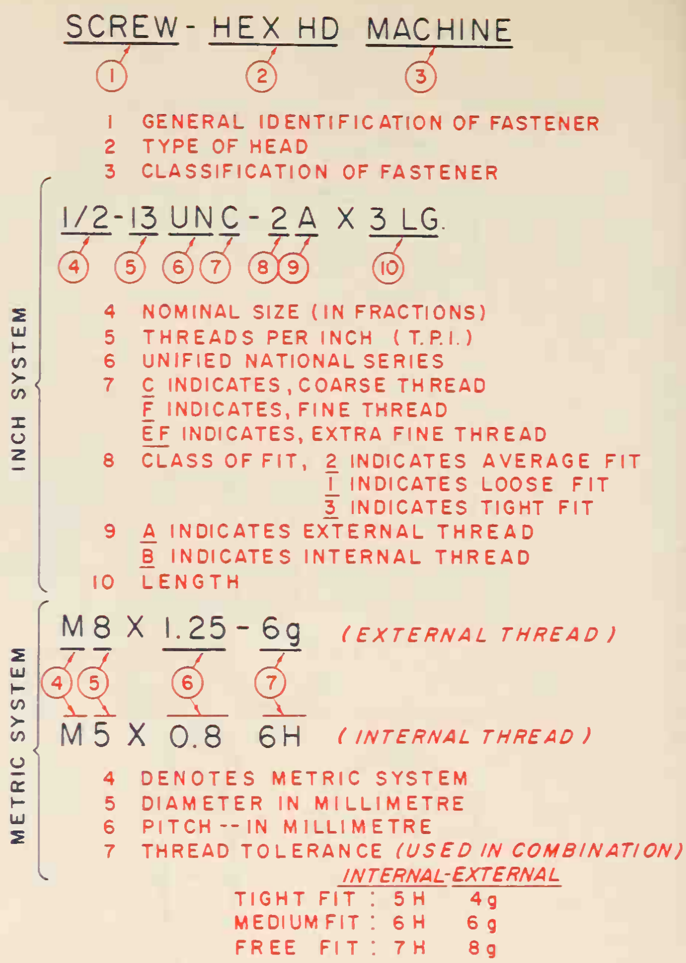


Figure 13-32 Thread call-off

Rivets

Rivets are permanent fasteners, usually used to hold sheet metal together. Most rivets are made of wrought iron or soft steel and, for aircraft and space missiles, copper, aluminum, alloy or other exotic metals.

Riveted joints are classified by applications, such as pressure vessels, structural and machine members. For data concerning joints for pressure vessels refer to such sources as ASME boiler codes. For data concerning larger field structural rivets, such as bridges, buildings and ships, see ANSI standards or a *Machinery's Handbook*. This chapter covers information for small-size rivets for machine-member riveted joints used for lighter mass produced applications.

Two kinds of basic rivet joints are the lap joint, and the butt joint, Figure 13-34. In the *lap joint*, the parts overlap each other, and are held together by one or more rows of rivets. In the butt joint, the parts are butted, and are held together by a cover plate or butt strap which is riveted to both parts.

Figure 13-33 Kinds of screw heads

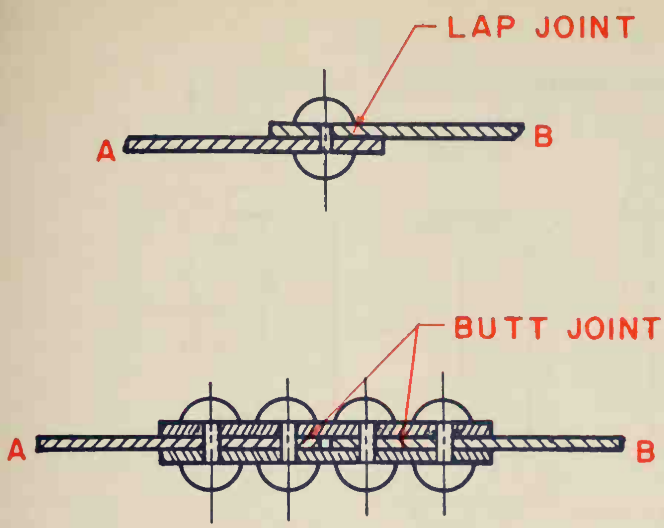


Figure 13-34 Two basic rivet joints (lap joint and butt joint)

Factors to consider are: type of joint, pitch of rivets, type and diameter of rivet, rivet material, and size of clearance holes, Figure 13-35. The diameter of a rivet is calculated from the thickness of metal, and commonly ranges between

$$d = 1.2 \sqrt{t} \text{ and } d = 1.4 \sqrt{t}$$

where d is the diameter, and t is the thickness of the plate.

Size and Type of Hole

Rivet holes must be punched, punched and then reamed, or drilled. As a general rule, holes are usually made .06 (1.5 mm) larger in diameter than the nominal rivet diameter.

Rivet Symbols

Rivets applied in mass produced applications are represented in Figure 13-36, illustrating the kind of rivet, to which side it is applied, and if it is to be countersunk, and so forth.

Kinds of Rivets

There are many different kinds of small-size rivets. The five major kinds are truss head, button head, pan head, countersunk head, and flat head. The countersunk-head rivet is not as strong as the other kinds of rivets; therefore, more rivets must be used to gain strength equal to the other types.

Drawing of Rivets

American standard small solid rivets are shown in their approximate standard proportions in Figure 13-36. These sizes are close enough to be used for drawing the rivet if necessary. For exact sizes, data must be obtained from other sources.

End Points

The end of a standard rivet is usually cut off straight. If a point is required, a standard size point is illustrated at the lower end of a countersunk head (refer back to Figure 13-36).

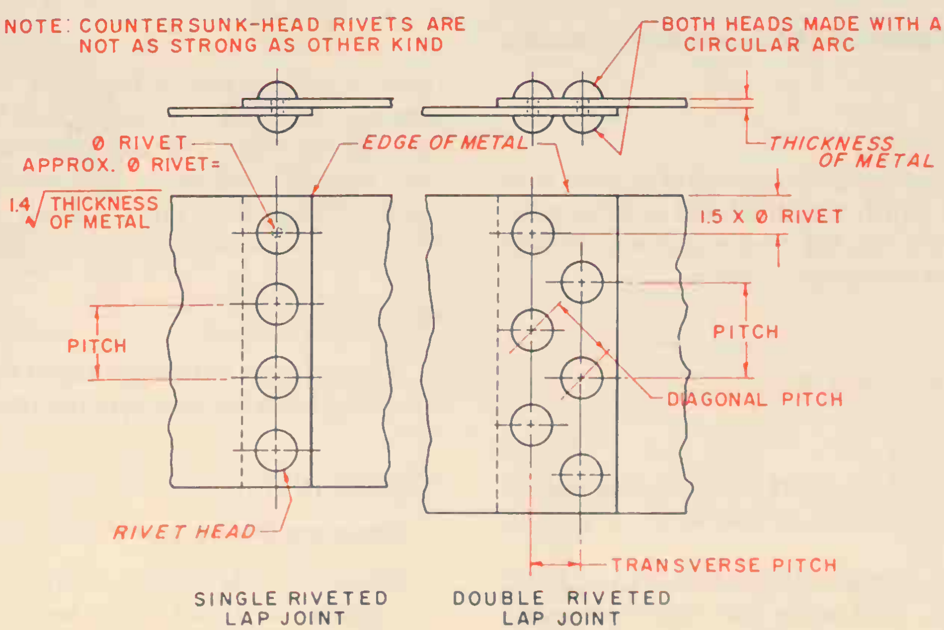


Figure 13-35 Factors to consider in rivet joints

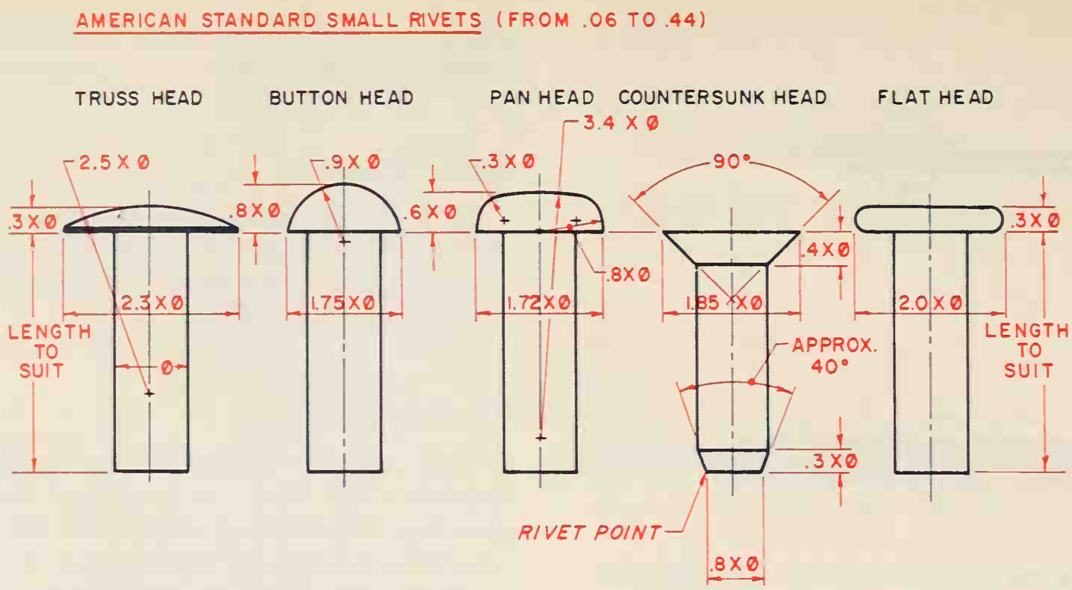


Figure 13-36 Approximate sizes for standard small rivets

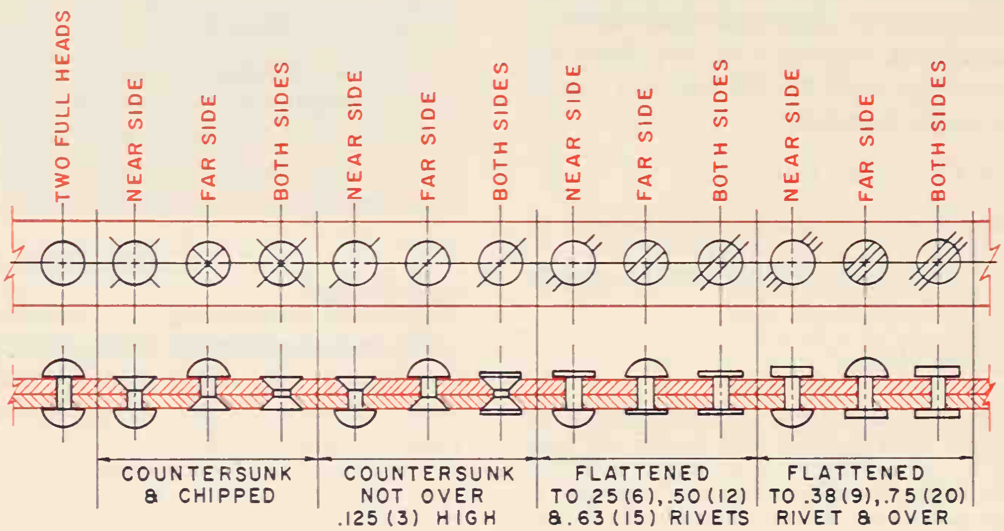


Figure 13-36A Illustrated rivet code

The drafter must indicate what kind of rivet is to be used, and on which side the head is to be positioned. To illustrate this, the drafter uses a code such as that illustrated in Figure 13-36A.

Keys and Keyseats

Key

A *key* is a demountable part that provides a positive means of transferring torque between a shaft and a hub.

Keys are used to prevent slippage and to transmit torque between a shaft and a hub. There are many kinds of keys. The five major kinds used in industry today are illustrated in Figure 13-37: square key, flat key, gib head key, Pratt & Whitney key and Woodruff key. Where a lot of torque is present, a double key and keyseat is often used. In extreme conditions, a spline is machined into the shaft and into the hub. For spline information, refer to a *Machinery's Handbook*.

Keyseat

A *keyseat* is an auxiliary-located rectangular groove machined into the shaft and/or hub to receive the key.

Classes of Fit

There are three classifications of fit:

Class 1. A side surface clearance fit obtained by using bar stock key and keyseat tolerances. This is a relatively free fit.

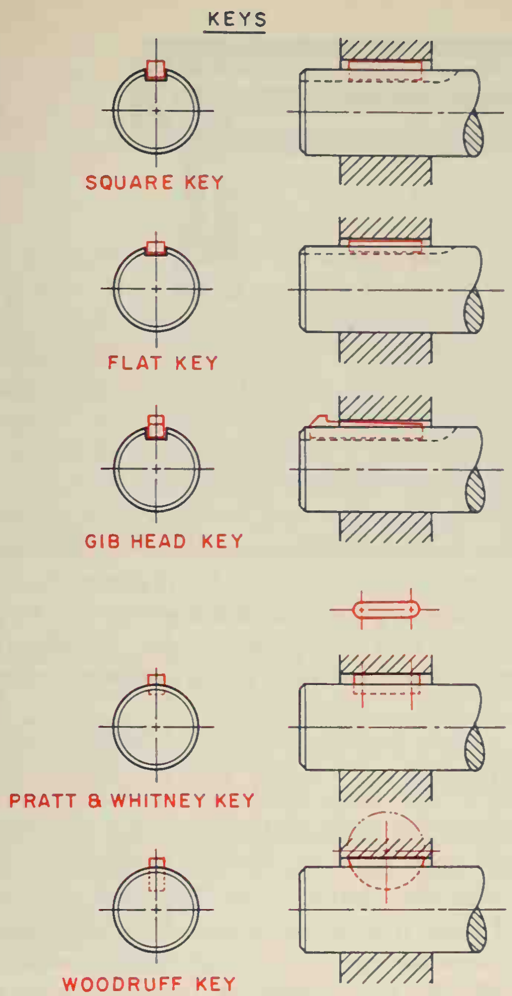


Figure 13-37 Keys and keyseats

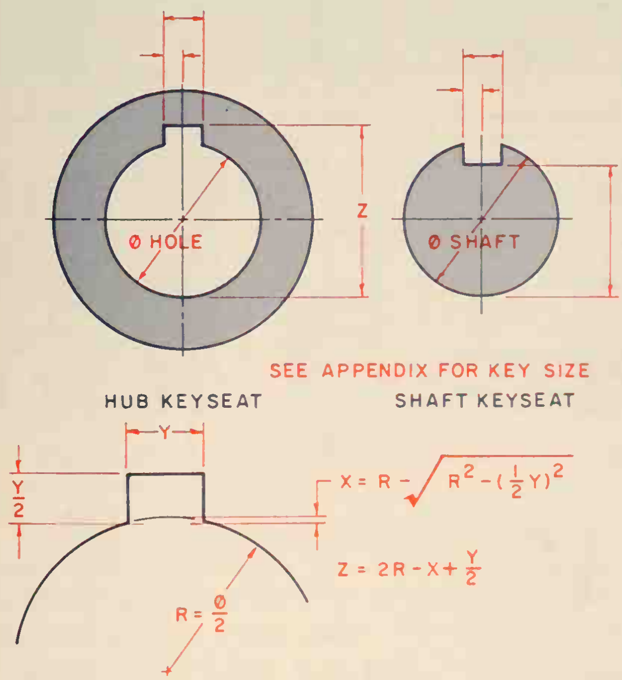


Figure 13-38 Dimensioning keyseats

Class 2. A possible side surface interference or side surface clearance fit obtained by using bar stock key and keyseat tolerances. This is a relatively tight fit.

Class 3. A side surface interference fit obtained by interference fit tolerances. This is a very tight fit and has not been generally standardized.

Key Sizes

For a general rule, the key width is about one-fourth the nominal diameter of the shaft. For exact recommended key sizes, refer to the Appendix in the text or a *Machinery's Handbook*.

Dimensioning Keyseats

Methods of dimensioning a stock key are shown in Figure 13-38.

For dimensioning a Woodruff keyseat, the key number must be included, Figure 13-39. Refer to the key size in the Appendix to obtain the exact sizes. To dimension a Pratt & Whitney keyseat, see Figure 13-40.

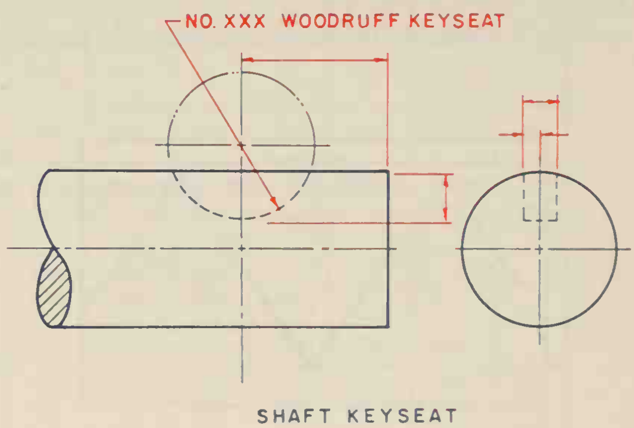


Figure 13-39 Woodruff keyseat

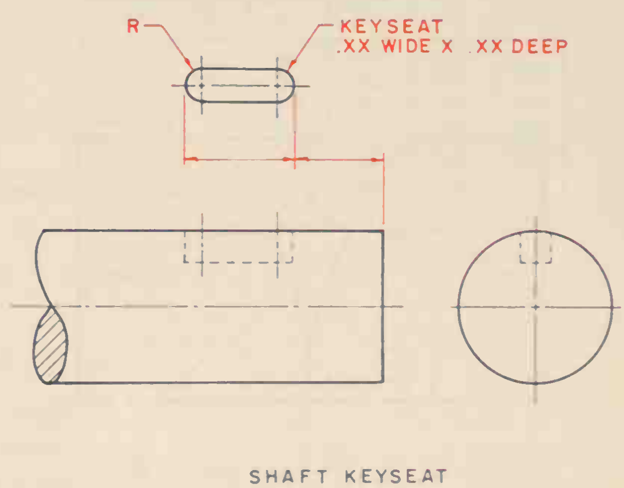


Figure 13-40 Pratt & Whitney keyseat

Figure 13-41 Grooved fastener

Grooved Fasteners

Many types of fasteners are used in industry, each with its own application. Threaded fasteners, such as nuts and bolts, are used to hold parts in tension. *Grooved fasteners* are used to solve metal-to-metal pinning needs with shear application, Figure 13-41.

Grooved fasteners have great holding power and are resistant to shock, vibration, and fatigue. They are available in a wide range of types, sizes, and materials. A grooved fastener often has a better appearance than most other methods of fastening. This can be important to the overall design, if the fastener is visible.

Grooved fasteners have three parallel grooves, equally spaced, impressed longitudinally on their exterior surface. To make these grooves, a grooving tool is pressed *below* the surface to displace a carefully determined amount of material. *Nothing* is removed. The metal is displaced to each side, forming a raised portion or flute extending along each side of the groove, Figure 13-42. The crest of the flute constitutes the *expanded diameter* (Dx). The expanded diameter (Dx) is a few thousandths larger than the nominal diameter (D) of the stock.

Grooved fasteners can be custom manufactured in order to meet most any application. For example, a custom grooved pin can be made with a cross-drilled hole, a groove for a snap ring, or a threaded hole in one end. The groove length can also be varied and placed anywhere along the length of the pin.

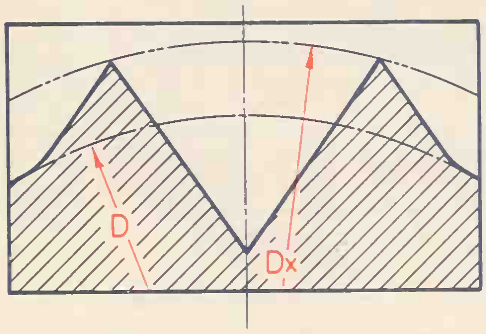


Figure 13-42 Enlarged sectional view of one of the grooves *before* inserting fastener

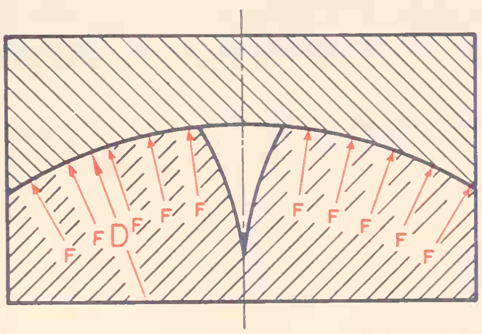


Figure 13-43 The same view *after* insertion. A powerful radial thrust is obtained.

Installation

The grooved fastener is forced into a drilled hole slightly larger than the nominal or specified diameter of the pin, Figure 13-43. The crest or flutes are forced back into the grooves when the fastener is driven into the hole. The resiliency of the metal forced back into the grooves creates powerful radial forces against the hole wall.

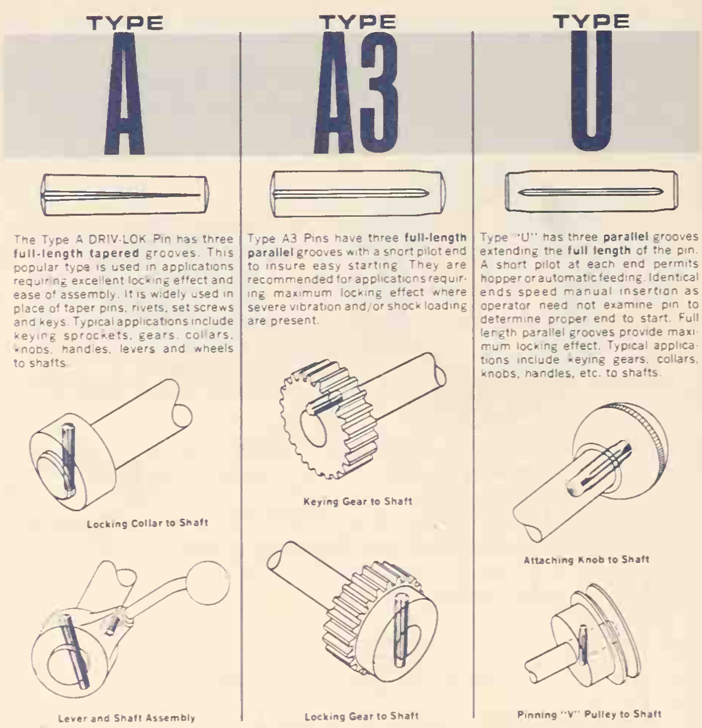
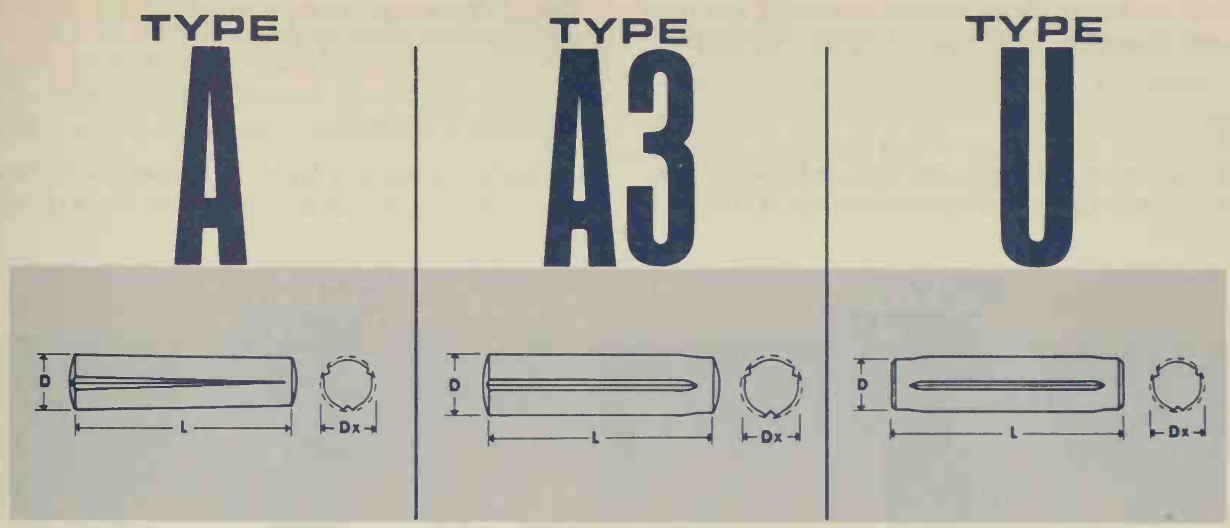


Figure 13-44 Typical applications for grooved pin types A, A3 and U



STANDARD SIZES

Nominal diameter and recommended drill sizes	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2
Dec. Equivalents	.0625	.0781	.0938	.1094	.1250	.1563	.1875	.2188	.2500	.3125	.3750	.4375	.5000
Crown Height, In.	.0065	.0087	.0091	.0110	.0130	.0170	.0180	.0220	.0260	.0340	.0390	.0470	.0520
Radius, In. ±.010	5/64	3/32	1/8	9/64	5/32	3/16	1/4	9/32	5/16	3/8	15/32	17/32	5/8
Pilot Length, In. (Ref.)	1/32	1/32	1/32	1/32	1/32	1/16	1/16	1/16	1/16	3/32	3/32	3/32	3/32
Chamfer Length, In. (Type U Only)	1/64	1/64	1/64	1/64	1/64	1/32	1/32	1/32	1/32	3/64	3/64	3/64	3/64
"Dx" EXPANDED DIAMETER—CAN BE DETERMINED ACCURATELY ONLY WITH RING GAGES													
LENGTH OF PIN IN INCHES													
1/4 (.250)	.068	.084	.101	.117	.134								
3/8 (.375)	.068	.084	.101	.117	.134	.166	.198						
1/2 (.500)	.068	.084	.101	.117	.134	.166	.198	.230	.263				
5/8 (.625)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329			
3/4 (.750)	.068	.084	.101	.116	.134	.166	.198	.230	.263	.329	.394		
7/8 (.875)	.068	.084	.101	.116	.133	.165	.198	.230	.263	.329	.394	.459	
1 (1.000)	.068	.084	.101	.115	.133	.165	.198	.230	.263	.329	.394	.459	.525
1 1/4 (1.250)			.101	.115	.132	.164	.197	.230	.263	.329	.394	.459	.525
1 1/2 (1.500)					.132	.164	.197	.229	.262	.329	.394	.459	.525
1 3/4 (1.750)						.163	.197	.229	.262	.328	.393	.459	.525
2 (2.000)						.163	.196	.229	.262	.328	.393	.458	.525
2 1/4 (2.250)							.196	.229	.262	.328	.393	.458	.524
2 1/2 (2.500)								.228	.261	.327	.393	.458	.524
2 3/4 (2.750)								.228	.261	.327	.393	.458	.524
3 (3.000)								.227	.260	.327	.392	.457	.523
3 1/4 (3.250)									.260	.326	.392	.457	.523
3 1/2 (3.500)										.326	.391	.456	.522
3 3/4 (3.750)											.391	.456	.522
4 (4.000)											.390	.455	.521
4 1/4 (4.250)											.390	.455	.521
4 1/2 (4.500)												.454	.520

Nom. Diam. (D)	Exp. Diam. (Dx) reduced by
1/16	.002
5/64	.002
3/32	.002
7/64	.002
1/8	.002
5/32	.002
3/16	.003
7/32	.003
1/4	.003
5/16	.004
3/8	.005
7/16	.006
1/2	.006

TOLERANCES:

On Nominal Diameter "D"
+.000—.001 up to 7/64" diameter
+.000—.002 7/64" and above

On Expanded Diameter "Dx"
±.001 up to 7/64" diameter
±.002 7/64" and above
On over-all Length "L"
±.010 for all diameters

◀ For stainless steels and other special materials, the expanded diameters shown in above table are reduced by amounts shown at left.

Note: Intermediate pin lengths, pin diameters up to 1/4", groove lengths, and groove positions to order as specials. When ordering, specify type, diameter, length, and special finishes.

Figure 13-45 Standard size chart of grooved pin types A, A3 and U

In many cases, grooved fasteners are lower in cost than knurled pins, taper pins, pins with cotter pins, rivets, set screws, keys or other methods used to fasten metal-to-metal parts together. The installation cost of grooved pins is invariably lower because of the required hole tolerances, and no special guides are required at assembly.

Material

Standard grooved fasteners are made of cold-drawn, low-carbon steel. The physical properties of this material are more than enough for ordinary applications. Alloy steel, hard brass, silicon bronze, stainless steel, and other exotic metals may also be specially ordered. These special materials are usually heat treated for optimum physical qualities.

Finish

Standard grooved fasteners have a finish of zinc electroplated, deposited approximately .00015 inch deep. Chromate, brass, cadmium, and black oxide can also be specially ordered.

Standard Types

Study the various types of grooved fasteners and the related technical data in Figures 13-44 (page 420),

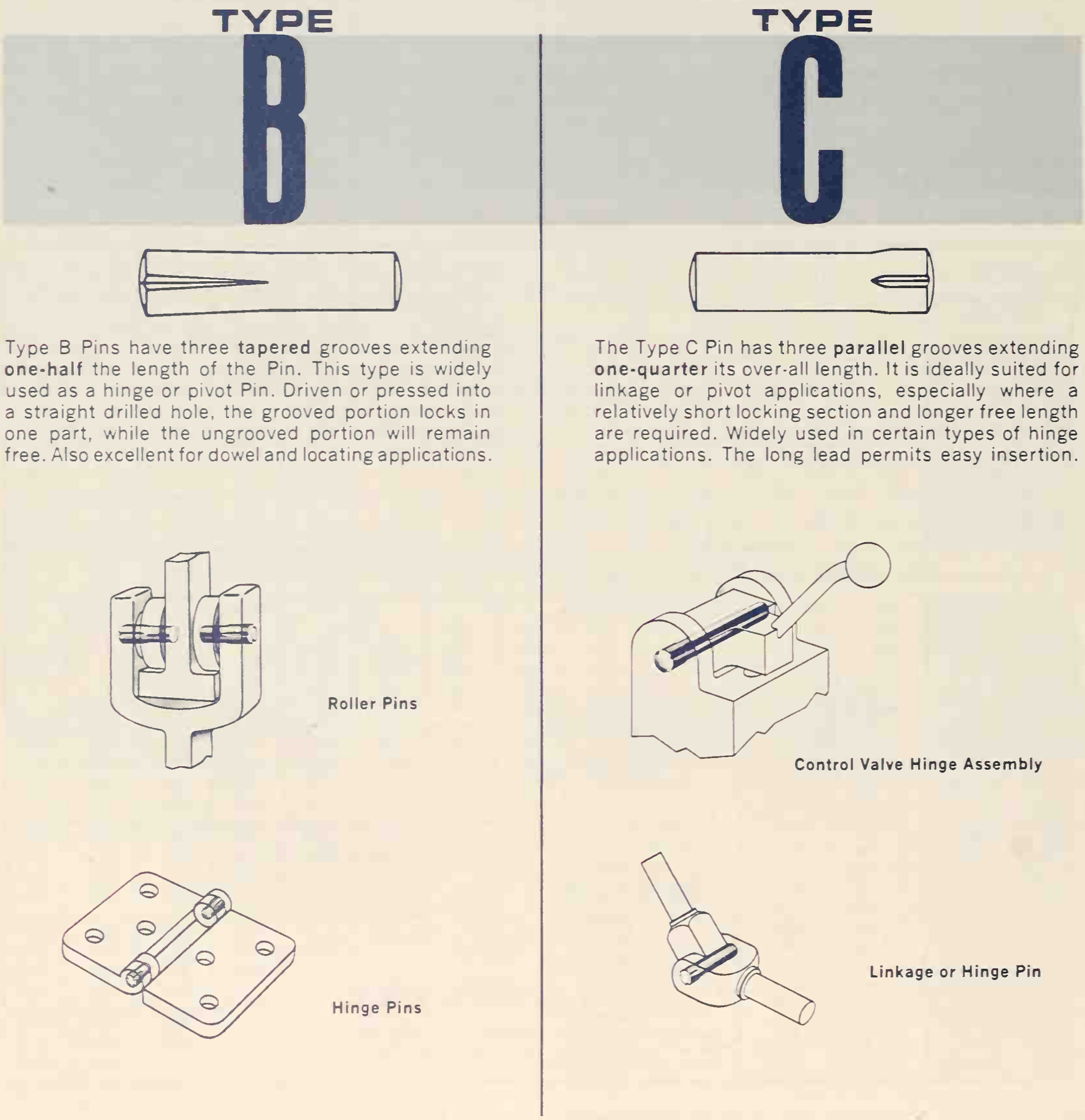
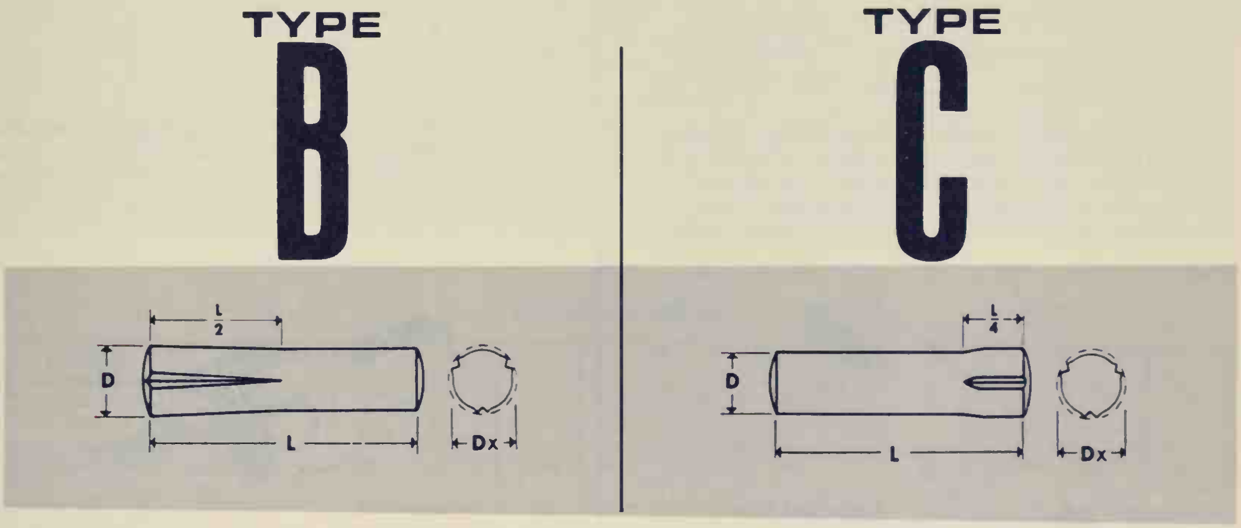


Figure 13-46 Typical applications for grooved pin types B and C

13-46, 13-48, 13-50, and 13-53. Note the various types of fasteners, how each functions, and what each replaces. For example, Type A is used in place of taper pins, rivets, set screws, and keys.

Standard Sizes

Refer to the standard size charts in Figures 13-45 (page 421), 13-47, 13-49, and 13-51. Across the top of each chart are the nominal sizes from 1/16-inch diameter to 1/2-inch diameter. At the left side of each



STANDARD SIZES

Nominal diameter and recommended drill sizes	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2
Dec. Equivalents	.0625	.0781	.0938	.1094	.1250	.1563	.1875	.2188	.2500	.3125	.3750	.4375	.5000
Crown Height, In.	.0065	.0087	.0091	.0110	.0130	.0170	.0180	.0220	.0260	.0340	.0390	.0470	.0520
Radius, In. ± .010	5/64	3/32	1/8	9/64	5/32	3/16	1/4	9/32	5/16	3/8	15/32	17/32	5/8

"Dx" EXPANDED DIAMETER—CAN BE DETERMINED ACCURATELY ONLY WITH RING GAGES

LENGTH OF PIN IN INCHES	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2
1/4 (.250)	.068	.084	.101	.117	.134								
3/8 (.375)	.068	.084	.101	.117	.134	.166	.198						
1/2 (.500)	.068	.084	.101	.117	.134	.166	.198	.230	.263				
5/8 (.625)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329			
3/4 (.750)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329	.394		
7/8 (.875)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	
1 (1.000)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/4 (1.250)			.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/2 (1.500)					.134	.166	.198	.230	.263	.329	.394	.459	.525
1 3/4 (1.750)						.165	.198	.230	.263	.329	.394	.459	.525
2 (2.000)						.165	.198	.230	.263	.329	.394	.459	.525
2 1/4 (2.250)							.197	.230	.263	.329	.394	.459	.525
2 1/2 (2.500)								.230	.263	.329	.394	.459	.525
2 3/4 (2.750)								.229	.262	.329	.394	.459	.525
3 (3.000)								.229	.262	.329	.394	.459	.525
3 1/4 (3.250)									.262	.328	.393	.459	.525
3 1/2 (3.500)										.328	.393	.459	.525
3 3/4 (3.750)											.393	.458	.525
4 (4.000)											.393	.458	.525
4 1/4 (4.250)											.393	.458	.524
4 1/2 (4.500)												.458	.524

Nom. Diam. (D)	Exp. Diam. (Dx) reduced by
1/16	.002
5/64	.002
3/32	.002
7/64	.002
1/8	.002
5/32	.002
3/16	.003
7/32	.003
1/4	.003
5/16	.004
3/8	.005
7/16	.006
1/2	.006

TOLERANCES

On Nominal Diameter "D"
+.000 −.001 up to 7/64" diameter
+.000 −.002 7/64" and above

On Expanded Diameter "Dx"
± .001 up to 7/64" diameter
± .002 7/64" and above
On over-all Length "L"
± .010 for all diameters

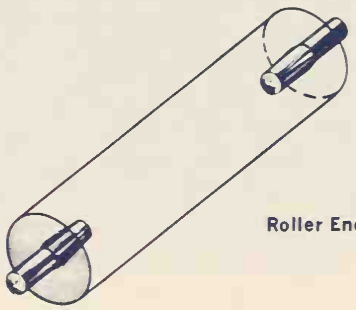
◀ For stainless steels and other special materials, the expanded diameters shown in above table are reduced by amounts shown at left.

Note: Intermediate pin lengths, pin diameters up to 1/4", groove lengths, and groove positions to order as specials. When ordering, specify type, diameter, length, and special finishes.

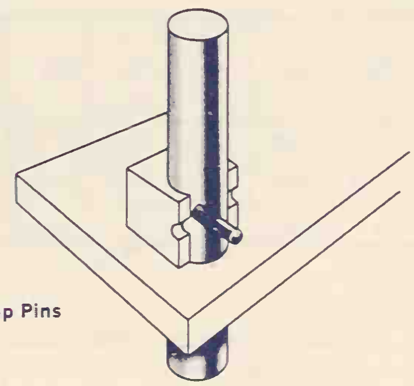
Figure 13-47 Standard size chart of grooved pin types B and C

TYPE D

Type D has three **reverse** taper grooves extending **one-half** the length of the pin. Recommended for use in blind holes as a stop pin, roller pivot, dowel, or for certain hinge or linkage applications. Reverse taper grooves permit easy insertion in blind holes.

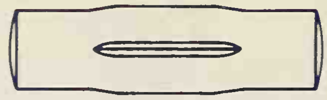


Roller End Pins

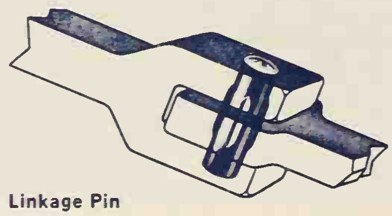


Stop Pins

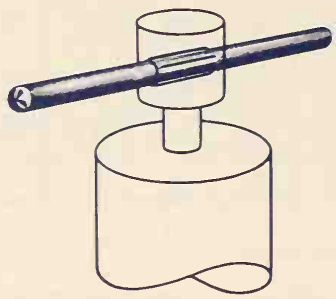
TYPE E



Type E has three **parallel half-length** grooves located equidistant from each end. Widely used as T handle on valves and tools. Also used as a cross pin, cotter pin, pivot pin, etc. where center locking is required.

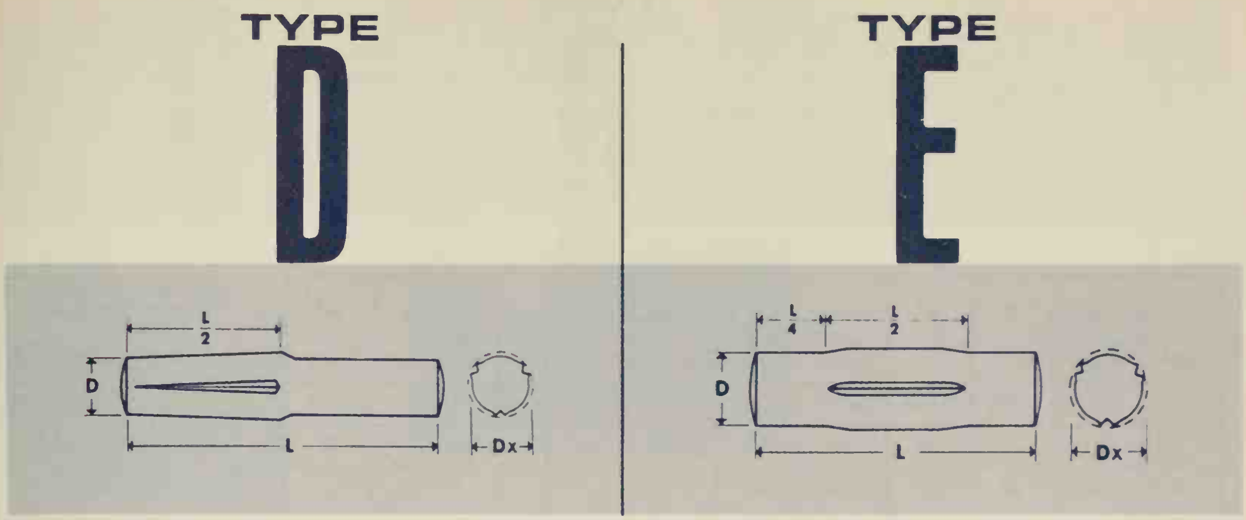


Linkage Pin



T Handle for Valve

Figure 13-48 Typical applications for grooved pin types D and E



STANDARD SIZES

Nominal diameter and recommended drill sizes	1/16	5/64	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2
Dec. Equivalents	.0625	.0781	.0938	.1094	.1250	.1563	.1875	.2188	.2500	.3125	.3750	.4375	5000
Crown Height, In.	.0065	.0087	.0091	.0110	.0130	.0170	.0180	.0220	.0260	.0340	.0390	.0470	.0520
Radius, In. ± .010	5/64	3/32	1/8	9/64	5/32	3/16	1/4	9/32	5/16	3/8	15/32	17/32	5/8

"Dx" EXPANDED DIAMETER—CAN BE DETERMINED ACCURATELY ONLY WITH RING GAGES

LENGTH OF PIN IN INCHES													
1/4 (.250)	.068	.084	.101	.117	.134								
3/8 (.375)	.068	.084	.101	.117	.134	.166	.198						
1/2 (.500)	.068	.084	.101	.117	.134	.166	.198	.230	.263				
5/8 (.625)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329			
3/4 (.750)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329	.394		
7/8 (.875)	.068	.084	.101	.117	.134	.166	.198	.230	.263	329	.394	.459	
1 (1.000)	.068	.084	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/4 (1.250)			.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/2 (1.500)					.134	.166	.198	.230	.263	.329	.394	.459	.525
1 3/4 (1.750)						.165	.198	.230	.263	.329	.394	.459	.525
2 (2.000)						.165	.198	.230	.263	.329	.394	.459	525
2 1/4 (2.250)							.197	.230	.263	.329	.394	.459	.525
2 1/2 (2.500)								.230	.263	.329	.394	459	.525
2 3/4 (2.750)								.229	.262	.329	.394	459	525
3 (3.000)								.229	.262	.329	.394	459	525
3 1/4 (3.250)									.262	.328	.393	.459	525
3 1/2 (3.500)										.328	.393	.459	.525
3 3/4 (3.750)											.393	.458	525
4 (4.000)											.393	.458	525
4 1/4 (4.250)											.393	.458	.524
4 1/2 (4.500)												.458	.524

Nom. Diam. (D)	Exp. Diam. (Dx) reduced by
1/16	.002
5/64	.002
3/32	.002
7/64	.002
1/8	.002
5/32	.002
3/16	.003
7/32	.003
1/4	.003
5/16	.004
3/8	.005
7/16	.006
1/2	.006

TOLERANCES

On Nominal Diameter "D"
+.000—.001 up to 7/64" diameter
+.000—.002 7/64" and above

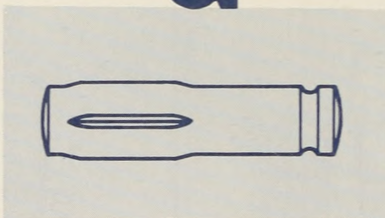
On Expanded Diameter "Dx"
±.001 up to 7/64" diameter
±.002 7/64" and above
On over-all Length "L"
±.010 for all diameters

For stainless steels and other special materials, the expanded diameters shown in above table are reduced by amounts shown at left.

Note: Intermediate pin lengths, pin diameters up to 1/4", groove lengths and groove positions to order as specials. When ordering, specify type, diameter, length, and special finishes.

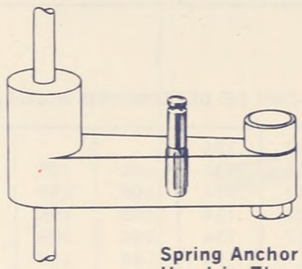
Figure 13-49 Standard size chart of grooved pin types D and E

TYPE G



Typical applications

Type G has three **parallel half-length** grooves including pilot. It is a very versatile pin, suitable for use in both blind and through holes as a spring anchor pin. The annular groove opposite the locking end is used to anchor the end loop of a tension spring. If snap or retainer rings are to be used, special section annular grooves can be machined to order.



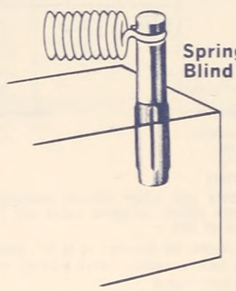
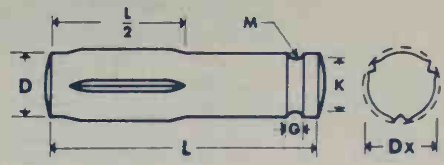


Figure 13-50 Typical application for grooved pin type G

TYPE G

(combined former F and G)



STANDARD SIZES

Nominal diameter and recommended drill sizes	3/32	7/64	1/8	5/32	3/16	7/32	1/4	5/16	3/8	7/16	1/2
Dec. Equivalents	.0938	.1094	.1250	.1563	.1875	.2188	.2500	.3125	.3750	.4375	.5000
Crown Height, In.	.0091	.0110	.0130	.0170	.0180	.0220	.0260	.0340	.0390	.0470	.0520
Radius, In., ±0.010	1/8	9/64	5/32	3/16	1/4	9/32	5/16	3/8	15/32	17/32	5/8
Pilot Length, In. (Ref.)	1/32	1/32	1/32	1/16	1/16	1/16	1/16	3/32	3/32	3/32	3/32
M Neck Radius (Ref.)	1/64	1/64	1/32	1/32	1/32	3/64	3/64	1/16	1/16	3/32	3/32
G Nock Width (Ref.)	1/32	1/32	1/16	1/16	1/16	3/32	3/32	1/8	1/8	3/16	3/16
Shoulder Width +.010—.000	1/32	1/32	1/32	3/64	3/64	1/16	1/16	3/32	1/8	1/8	1/8
K Neck Diameter ±.005	.062	.078	.083	.104	.125	.146	.167	.209	.250	.293	.312
"Dx" EXPANDED DIAMETER—CAN BE DETERMINED ACCURATELY ONLY WITH RING GAGES											
LENGTH OF PIN IN INCHES											
3/8 (.375)	.101	.117	.134	.166	.198						
1/2 (.500)	.101	.117	.134	.166	.198	.230	.263				
5/8 (.625)	.101	.117	.134	.166	.198	.230	.263	.329			
3/4 (.750)	.101	.117	.134	.166	.198	.230	.263	.329	.394		
7/8 (.875)	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	
1 (1.000)	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/4 (1.250)	.101	.117	.134	.166	.198	.230	.263	.329	.394	.459	.525
1 1/2 (1.500)			.134	.166	.198	.230	.263	.329	.394	.459	.525
1 3/4 (1.750)				.165	.198	.230	.263	.329	.394	.459	.525
2 (2.000)				.165	.198	.230	.263	.329	.394	.459	.525
2 1/4 (2.250)					.197	.230	.263	.329	.394	.459	.525
2 1/2 (2.500)						.230	.263	.329	.394	.459	.525
2 3/4 (2.750)						.229	.262	.329	.394	.459	.525
3 (3.000)						.229	.262	.329	.394	.459	.525
3 1/4 (3.250)							.262	.328	.393	.459	.525
3 1/2 (3.500)								.328	.393	.459	.525
3 3/4 (3.750)									.393	.458	.525
4 (4.000)									.393	.458	.525
4 1/4 (4.250)									.393	.458	.524
4 1/2 (4.500)										.458	.524

Nom. Diam. (D)	Exp. Diam. (Dx) reduced by
3/32	.002
7/64	.002
1/8	.002
5/32	.002
3/16	.003
7/32	.003
1/4	.003
5/16	.004
3/8	.005
7/16	.006
1/2	.006

TOLERANCES:

On Nominal Diameter "D"
+.000—.001 up to 7/64" diameter
+.000—.002 7/64" and above

On Expanded Diameter "Dx"
±.001 up to 7/64" diameter
±.002 7/64" and above
On over-all Length "L"
±.010 for all diameters

◀ For stainless steels and other special materials, the expanded diameters shown in above table are reduced by amounts shown at left.

Note: Intermediate pin lengths, pin diameters up to 1/4", groove lengths, and groove positions to order as specials. When ordering, specify type, diameter, length, and special finishes.

Figure 13-51 Standard size chart of groove pin type G

chart are listed the standard lengths from 1/4-inch long to 4 1/2-inches long. Various other technical information can be derived from the charts. For drilling procedure, hole tolerances, application data, and high-alloy pin applications, see Figures 13-52, 13-54, 13-55.

Grooved Studs

Grooved studs are widely used for fastening light metal or plastic parts to heavier members or assemblies, Figures 13-56 and 13-57. They replace screws, rivets, peened pins, and many other types of fasteners. The grooves function as any grooved fastener.

Pin Diameter	Decimal Equivalent	Recommended Drill Size	Hole Tolerances ADD To Nominal Diameter
1⁄16″	.0625	1⁄16″	.002″
5⁄64	.0781	5⁄64	.002″
3⁄32	.0938	3⁄32	.003″
7⁄64	.1094	7⁄64	.003″
1⁄8	.1250	1⁄8	.003″
5⁄32	.1563	5⁄32	.003″
3⁄16	.1875	3⁄16	.004″
7⁄32	.2188	7⁄32	.004″
1⁄4	.2500	1⁄4	.004″
5⁄16	.3125	5⁄16	.005″
3⁄8	.3750	3⁄8	.005″
7⁄16	.4375	7⁄16	.006″
1⁄2	.5000	1⁄2	.006″

Tolerances for drilled holes shown in table are based on depth to diameter ratio of approximately 5 to 1. Higher ratios may cause these figures to be exceeded, but in no case should they be exceeded by more than 10%. Specifications for holes having a depth to diameter ratio of 1 to 1 or less should be held extremely close; 60% of figures shown in table is recommended.

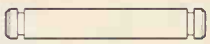
Undersized drills should never be used to produce holes for Driv-Lok Pins. This malpractice results from the false assumption that the pins will "hold better." Instead, they bend, damage the hole wall, crack castings, and peel their expanded flutes, thus reducing their retaining characteristics and preventing their reuse.

Holes made in hardened steel or cast iron are recommended to have a slight chamfer at the entrance. This eliminates shearing of the flutes as the pins are forced in.

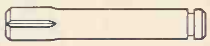
Care should be exercised in all drilling for Driv-Lok Pins. Drills used should be new or properly ground with the aid of an approved grinding fixture. The drilling machine spindle must be in good condition and operated at correct speeds and feeds for the metal being drilled, and suitable coolant is always recommended. Drill jigs with accurate bushings always facilitate good drilling practice.

Figure 13-52 Drilling procedure and hole tolerance

1 Straight pin with annular grooves at each end designed to accommodate snap or retainer rings. Available 3⁄16″ through 3⁄4″ diameters.

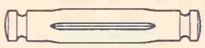


2 Pin with locking grooves on one end and annular groove on other end. Often used for roller or collar retension. Available 3⁄16″ through 3⁄8″ diameters.



3 Straight pin with both ends chamfered. Available 1⁄16″ through 3⁄8″ diameters.

4 Grooved spring anchor pin with annular grooves at both ends. Available 3⁄32″ through 3⁄4″ diameters.



5 Special pin with grooves extending one-third length of pin. Groove length and position can be varied to suit specific applications. Available 1⁄16″ through 3⁄4″ diameters.

6 Special straight pin with both ends chamfered and cross-drilled for cross pin or cotter. Available 1⁄4″ through 3⁄4″ diameters.

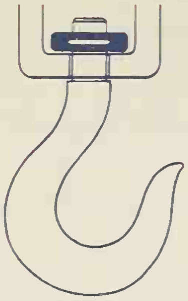
Figure 13-53 Special pins

RECOMMENDED PIN DIAMETER FOR VARIOUS SHAFT SIZES AND TORQUE TRANSMITTED BY PIN IN DOUBLE SHEAR							
Shaft Size	Pin Diameter	Torque Inch Lbs.	H.P. at 100 R.P.M.	Shaft Size	Pin Diameter	Torque Inch Lbs.	H.P. at 100 R.P.M.
3/16	1/16	4.6	.007	7/8	1/4	347	.555
7/32	5/64	8.4	.013	15/16	5/16	580	.927
1/4	3/32	13.7	.022	1	5/16	618	.990
5/16	7/64	23.6	.038	1 1/16	5/16	657	1.05
3/8	1/8	37.2	.060	1 1/8	3/8	1010	1.61
7/16	5/32	67.6	.108	1 3/16	3/8	1065	1.70
1/2	5/32	77.2	.124	1 1/4	3/8	1120	1.79
9/16	3/16	125.0	.200	1 5/16	7/16	1590	2.55
5/8	3/16	139.0	.222	1 3/8	7/16	1670	2.67
11/16	7/32	207.0	.332	1 7/16	7/16	1740	2.79
3/4	1/4	297.0	.476	1 1/2	1/2	2380	3.81
13/16	1/4	322	.516				

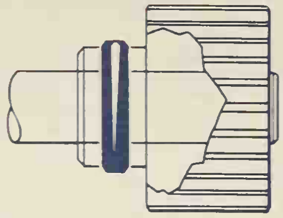
This table is a guide in selecting the proper size Driv-Lok Grooved Pin to use in keying machine members to shafts of given sizes and for specific load requirements. Torque and horsepower ratings are based on pins made of cold finished, low carbon steel and a safety factor of 8 is assumed.

MINIMUM SINGLE SHEAR VALUES (LBS.) OF DRIV-LOK PINS OF VARIOUS MATERIALS					
	MATERIAL				
DRIV-LOK PIN DIAM.	Cold Finished 1213 Steel	Shear-Proof* ALLOY STEEL R.C. 40 - 48	Brass	Silicon Bronze	Heat Treated Stainless Steel
1/16	200	363	124	186	308
5/64	312	562	192	288	478
3/32	442	798	272	408	680
7/64	605	1091	372	558	933
1/8	800	1443	492	738	1230
5/32	1240	2236	764	1145	1910
3/16	1790	3220	1100	1650	2750
7/32	2430	4386	1495	2240	3740
1/4	3190	5753	1960	2940	4910
5/16	4970	8974	3060	4580	7650
3/8	5810	12960	4420	6630	11050
7/16	7910	17580	6010	9010	15000
1/2	10300	23020	7850	11800	19640

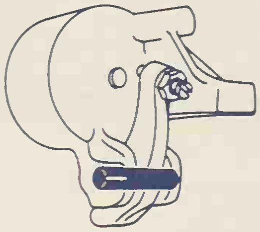
Figure 13-54 Grooved pin application/engineering data



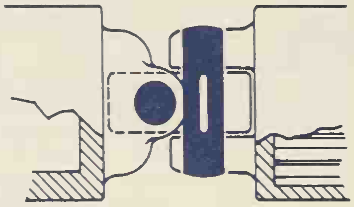
MATERIAL HANDLING EQUIPMENT—The Type E pin provides positive locking with a half-length groove in the center of the Pin. Extreme shear is exerted in this application, yet the Shear-Proof Pin is used with complete safety for both men and materials. Type E is a special Pin.



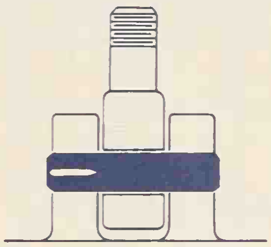
HEAVY-DUTY GEAR AND SHAFT ASSEMBLY—Type A Shear-Proof Pin as specified for this application to give maximum locking power over the entire pin and gear hub area. The Type A Pin, with grooves the full length of the Pin, is the standard stock Pin which meets most applications.



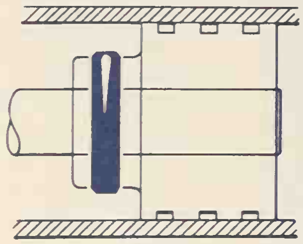
AUTOMATIC TRANSMISSION IN AUTOMOBILES—Special Type C was selected as a shaft in this transmission servo to replace a cross drilled shaft with a cross pin for holding shaft in position. This eliminated a costly drilling operation and the cross pin.



UNIVERSAL JOINTS IN HAND TOOLS—Special Type E Pin with center groove eliminates costly staking and grinding operations and improves product appearance. This Pin is easily installed, fits flush and permits plating before assembly.

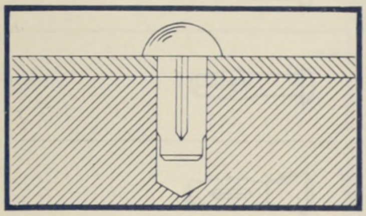


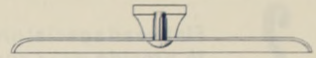
EYE BOLT HINGE PIN — Type C Pin, with quarter-length grooves, provides maximum ease of assembly. There is no interference until three-fourths of the pin is in position. The high safety factor inherent in Shear-Proof Pins makes them practical and efficient for such constant shear applications. Type C is a special Pin.



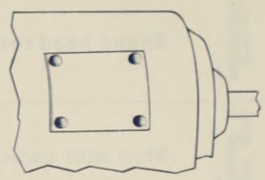
HIGH-PRESSURE PISTON AND ROD ASSEMBLY—Type B Pin was used here because the half-length grooves simplified the job of starting the pin into the hole. Ease of assembly was matched with sufficient locking power even when subjected to continuous, strong reciprocating forces. Type B is a special Pin.

Figure 13-55 High alloy shear-proof pins





Fastening knobs handles, etc.



Attaching nameplates, instruction panels

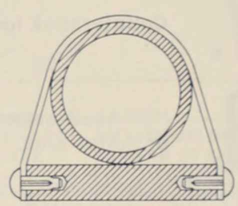
Stud Number	Nominal Shank Diameter	Recom-mended Drill Size	Head Dia. Max.	Head Dia. Min.	Head Height Max.	Head Height Min.
0	.067	51	.130	.120	.050	.040
2	.086	44	.162	.146	.070	.059
4	.104	37	.211	.193	.086	.075
6	.120	31	.260	.240	.103	.091
7	.136	29	.309	.287	.119	.107
8	.144	27	.309	.287	.119	.107
10	.161	20	.359	.334	.136	.124
12	.196	9	.408	.382	.152	.140
14	.221	2	.457	.429	.169	.156
16	.250	¼″	.472	.443	.174	.161

Maximum Expansion—Standard Lengths

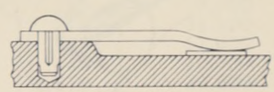
Stud No.	⅛″	3⁄16″	¼″	5⁄16″	⅜″	½″
0	.074	.074	.074			
2	.096	.096	.095			
4		.115	.113	.113		
6			.132	.130	.130	
7				.147	.147	.144
8					.155	.153
10					.173	.171
12						.206
14						.234
16						.263

TOLERANCES:
On length ± .010
On Exp. Diameter ± .002
On Nominal Diameter +.000 —.002

Note: The expanded diameter can be determined accurately only with ring gages.



Widely used for fastening brackets



Fastening spring assemblies or control arms

Figure 13-56 Standard studs

1. Flat head special stud with one-third length groove at lead end. Groove length can be varied.

2. Flat head special grooved stud with shoulder. Often hardened to provide wear surface in shoulder area.

3. Flat head grooved stud.

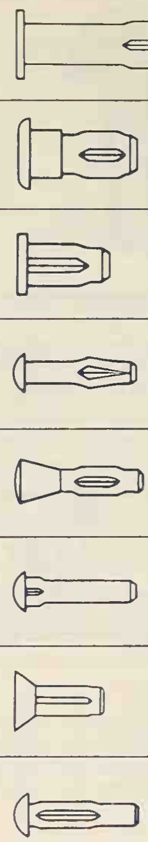
4. Round head reverse taper groove stud.

5. Stud with conical head and parallel grooves.

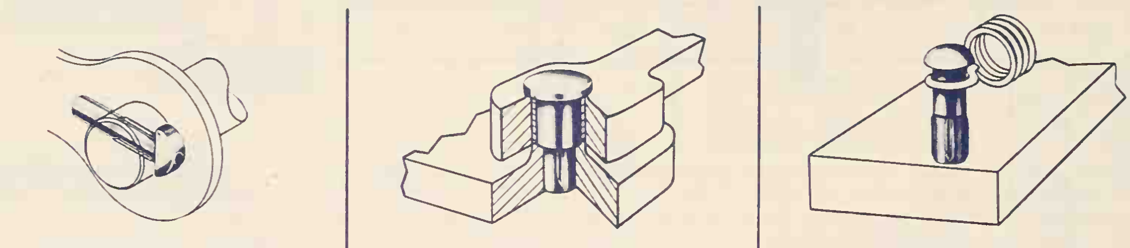
6. Round head stud with parallel grooves of special length.

7. Countersunk head grooved stud.

8. "T" head cotter used extensively in chain industry in place of cotter pins.



SPECIAL STUD APPLICATIONS



*Available as specials through ½" diameter.

Figure 13-57 Special studs

Spring Pins

Another type of fastener is the *spring pin*, Figure 13-58. Spring pins are manufactured by cold forming strip metal in a progressive roll forming operation. After forming, the pins are broken off and deburred to eliminate any sharp edges. They are then heat treated to a R/C 46/53. This develops spring qualities or resiliency in the metal.

In the free state, the pins are larger in diameter than the hole into which they are to be inserted. The pins compress themselves as they are driven into the hole, thus exerting radial forces around the entire circumference of the hole.

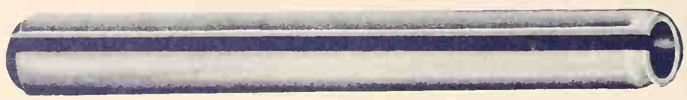
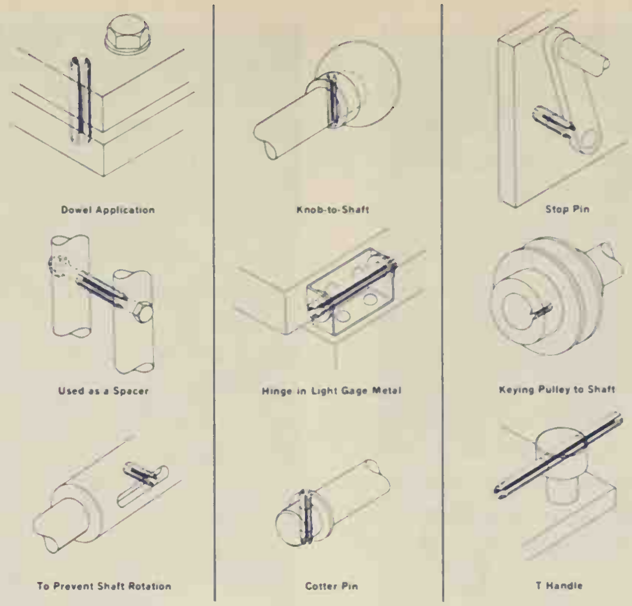
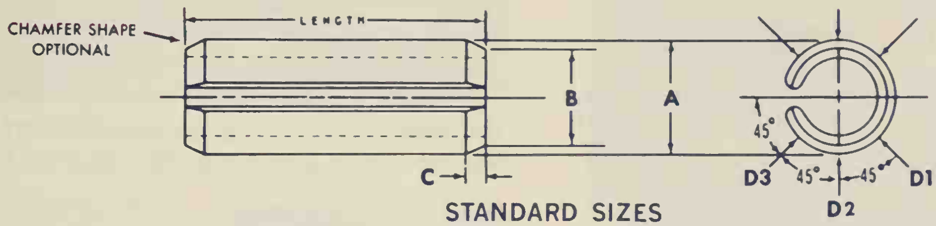


Figure 13-58 Spring pin

Spring pins are made from a high carbon steel—1074, stainless steel, either 420 heat treated or 300 series cold worked. Some spring pins are also made from brass or beryllium copper. Spring pins meet the demand of many industrial applications. Figures 13-59 and 13-60 list some suggested applications.

Figure 13-59
Spring pin application





STANDARD SIZES

A			B Max.	C		WALL THICK-NESS	RECOMMENDED HOLE SIZE		MINIMUM DOUBLE SHEAR STRENGTH POUNDS Carbon Steel and Stainless Steel
Nominal	Minimum $\frac{1}{3}(D_1+D_2+D_3)$	Maximum (Go Ring Gage)		Min.	Max.		Min.	Max.	
.062	.066	.069	.059	.007	.028	.012	.062	.065	425
.078	.083	.086	.075	.008	.032	.018	.078	.081	650
.094	.099	.103	.091	.008	.038	.022	.094	.097	1,000
.125	.131	.135	.122	.008	.044	.028	.125	.129	2,100
.156	.162	.167	.151	.010	.048	.032	.156	.160	3,000
.187	.194	.199	.182	.011	.055	.040	.187	.192	4,400
.219	.226	.232	.214	.011	.065	.048	.219	.224	5,700
.250	.258	.264	.245	.012	.065	.048	.250	.256	7,700
.312	.321	.328	.306	.014	.080	.062	.312	.318	11,500
.375	.385	.392	.368	.016	.095	.077	.375	.382	17,600
.437	.448	.456	.430	.017	.095	.077	.437	.445	20,000
.500	.513	.521	.485	.025	.110	.094	.500	.510	25,800

All dimensions listed on this page are in accordance with National Standards. Wall thicknesses within the Spring Pin industry are standard.

SPRING PIN WEIGHT PER 1000 PIECES
Material—Steel · Nominal Diameter

LENGTH	.062	.078	.094	.125	.156	.187
0.187	.10	0.18				
0.250	.15	0.22	0.33			
0.312	.19	0.28	0.41			
0.375	.23	0.34	0.50	0.89		
0.437	.27	0.40	0.58	1.00	1.50	
0.500	.30	0.46	0.66	1.20	1.70	2.50
0.562	.34	0.51	0.75	1.30	1.90	2.90
0.625	.38	0.57	0.83	1.50	2.10	3.20
0.687	.42	0.63	0.92	1.60	2.40	3.50
0.750	.46	0.69	1.00	1.80	2.60	3.80
0.812	.49	0.74	1.10	1.90	2.80	4.10
0.875	.53	0.80	1.20	2.10	3.00	4.50
0.937	.57	0.86	1.30	2.20	3.20	4.80
1.000	.61	0.92	1.40	2.40	3.40	5.10
1.125		1.00	1.50	2.70	3.80	5.70
1.250		1.20	1.70	3.00	4.30	6.40
1.375		1.30	1.80	3.30	4.70	7.00
1.500		1.40	2.00	3.60	5.10	7.60
1.625				3.90	5.50	8.30
1.750				4.20	6.00	8.90
1.875				4.50	6.40	9.60
2.000				4.70	6.80	10.0
2.250					7.80	12.0
2.500					8.60	13.0

LENGTH	.219	.250	.312	.375	.437	.500
0.562	4.00					
0.625	4.50	5.30				
0.687	4.90	5.90				
0.750	5.30	6.30	9.90	15.0		
0.812	5.80	6.90	11.0			
0.875	6.20	7.40	12.0			
0.937	6.70	8.00	12.0			
1.000	7.00	8.50	13.0	20.0	24.0	
1.125	7.90	9.50	14.0			
1.250	8.80	11.0	16.0	24.0	30.0	41.0
1.375	9.70	12.0	18.0			
1.500	11.0	13.0	19.0	29.0	36.0	49.0
1.625	12.0	14.0	21.0			
1.750	12.0	15.0	22.0	34.0	42.0	57.0
1.875	13.0	16.0	24.0			
2.000	14.0	17.0	25.0	38.0	48.0	65.0
2.250	16.0	19.0	29.0	43.0	54.0	73.0
2.500	18.0	21.0	32.0	48.0	60.0	81.0
2.750	19.0	23.0	35.0	53.0	66.0	89.0
3.000	21.0	25.0	38.0	58.0	72.0	97.0
3.250		28.0	41.0	62.0	77.0	105.0
3.500		31.0	44.0	67.0	83.0	114.0
3.750			48.0	72.0	89.0	122.0
4.000			51.0	77.0	95.0	130.0

Figure 13-60 Spring pin data

Fastening Systems

Fastening systems play a critical role in most product design. They often do more than position and secure components. In many cases, fastening systems have a direct effect upon the product's durability, reliability, size, and weight. They affect the speed with which the product may be assembled and disassembled, both during manufacturing and later in field service. Fastening systems also affect cost; not only for the fasteners, but for the machining and assembly operations they require.

Unless a drafter has had a great deal of experience in using different fastening devices and techniques, it is often difficult to choose a fastener that combines optimum function with maximum economy. A fastening system that is best for one product may not be desirable for another.

Retaining Rings

Retaining rings are precision-engineered fasteners. They provide removable shoulders for positioning or limiting the movement of parts in an assembly, Figure 13-61. Applications range from miniaturized electronic systems to massive earth-moving equipment. Retaining rings are used in automobiles, business machines, and complex components for guided missiles. They are found in such commonplace items as doorknobs to sophisticated underwater seismic cable connectors.

Typical ring applications are shown in Figures 13-62 through 13-66. From these figures, the drafter may examine the design of various types of rings, determine their purpose and function, and decide how they may be used to the best advantage.

Most retaining rings are made of materials that have good spring properties. This permits the rings to be deformed elastically to a substantial degree, yet still spring back to their original shape during assembly and disassembly. This allows most rings to function in one of two ways: 1) they may be sprung into a groove or other recess in a part, or 2) they may be seated on a part in a deformed condition so that they grip the part by frictional means. In either case, the rings form a fixed shoulder against which other components may be abutted and prevented from moving.

Unlike wire-formed rings which have a uniform section height, stamped rings have a tapered radial width. The width decreases symmetrically from the center section to the free ends. The tapered section per-

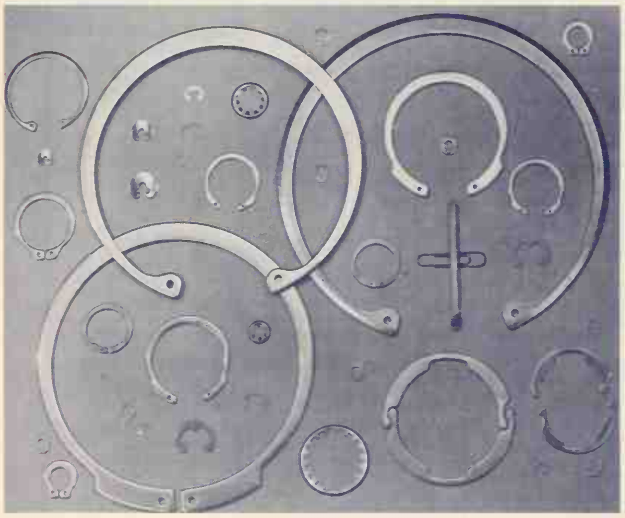


Figure 13-61 Retaining rings (*Courtesy Waldes Kohinoor, Inc.*)

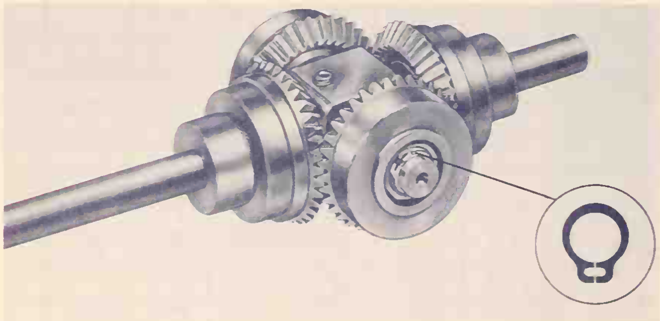


Figure 13-62 Ring application in a precision differential (*Courtesy Waldes Kohinoor, Inc.*)

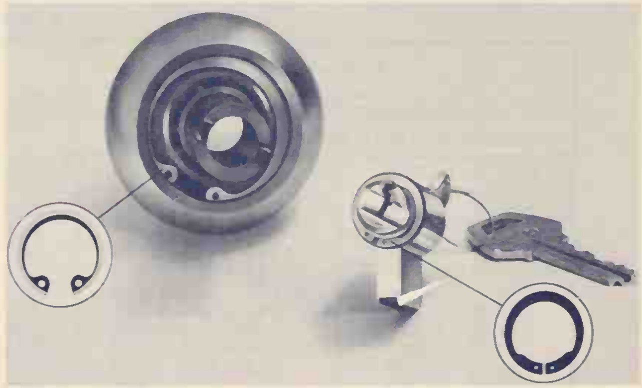


Figure 13-63 Ring application in a cylindrical lockset (*Courtesy Waldes Kohinoor, Inc.*)

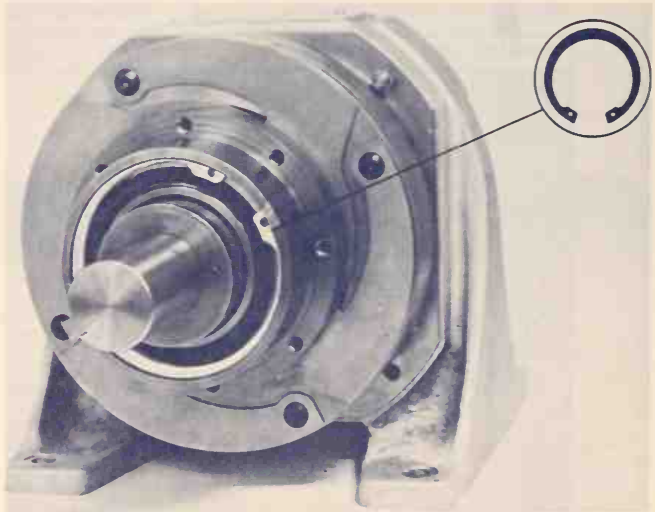


Figure 13-64 Ring application in an electromagnetic clutch brake (*Courtesy Waldes Kohinoor, Inc.*)

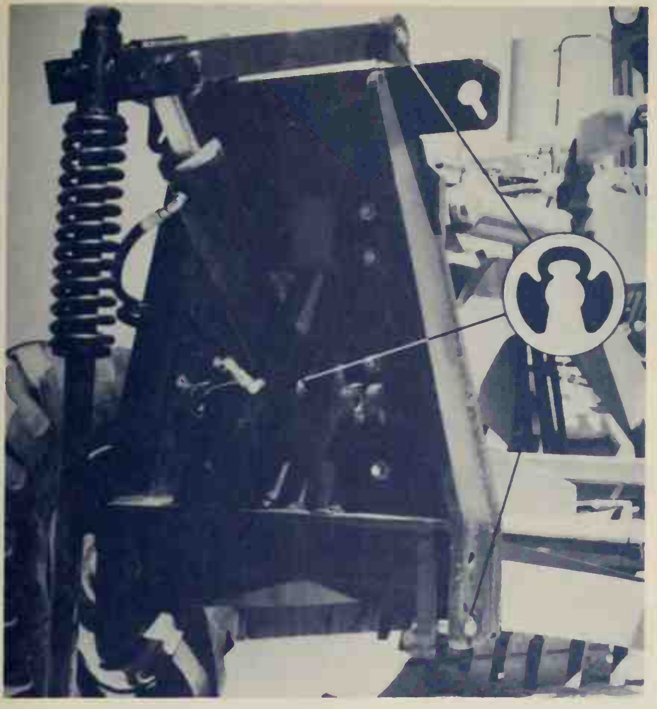


Figure 13-65 Ring application in a road grader (*Courtesy Waldes Kohinoor, Inc.*)

mits the rings to remain circular after they have been compressed for insertion into a bore or expanded for assembly over a shaft. Most rings are designed to be seated in grooves. This constant circularity assures maximum contact surface with the bottom of the groove. It is also an important factor in achieving high static and dynamic thrust load capacities.

Types of Retaining Rings

A great number of fastening requirements are involved in product design. This factor has led to the development of many different types of retaining rings. Standard rings are shown in Figure 13-67.

Limited space prevents describing in detail all the different ring types available. In general, however, retaining rings can be grouped into two major categories.

Internal rings for axial assembly are compressed for insertion into a bore or housing. They generally have a large gap and holes in the lugs, located at the free ends, for pliers which are used to grasp the rings securely during installation and removal, Figure 13-68.

External rings for axial assembly are expanded with pliers, Figure 13-69, so they may be slipped over the end of a shaft, stud, or similar part. They have a small gap and the lug position is reversed from that of the internal ring. Radially assembled external rings do not have holes for pliers. Instead, the rings have a large gap and are pushed into the shaft directly in the plane of the groove with a special application tool, Figure 13-70.

In addition to the tools shown here, retaining rings can be installed with automatic equipment. This equipment can be designed for specific, high-speed

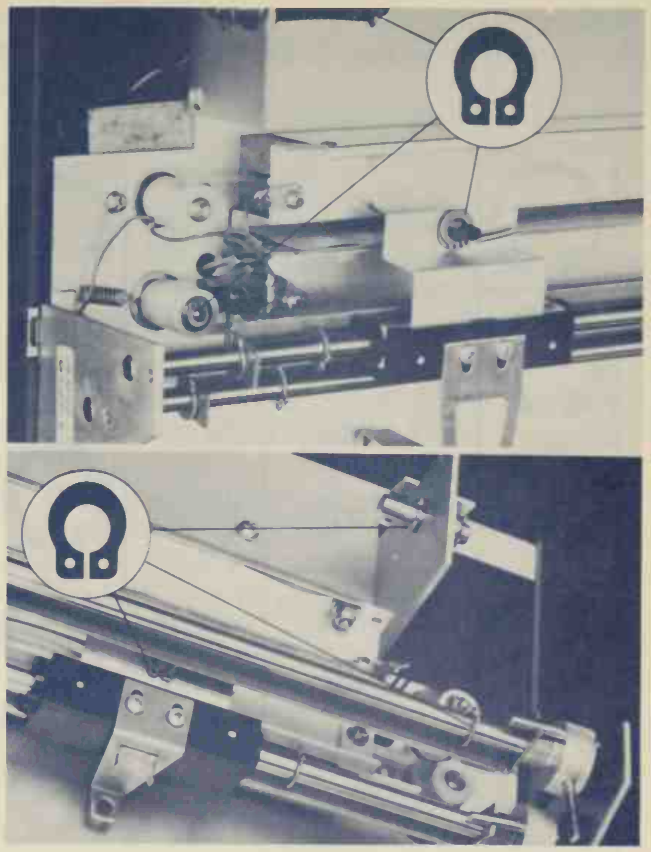


Figure 13-66 Ring application in strip chart recorder (*Courtesy Waldes Kohinoor, Inc.*)

automatic assembly lines. Retaining ring grooves serve two purposes: 1) they assure precise seating of the ring in the assembly, and 2) they permit the ring to withstand heavy thrust loads. The grooves must be located accurately and precut in the housing or shaft before the rings are assembled. Shaft grooves often can be made at no additional cost during the cut-off and chamfering operations.

Self-locking rings do not require any grooves because they exert a frictional hold against axial displacement. They are used mainly as positioning and locking devices where the ring will be subjected to only moderate or light loading.

Bowed rings differ from conventional types in that they are bowed around an axis perpendicular to the diameter bisecting the gap. The bowed construction permits the rings to function as springs as well as fasteners. This provides resilient end play take-up in the assembly.

Beveled rings have a 15-degree bevel on the groove-engaging edge. They are installed in grooves having a comparable bevel on the load-bearing wall. When the ring is seated in the groove, it acts as a wedge against the retained part. Sometimes play develops between the ring and retained part because of accumulated tolerances or wear in the assembly. If play develops, the spring action of the ring causes the fastener to seat more deeply in its groove and move in an axial direction, automatically taking up the end

Standard Truarc® Retaining Ring Series

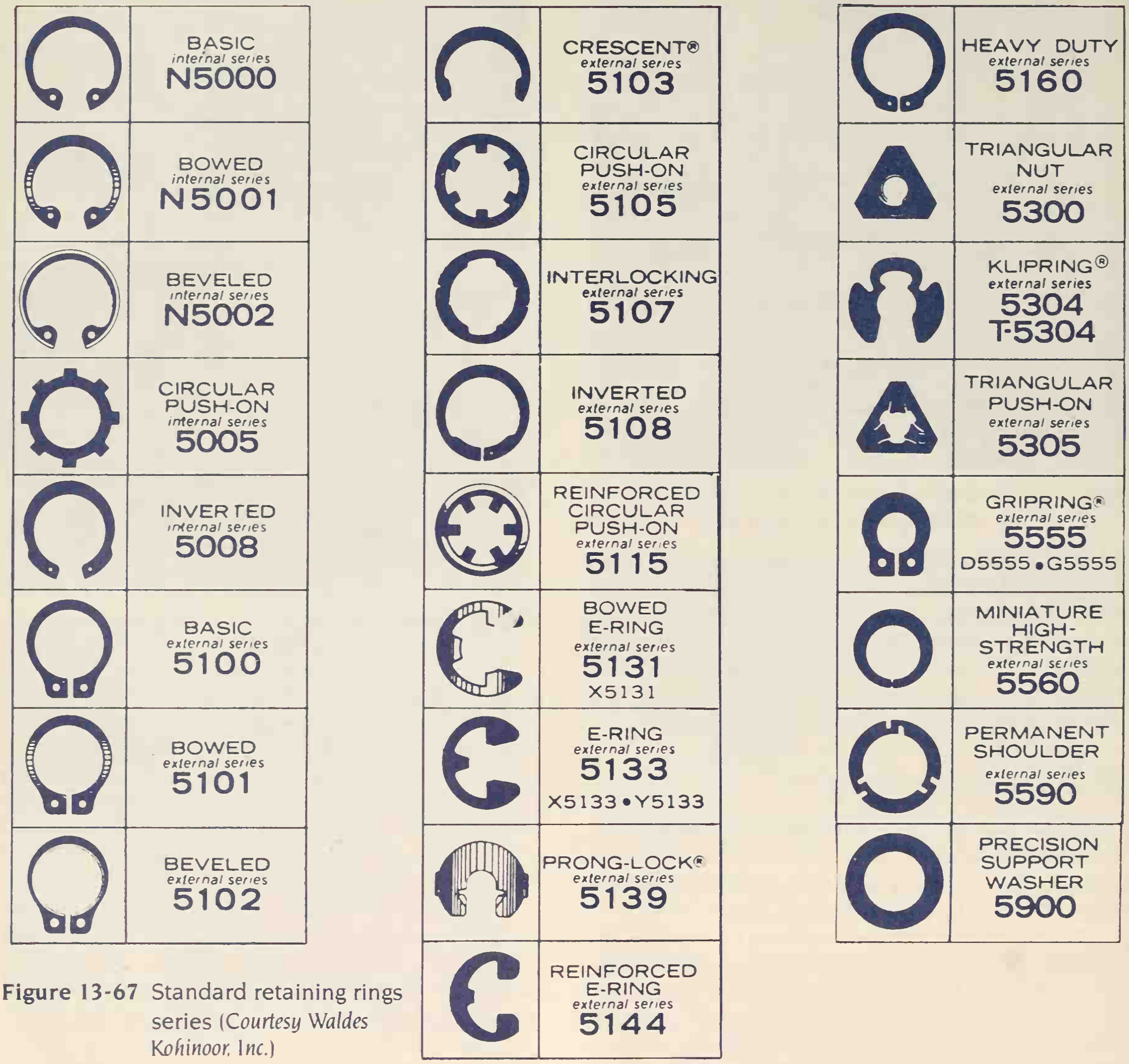


Figure 13-67 Standard retaining rings series (*Courtesy Waldes Kohinoor, Inc.*)

Figure 13-68 Internal ring pliers (*Courtesy Waldes Kohinoor, Inc.*)

Figure 13-69 External ring pliers (*Courtesy Waldes Kohinoor, Inc.*)

Figure 13-70 Applicator and dispenser for retaining rings (*Courtesy Waldes Kohinoor, Inc.*)

play. (Because self-locking rings can be seated at any point on a shaft or in a bore, they too can be used to compensate for tolerances and eliminate end play.)

Materials and Finishes

As indicated previously, retaining rings are made of materials having good spring properties. Some also have high tensile and yield strengths. They must also have an adequate ratio of ultimate tensile strength to elasticity. This permits the required deformation without too much permanent set. A ratio of 1:100 is satisfactory for most rings having the tapered-section design.

Standard material for most rings is carbon spring steel (SAE 1060-1090). For special applications, rings are also available in stainless steel (PH 15-7 Mo), beryllium copper (Alloy #25), and aluminum (Alclad 7075-T6). Rings are normally phosphate coated. Cadmium, zinc, and other platings and finishes are used for assemblies where extra corrosion resistance is needed or if the rings must withstand other unusual environmental conditions. Selection of the ring material and finish for a specific product design should be based upon the operating conditions under which the ring must function. These may include temperature, the presence of corrosive elements, thrust loads, and other factors.

Selection Considerations

Selecting the best ring for a product load capacity is a critical factor in some product designs. There are other factors the drafter should consider, however, before selecting specific ring types for a given product.

- Will there be adequate clearance to assemble the ring with pliers or other tools?
- Must the ring take up accumulated tolerances, either resiliently or rigidly?
- Is it possible to machine a ring groove on the shaft or inside a bore?
- Should the ring be adjustable to several positions on a shaft?

Making the Choice

After considering all these conditions, the drafter may find that more than one ring type is suitable. How, then, can the drafter make the best choice?

The most important design criterion is the ability of the ring to do the fastening job required. Before a final selection of ring type is made, the drafter should consider savings which may be possible in various parts of the assembly. These include:

- The cost of installing the ring.
- Whether or not a groove is required.
- If the ring can be installed *permanently* or if it may have to be removed for field service.

A self-locking ring, for example, eliminates the need for the ring grooves. If the ring will be subjected to only moderate loading, this may be ideal for the assembly. But most self-locking rings must be destroyed for removal. If field service is anticipated, another style of ring should be adopted.

The ideal ring is the one which will function adequately and provide the most economical means of fastening. Retaining rings are designed primarily as shoulders for positioning and retaining machine components on shafts and in housings and bores. Different rings have been developed and manufactured to meet specific fastening needs and problems.

To ensure correct selection of the proper type for any individual application, rings have been grouped according to their basic function. The selector guides, Figures 13-71 and 13-72, provide a visual index to all standard types.

Figures 13-73 and 13-74 are from the latest *Truarc Technical Manual*. Figure 13-73 is a sample of an internal series (N5000); Figure 13-74 is from an external series (5100).

DESIGN FEATURES

RING TYPES FOR AXIAL ASSEMBLY

Series N5000, 5100: Tapered section assures constant circularity and groove pressure. Secure against heavy thrust loads and high rotational speeds.

Series 5008, 5108: Lugs inverted to abut groove bottom. Rings form high circular shoulder, concentric with bore or shaft. Good for parts having large corner radii or chamfers.

Series 5160: Heavy-duty ring resists high thrust, impact loads. Eliminates spacer washers in bearing assemblies.

Series 5560: New miniature, high-strength ring. Forms tamper-proof shoulder on small diameter shafts subject to heavy thrust loads.

Series 5590: Permanent-shoulder ring for small diameter shafts. When compressed into groove, notches deform to close gaps, reducing both I.D. and O.D.

RING TYPES FOR RADIAL ASSEMBLY

Series 5103: Forms narrow, uniformly concentric shoulder. Excellent for assemblies where clearance is limited.

Series 5133: Provides large shoulder on small diameter shafts. Installed in deep groove for added thrust capacity.

Series 5144: Reinforced to provide five times greater gripping strength, 50% higher rpm limits than conventional E-rings. Secure against rotation.

Series 5107: Two-part ring balanced to withstand high rpm's, heavy thrust loads, relative rotation between parts.

Series 5304: New high-strength ring for large bearing surface. Can be installed quickly with pliers or mallet, removed with ordinary screw driver.

Series T5304: Thinner model of 5304. Can be seated in same width grooves as E-rings, has more gripping power. Good for cast or molded grooves.

RING TYPES FOR TAKING UP END-PLAY

Series N5001, 5101: Bowed cylindrically to accommodate large tolerances, provide resilient end-play take-up.

Series N5002, 5102: Rings beveled 15° on groove-engaging edge for use in groove with similar bevel. Wedge action provides rigid end-play take-up.

Series 5131: Provides large shoulder on small diameter shafts. Bowed for resilient end-play take-up.

Series 5139: Bowed ring designed for use as shoulder against rotating parts. Prongs lock against shaft, prevent ring from being forced from groove.

SELF-LOCKING TYPE RINGS (No groove required)

Series 5115: Push-on type fastener for ungrooved shafts and studs. Has arched rim for extra strength, long prongs for wide shaft tolerances.

Series 5105, 5005: Flat rim, shorter prongs, smaller O.D. than 5115. For flat contact surface, better clearance.

Series 5555: Secure against axial displacement from either direction. No groove needed. Adjustable, reusable.

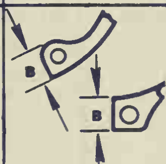
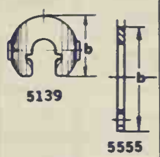
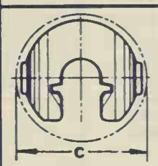
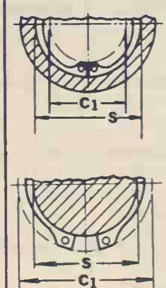
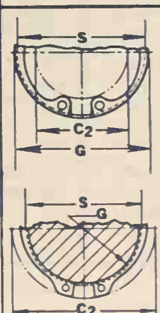
Series 5305: Dished body, three heavy prongs lock on shaft under spring tension. Withstands heavy thrust loads.

Series 5300: Free-spinning nut. Dished body flattens under torque, eliminating need for separate lock washers.

Type	Name	Series	Use	Size Range	
INTERNAL	BASIC	N5000	For housings and bores	.250—10.0 in.	6.4—254.0 mm
EXTERNAL	BOWED	5101	For shafts and pins	.188—1.750 in.	4.8—44.4 mm.
EXTERNAL	REINFORCED	5115	For shafts and pins	.094—1.0 in.	•
EXTERNAL	TRIANGULAR NUT	5300	For threaded parts	6-32 and 8-32 10-24 and 10-32 1/4-20 and 1/4-28	
INTERNAL	BOWED	N5001	For housings and bores	.250–1.750 in.	6.4–44.4 mm.
EXTERNAL	BEVELED	5102	For shafts and pins	1.0—10.0 in.	25.4—254.0 mm.
EXTERNAL	BOWED E-RING	5131	For shafts and pins	.110—1.375 in.	2.8—34.9 mm.
EXTERNAL	KLIPRING	5304 T-5304	For shafts and pins	.156–1.000 in.	4.0–25.4 mm.
INTERNAL	BEVELED	N5002	For housings and bores	1.0—10.0 in.	25.4—254.0 mm.
EXTERNAL	CRESCENT®	5103	For shafts and pins	.125—2.0 in.	3.2—50.8 mm.
EXTERNAL	E-RING	5133	For shafts and pins	.040—1.375 in.	1.0—34.9 mm.
EXTERNAL	TRIANGULAR	5305	For shafts and pins	.062—.438 in.	•
INTERNAL	CIRCULAR	5005	For housings and bores	.312—2.0 in.	•
EXTERNAL	CIRCULAR	5105	For shafts and pins	.094—1.0 in.	•
EXTERNAL	PRONG-LOCK®	5139	For shafts and pins	.092—.438 in.	•
EXTERNAL	GRIPRING®	5555	For shafts and pins	.079—.750 in.	2.0—19.0 mm.
INTERNAL	INVERTED	5008	For housings and bores	.750—4.0 in.	19.0—101.6 mm
EXTERNAL	INTERLOCKING	5107	For shafts and pins	.469—3.375 in.	11.9—85.7 mm.
EXTERNAL	REINFORCED E-RING	5144	For shafts and pins	.094—.562 in.	2.4—14.3 mm.
EXTERNAL	HIGH-STRENGTH	5560	For shafts and pins	.101—.328 in.	•
EXTERNAL	BASIC	5100	For shafts and pins	.125—10.0 in.	3.2—254.0 mm.
EXTERNAL	INVERTED	5108	For shafts and pins	.500—4.0 in.	12.7—101.6 mm.
EXTERNAL	HEAVY-DUTY	5160	For shafts and pins	.394—2.0 in.	10.0—50.8 mm.
EXTERNAL	PERMANENT SHOULDER	5590	For shafts and pins	.250–.750	6.4–19.0 mm.

Figure 13-71 Selector guide: standard ring series (*Courtesy Waldes Kohinoor, Inc.*)

The symbols listed below are used in the data charts for various ring types. Ring, groove and retained part dimensions are in inches; allowable thrust loads are in pounds.

SYMBOL		DEFINITION	RING SERIES WHERE APPLICABLE
A		Minimum gap width: internal ring installed in groove	N5000, N5001, N5002, 5008
B		Lug height	N5000, N5001, N5002, 5100, 5101, 5102, 5160, 5555
b		Ring height	5139, 5555, 5305, 5300, 5304
C		Clearance diameter	5139, 5590
C_1		Clearance diameter: ring sprung into housing or over shaft, prior to installation in groove	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5108, 5160, 5555, 5560, 5590
C_2		Clearance diameter: ring installed in groove	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5103, 5107, 5108, 5131, 5133, 5144, 5160, 5560

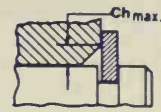
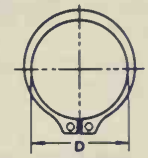
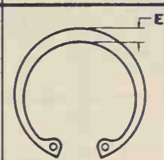
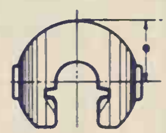
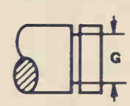
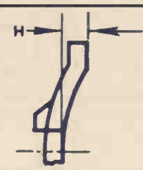
SYMBOL		DEFINITION	RING SERIES WHERE APPLICABLE
$Ch_{max.}$		Maximum allowable chamfer height of retained part	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5103, 5107, 5108, 5131, 5133, 5144, 5160, 5555, 5560
D		Free diameter	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5103, 5107, 5108, 5131, 5133, 5144, 5160, 5304, 5555, 5560, 5590
d		Nominal groove depth	ALL RINGS USED IN GROOVES
E		Large section height	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5103, 5107, 5108, 5160, 5560
e REF.		Distance from center of ring to outer edge (Reference)	5139
G		Groove diameter	ALL RINGS USED IN GROOVES
H		Bow height	5139
h		Ring height	5115

Figure 13-72 Definition symbols (*Courtesy Waldes Kohinoor, Inc.*)

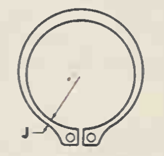
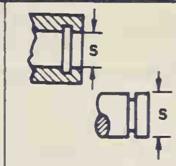
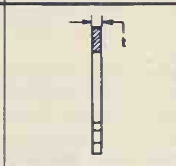
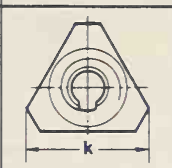
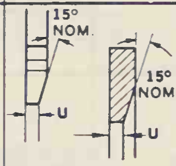
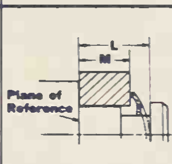
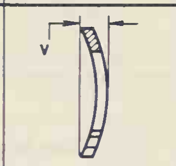
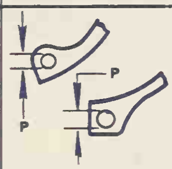
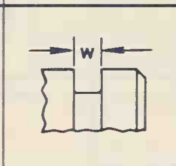
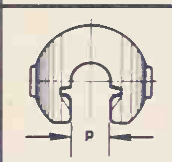
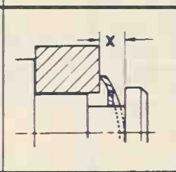
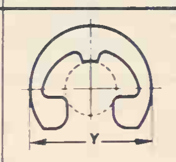
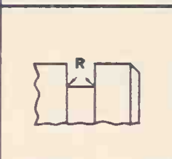
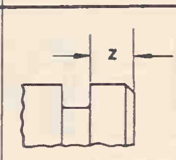
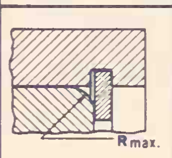
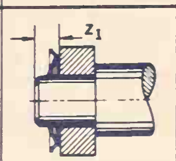
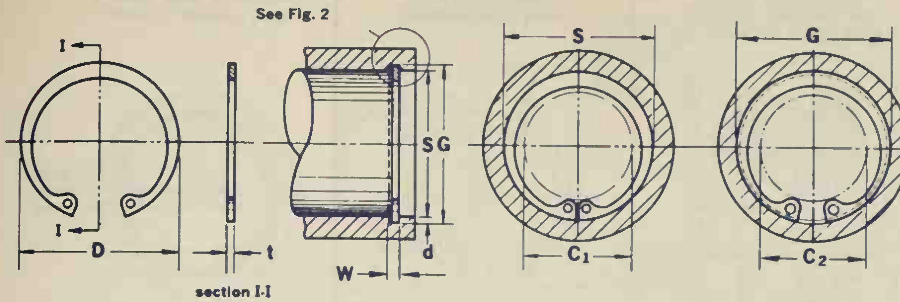
SYMBOL		DEFINITION	RING SERIES WHERE APPLICABLE	SYMBOL		DEFINITION	RING SERIES WHERE APPLICABLE
J		Small section height	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5108, 5160, 5560	S		Shaft or housing diameter	ALL RINGS
K		Maximum gaging diameter: ring installed in groove	5100, 5101, 5102, 5108, 5160, 5560	t		Ring thickness	ALL RINGS
k		Overall ring width	5305, 5300	U		Ring thickness at beveled edge	N5002, 5102
L M		L: Location of outer groove wall from plane of reference M: Width of retained part	N5001, N5002, 5101, 5102, 5131, 5139	V		Overall bow height	N5001, 5101, 5131
P		Pliers hole diameter	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5108, 5160, 5555	W		Groove width	ALL RINGS USED IN GROOVES
p		Gap width	5139	X		Distance from outer groove wall to face of retained part	N5001, 5101, 5131, 5139
P_r P'_r P_g	Allowable thrust load for ring (lbs.) Allowable assembly load with maximum corner radius or chamfer Allowable thrust load for groove (lbs.)		ALL RINGS USED IN GROOVES	Y		Free outside diameter	5103, 5133, 5144, 5131, 5304
R		Radius of groove bottom	ALL RINGS USED IN GROOVES	Z		Edge margin	ALL RINGS USED IN GROOVES
$R_{max.}$		Maximum allowable corner radius of retained part	N5000, N5001, N5002, 5008, 5100, 5101, 5102, 5103, 5107, 5108, 5131, 5133, 5144, 5160, 5555, 5560	Z_1		Minimum distance from face of retained part to end of shaft or housing	5115, 5005, 5105, 5305

Figure 13-72 (continued)



HOUSING DIA. Dec. equiv. inch S	HOUSING DIA. Approx. fract. equiv. inch S	HOUSING DIA. Approx. mm. S	MIL-R-21248 MS 16625 INTERNAL SERIES N5000 size—no.	TRUARC RING DIMENSIONS FREE DIA. D	FREE DIA. tol.	THICKNESS t	THICKNESS tol.	Approx. weight per 1000 pieces lbs.	GROOVE DIMENSIONS DIAMETER G	DIAMETER tol.	WIDTH W	WIDTH tol.	Nominal groove depth d	APPLICATION DATA CLEARANCE DIAMETER When sprung into housing S C_1	When sprung into groove G C_2	ALLOW. THRUST LOAD (lbs.) Sharp corner abutment RINGS (Standard material) Safety factor = 4 P_r	GROOVES (Cold rolled steel bores and housings) Safety factor = 2 P_g
.250	1/4	6.4	N5000-25	.280	+.010 −.005	.015	±.002	.08	.268	±.001 .0015 T.I.R.	.018	+.002 −.000	.009	.115	.133	420	190
.312	5/16	7.9	N5000-31	.346		.015		.11	.330		.018		.009	.173	.191	530	240
.375	3/8	9.5	N5000-37	.415		.025		.25	.397	±.002 .002 T.I.R.	.029	+.003 −.000	.011	.204	.226	1050	350
.438	7/16	11.1	N5000-43	.482		.025		.37	.461		.029		.012	.23	.254	1220	440
.453	29/64	11.5	N5000-45	.498		.025		.43	.477		.029		.012	.25	.274	1280	460
.500	1/2	12.7	N5000-50	.548		.035		.70	.530	±.002 .004 T.I.R.	.039		.015	.26	.29	1980	510
.512	—	13.0	N5000-51	.560		.035		.77	.542		.039		.015	.27	.30	2030	520
.562	9/16	14.3	N5000-56	.620		.035		.86	.596		.039		.017	.275	.305	2220	710
.625	5/8	15.9	N5000-62	.694		.035		1.0	.665		.039		.020	.34	.38	2470	1050
.688	11/16	17.5	N5000-68	.763		.035		1.2	.732		.039		.022	.40	.44	2700	1280
.750	3/4	19.0	N5000-75	.831		.035		1.3	.796		.039		.023	.45	.49	3000	1460
.777	—	19.7	N5000-77	.859	+.015 −.010	.042		1.7	.825	±.003 .004 T.I.R.	.046		.024	.475	.52	4550	1580
.812	13/16	20.6	N5000-81	.901		.042		1.9	.862		.046		.025	.49	.54	4800	1710
.866	—	22.0	N5000-86	.961		.042		2.0	.920		.046		.027	.54	.59	5100	1980
.875	7/8	22.2	N5000-87	.971		.042		2.1	.931		.046		.028	.545	.60	5150	2080
.901	—	22.9	N5000-90	1.000		.042		2.2	.959		.046		.029	.565	.62	5350	2200
.938	15/16	23.8	N5000-93	1.041		.042		2.4	1.000		.046		.031	.61	.67	5600	2450
1.000	1	25.4	N5000-100	1.111		.042		2.7	1.066		.046		.033	.665	.73	5950	2800
1.023	—	26.0	N5000-102	1.136		.042		2.8	1.091		.046		.034	.69	.755	6050	3000
1.062	1 1/16	27.0	N5000-106	1.180	+.025 −.020	.050		3.7	1.130	±.004 .005 T.I.R.	.056	+.004 −.000	.034	.685	.75	7450	3050
1.125	1 1/8	28.6	N5000-112	1.249		.050		4.0	1.197		.056		.036	.745	.815	7900	3400
1.181	—	30.0	N5000-118	1.319		.050		4.3	1.255		.056		.037	.79	.86	8400	3700
1.188	1 3/16	30.2	N5000-118	1.319		.050		4.3	1.262		.056		.037	.80	.87	8400	3700
1.250	1 1/4	31.7	N5000-125	1.388		.050		4.8	1.330		.056		.040	.875	.955	8800	4250
1.259	—	32.0	N5000-125	1.388		.050		4.8	1.339		.056		.040	.885	.965	8800	4250
1.312	1 5/16	33.3	N5000-131	1.456		.050		5.0	1.396		.056		.042	.93	1.01	9300	4700
1.375	1 3/8	34.9	N5000-137	1.526		.050		5.1	1.461		.056		.043	.99	1.07	9700	5050
1.378	—	35.0	N5000-137	1.526		.050		5.1	1.464		.056		.043	.99	1.07	9700	5050
1.438	1 7/16	36.5	N5000-143	1.596		.050		5.8	1.528		.056		.045	1.06	1.15	10200	5500
1.456	—	37.0	N5000-145	1.616		.050		6.4	1.548		.056		.046	1.08	1.17	10300	5700
1.500	1 1/2	38.1	N5000-150	1.660		.050		6.5	1.594		.056		.047	1.12	1.21	10550	6000
1.562	1 9/16	39.7	N5000-156	1.734	+.035 −.025	.062	±.003	8.9	1.658	±.005 .005 T.I.R.	.068		.048	1.14	1.23	13700	6350
1.575	—	40.0	N5000-156	1.734		.062		8.9	1.671		.068		.048	1.15	1.24	13700	6350
1.625	1 5/8	41.3	N5000-162	1.804		.062		10.0	1.725		.068		.050	1.15	1.25	14200	6900
1.653	—	42.0	N5000-165	1.835		.062		10.4	1.755		.068		.051	1.17	1.27	14500	7200
1.688	1 11/16	42.9	N5000-168	1.874		.062		10.8	1.792		.068		.052	1.21	1.31	14800	7450

Thickness t applies only to unplated rings. For plated and stainless steel (Type H) rings, add .002" to the listed maximum thickness. Maximum ring thickness will be at least .0002" less than the listed minimum groove width (W).

T.I.R. (total indicator reading) is the maximum allowable deviation of concentricity between groove and housing.

Figure 13-73 Internal series N5000 (*Courtesy Waldes Kohinoor, Inc.*)

Example (Refer to Figure 13-73):

A shaft of 1.000 (25.4) diameter would use a No. N5000-100.

- Free diameter = $1.111 \pm {}^{.015}_{.010}$
- Thickness = .042 ± .002
- Lug size = .155 ± .005
- Plier hole diameter = .062

The required groove must be:

- Diameter = 1.066 ± .003 (.004 TIR)
- Width = $.046 \pm {}^{.003}_{.000}$

FIG. 1:
MAXIMUM ALLOWABLE CORNER RADIUS (R_{max}) AND CHAMFER (Ch_{max})

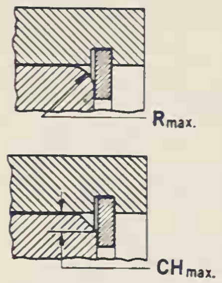
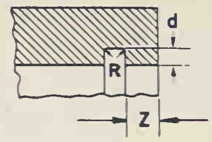


FIG. 2:
ENLARGED DETAIL OF GROOVE PROFILE AND EDGE MARGIN (Z)



MAXIMUM BOTTOM RADII	
Ring Size	R
-25 thru -100	.005
-102 thru -1000	.010

FIG. 3:
SUPPLEMENTARY RING DIMENSIONS

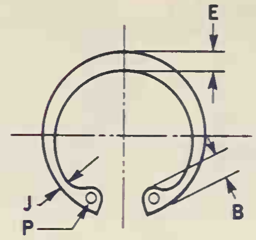
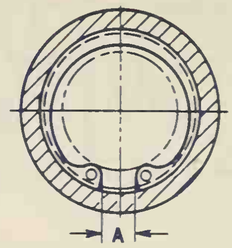


FIG. 4:
MINIMUM GAP WIDTH
(Ring installed in groove)



INTERNAL SERIES N5000	SUPPLEMENTARY APPLICATION DATA: Maximum allowable corner radii and chamfers of retained parts (Fig. 1)		Allow. assembly load with Rmax. or Chmax.	Edge margin (Fig. 2)	SUPPLEMENTARY RING DIMENSIONS: LUG		LARGE SECTION		SMALL SECTION		HOLE DIAMETER		MIN. GAP WIDTH (Fig. 4) Ring installed in groove
size—no.	$R_{max.}$	Ch_{max}	P'_{r} (lbs.)	Z	B	tol.	E	tol.	J	tol.	P	tol.	A
N5000-25	.011	.0085	190	.027	.065		.025	±.002	.015	±.002	.031		.047
N5000-31	.016	.013	190	.027	.066		.033		.018		.031		.055
N5000-37	.023	.018	530	.033	.082		.040		.028		.041		.063
N5000-43	.027	.021	530	.036	.098	±.003	.049	±.003	.029	±.003	.041		.063
N5000-45	.027	.021	530	.036	.098		.050		.030		.047		.071
N5000-50	.027	.021	1100	.045	.114		.053		.035		.047		.090
N5000-51	.027	.021	1100	.045	.114		.053		.035		.047		.092
N5000-56	.027	.021	1100	.051	.132		.053		.035		.047		.095
N5000-62	.027	.021	1100	.060	.132		.060	±.004	.035	±.004	.062		.104
N5000-68	.027	.021	1100	.066	.132		.063		.036		.062	+.010 −.002	.118
N5000-75	.032	.025	1100	.069	.142		.070		.040		.062		.143
N5000-77	.035	.028	1650	.072	.146		.074		.044		.062		.145
N5000-81	.035	.028	1650	.075	.155		.077		.044		.062		.153
N5000-86	.035	.028	1650	.081	.155		.081		.045		.062		.172
N5000-87	.035	.028	1650	.084	.155		.084	±.005	.045	±.005	.062		.179
N5000-90	.038	.030	1650	.087	.155		.087		.047		.062		.188
N5000-93	.038	.030	1650	.093	.155		.091		.050		.062		.200
N5000-100	.042	.034	1650	.099	.155		.104		.052		.062		.212
N5000-102	.042	.034	1650	.102	.155		.106		.054		.062		.220
N5000-106	.044	.035	2400	.102	.180		.110		.055		.078		.213
N5000-112	.047	.036	2400	.108	.180		.116		.057		.078		.232
(S=1.181) N5000-118	.047	.036	2400	.111	.180	±.005	.120		.058		.078		.226
(S=1.188) N5000-118	.047	.036	2400	.111	.180		.120		.058		.078		.245
(S=1.250) N5000-125	.048	.038	2400	.120	.180		.124		.062		.078		.265
(S=1.259) N5000-125	.048	.038	2400	.120	.180		.124	±.006	.062	±.006	.078		.290
N5000-131	.048	.038	2400	.126	.180		.130		.062		.078		.284
(S=1.375) N5000-137	.048	.038	2400	.129	.180		.130		.063		.078	+.015 −.002	.297
(S=1.378) N5000-137	.048	.038	2400	.129	.180		.130		.063		.078		.305
N5000-143	.048	.038	2400	.135	.180		.133		.065		.078		.313
N5000-145	.048	.038	2400	.138	.180		.133		.065		.078		.320
N5000-150	.048	.038	2400	.141	.180		.133		.066		.078		.340
(S=1.562) N5000-156	.064	.050	3900	.144	.202		.157		.078		.078		.338
(S=1.575) N5000-156	.064	.050	3900	.144	.202		.157		.078		.078		.374
N5000-162	.064	.050	3900	.150	.227		.164	±.007	.082	±.007	.078		.339
N5000-165	.064	.050	3900	.153	.227		.167		.083		.078		.348
N5000-168	.064	.050	3900	.156	.227		.170		.085		.078		.357

Figure 13-73 (continued)

Example (Refer to Figure 13-74):

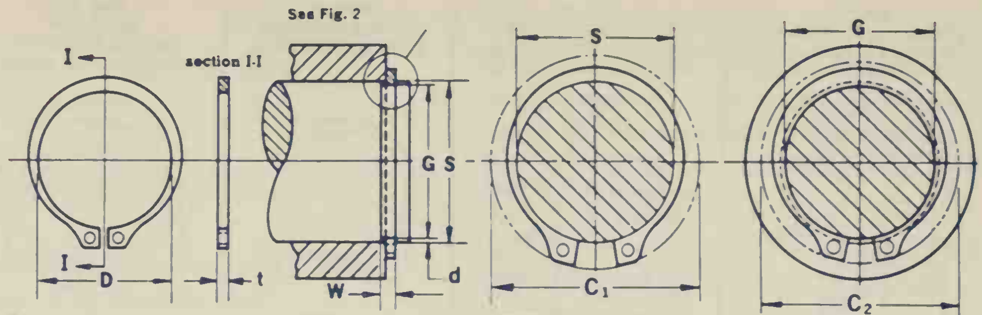
A shaft of 4.000 (101.6) diameter would use a No. 5100-400.

- Free diameter = 3.700 $\pm\,^{.020}_{.030}$
- Thickness = .109 ± .003
- Lug size = .352 ± .005
- Plier hole size = .125 $\pm\,^{.015}_{.002}$

The required groove must be:

- Diameter = 3.792 ± .006 (.006 TIR)
- Width = .120 $\pm\,^{.005}_{.000}$

• Sizes -206 thru -1000 are available in banded or tape-wrapped Rol-Pak cartridges.



SHAFT DIAMETER			MIL-R-21248 MS 16624 EXTERNAL SERIES 5100	TRUARC RING DIMENSIONS (Thickness t applies only to unplated rings. For plated and stainless steel (Type H) rings, add .002" to the listed maximum thickness. Maximum ring thickness will be at least .0002" less than the listed minimum groove width (W).)					GROOVE DIMENSIONS (T.I.R. (total indicator reading) is the maximum allowable deviation of concentricity between groove and shaft)					APPLICATION DATA			
Dec. equiv. inch	Approx fract. equiv. inch	Approx mm		FREE DIA.		THICKNESS		Approx. weight per 1000 pieces	DIAMETER		WIDTH		Nominal groove depth	CLEARANCE DIAMETER: When sprung over shaft S	CLEARANCE DIAMETER: When sprung into groove G	ALLOW. THRUST LOAD (lbs.) Sharp Corner Abutment: RINGS (standard material) Safety factor = 4	ALLOW. THRUST LOAD (lbs.): GROOVES (Cold Rolled steel shafts) Safety factor = 2
S	S	S	size — no.	D	tol.	t	tol.	lbs.	G	tol.	W	tol.	d	C_1	C_2	P_r	P_g
3 438	3 7/16	87 3	5100-343	3 179		093		66 0	3 257		103		090	4 14	3 96	37700	21900
3 500	3 1/2	88 9	5100-350	3 237		109		72 0	3 316		120		092	4 25	4 07	44900	22800
3 543	--	90 0	5100-354	3 277	+ 020 − 030	109		73 0	3 357	± 006 .006 T I R	120		093	4 29	4 11	45500	23300
3 625	3 5/8	92 1	5100-362	3 352		109	±.003	76 0	3 435		120	+ 005 − 000	095	4 37	4 18	46600	24300
3 688	3 11/16	93 7	5100-368	3 410		109		80 0	3 493		120		097	4 43	4 24	47300	25300
3 750	3 3/4	95 2	5100-375	3 468		109		83 0	3 552		120		099	4 50	4 31	48100	26200
3 875	3 7/8	98 4	5100-387	3 584		109		88 0	3 673		120		101	4 60	4 40	49700	27700
3 938	3 15/16	100 0	5100-393	3 642		109		95 0	3 734		120		102	4 70	4 50	50600	28400
4 000	4	101 6	5100-400	3 700		109		101 0	3 792		120		104	4 78	4 58	51400	29400
4 250	4 1/4	108 0	5100-425	3 989		109		112 0	4 065		120		092	5 09	4 91	54600	27600
4 375	4 3/8	111 1	5100-437	4 106		109		115 0	4 190		120		092	5 22	5 04	56200	28400
4 500	4 1/2	114 3	5100-450	4 223		109		101 0	4 310		120		095	5 37	5 18	57800	30200
4 750	4 3/4	120 6	5100-475	4 458		109		113 0	4 550		120		100	5 67	5 47	61000	33600
5 000	5	127 0	5100-500	4 692		109		149 0	4 790		120		105	5 96	5 75	64200	37100
5 250	5 1/4	133 3	5100-525	4 927		125		190 0	5 030		139		110	6 27	6 05	77300	40800
5 500	5 1/2	139 7	5100-550	5 162	+ 020 − 040	125	± 004	202.5	5 265	± 007 .006 T.I.R.	139	+ 006 − 000	117	6 57	6 34	81000	45500
5 750	5 3/4	146 0	5100-575	5 396		125		220.0	5 505		139		122	6 86	6 62	84700	49600
6 000	6	152 4	5100-600	5 631		125		210 0	5 745		139		127	7 16	6 91	88300	53800
6 250	6 1/4	158 7	5100-625	5 866		156		282 0	5 985		174		132	7 46	7 20	114800	58300
6 500	6 1/2	165 1	5100-650	6 100	+ 020 − 050	156		330 0	6 225		174		137	7 87	7 60	119400	62900
6 750	6 3/4	171 4	5100-675	6 335		156		356 0	6 465		174		142	8 06	7 78	124000	67700
7 000	7	177 8	5100-700	6 570		156		388 0	6 705		174		147	8 36	8 07	128600	72700
7 250	7 1/4	184 2	5100-725	6 775		187	± 005	510	6 942		209		154	8 70	8 39	159700	78900
7 500	7 1/2	190 5	5100-750	7 009		187		534	7 180		209		160	8 96	8 64	165200	84800
7 750	7 3/4	196 9	5100-775	7 243		187		545	7 420		209		165	9 20	8 87	170700	90450
8 000	8	203 2	5100-800	7 476		187		640	7 660		209		170	9 60	9 26	176200	96100
8 250	8 1/4	209 6	5100-825	7 712		187		665	7 900		209		175	9 85	9 50	181700	102100
8 500	8 1/2	215 9	5100-850	7 947	+ 050 − 130	187		692	8 140	± 008 006 T I R	209	+ 008 − 000	180	10 10	9 74	187200	108100
8 750	8 3/4	222 3	5100-875	8 181		187		712	8 380		209		185	10 40	10 00	192700	114450
9 000	9	228 6	5100-900	8 415		187		737	8 620		209		190	10 60	10 22	198200	120800
9 250	9 1/4	234 9	5100-925	8 650		187		760	8 860		209		195	10 85	10 50	203700	128225
9 500	9 1/2	241 3	5100-950	8 885		187		785	9 100		209		200	11 10	10 70	209200	134200
9 750	9 3/4	247 6	5100-975	9 120		187		845	9 338		209		206	11 35	10 95	214700	142000
10 000	10	254 0	5100-1000	9 355		187		910	9 575		209		212	11 60	11 20	220200	149800

Figure 13-74 External series 5100 (*Courtesy Waldes Kohinoor, Inc.*)

FIG. 1: MAXIMUM ALLOWABLE CORNER RADIUS (R_{max}) AND CHAMFER (Ch_{max})

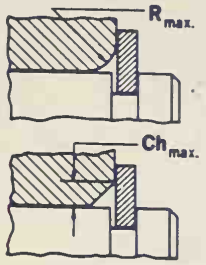
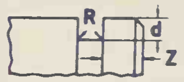


FIG. 2: ENLARGED DETAIL OF GROOVE PROFILE AND EDGE MARGIN (Z)



MAXIMUM BOTTOM RADII	
Ring size	R
-12 thru -23	Sharp corners
-25 thru -35	.003
-37 thru -100	.005
-102 thru -200	.010

FIG. 3: SUPPLEMENTARY RING DIMENSIONS

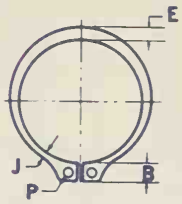


FIG. 4: MAXIMUM GAGING DIAMETER (Ring installed in groove)

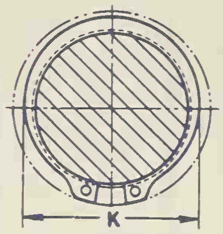
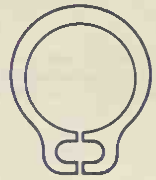


FIG. 5: LUG DESIGN Sizes -12 thru -23



EXTERNAL SERIES 5100	SUPPLEMENTARY APPLICATION DATA: Maximum allowable corner radii and chamfers of retained parts (Fig. 1)		Allow. assembly load with R max. or Ch max.	Edge margin (Fig. 2)	Calculated RPM limits (Std. ring mat'l.) Apply req'd. safety factor	SUPPLEMENTARY RING DIMENSIONS (Fig. 3): LUG		LARGE SECTION		SMALL SECTION		HOLE DIAMETER		MAX. GAGING DIA. Ring installed in groove (Fig. 4)
size — no.	R_{max}	Ch_{max}	P_r' (lbs.)	Z		B	tol.	E	tol.	J	tol.	P	tol.	K
5100-343	.129	.077	7350	.270	5900	.308		.292		.148		.125		3.712
5100-350	.122	.073	10500	.276	5900	.328		.285		.148		.125		3.764
5100-354	.123	.074	10500	.279	5800	.328	±.005	.288	±.008	.149	±.008	.125		3.809
5100-362	.127	.076	10500	.285	5700	.328		296		.153		.125		3.898
5100-368	.1295	.078	10500	.291	5600	.330		.302		.156		.125	+.015 −.002	3.966
5100-375	.133	.080	10500	.297	5500	.332		.310		.160		.125		4.037
5100-387	.137	.082	10500	.303	5100	.330		.318		.163		.125		4.169
5100-393	.137	.082	10500	.306	5200	.342		.318		.163		.125		4.230
5100-400	.135	.081	10500	.312	5000	.352		.318		.163		.125		4.288
5100-425	.146	.088	10500	.276	4800	.395		.318		.176		.125		4.558
5100-437	.146	.088	10500	.276	4700	.395		.318		.181		.125		4.683
5100-450	.102	.061	10500	.285	4500	.404		.285		.128		.125		4.730
5100-475	.115	.069	10500	.300	4200	.429		.303		.136		.125		4.996
5100-500	.165	.099	10500	.315	4000	.450	±.008	.360	±.010	194	±.010	.156		5.346
5100-525	.169	.101	13500	.330	3900	.472		.372		.211		.156		5.605
5100-550	.175	.105	13500	.351	3700	.497		.390		.209		.156		5.867
5100-575	.184	.110	13500	.366	3500	.518		.408		.220		.156		6.134
5100-600	.143	.086	13500	.381	3400	.540		.381		.171		.156		6.302
5100-625	.148	.089	21000	.396	3100	.561		.396		.176		.156		6.568
5100-650	.191	.114	21000	.411	3000	.586		.438		.236		.156		6.905
5100-675	.200	.120	21000	.426	3000	.608		.456		.246		.187		7.172
5100-700	.208	.125	21000	.441	2900	.629		.474		.256		.187		7.439
5100-725	.214	.128	30000	.460	2800	.660		490		.267		.187		7.700
5100-750	220	.132	30000	.480	2700	.676		507		.277		.187		7.963
5100-775	.227	.136	30000	495	2600	.660		523		.285		.187		8.228
5100-800	.235	141	30000	510	2500	.735		.540		294		.187		8.493
5100-825	.242	146	30000	.525	2400	.735		.556		304		.187	+.020	8.758
5100-850	.250	150	30000	540	2300	.735	±.012	.573	±.015	.314	±.015	.187	−.005	9.023
5100-875	.258	155	30000	555	2200	.735		.591		.322		.187		9.280
5100-900	267	160	30000	570	2200	.735		.609		.333		.187		9.557
5100-925	.274	.164	30000	.585	2100	.735		625		341		.187		9.830
5100-950	.281	.168	30000	.800	2100	.735		.642		.350		.187		10.086
5100-975	287	.172	30000	.616	2000	.735		.658		.358		.187		10.340
5100-1000	.294	.176	30000	.636	2000	.735		.675		.367		.187		10.810

Figure 13-74 (continued)

Review

1. In addition to fastening parts together, what are two other uses for threads?
2. What number 5100 series retaining ring would be recommended for a shaft diameter of 203.2 mm?
3. List four factors to consider before selecting any type of retaining ring, other than load capacity.
4. Explain in full what ⅝ - 11 UNC - 2A X 2½ LG means.
5. What is the recommended hole size for a .312-inch (8) diameter spring pin?
6. If you have a ¼ - 20 UNC threaded screw and rotate it 10 full turns, how far will the end travel?
7. What series retaining ring would be recommended to provide rigid end play take-up?
8. How is a screw called-out that is 3 inches long, ⅜-inch in diameter, coarse, right-hand threads, average fit, and round-head style?
9. What is the free diameter of an external 5100-775 retaining ring? What is the tolerance of the dimension?
10. A 2-inch (50.8) diameter shaft uses what size square key?
11. What is the pliers hole diameter and tolerance for an internal N5000-131 retaining ring?
12. How is the depth of thread figured?

Chapter Thirteen Problems

The following problems are intended to give the beginning drafter practice using various size charts of fastener and, by using these charts, practice in laying out and drawing the many fasteners used.

The steps to follow in laying out fasteners are:

Step 1. Study all required specifications.

Step 2. Using the appropriate size chart, for size dimension, *lightly* lay out fastener in place.

Step 3. Check each dimension.

Step 4. Darken in the fastener, starting with diameters and arcs first to correct line thickness. Use simplified thread representation.

Step 5. Neatly add all required call-off specifications, using the latest drafting standard.

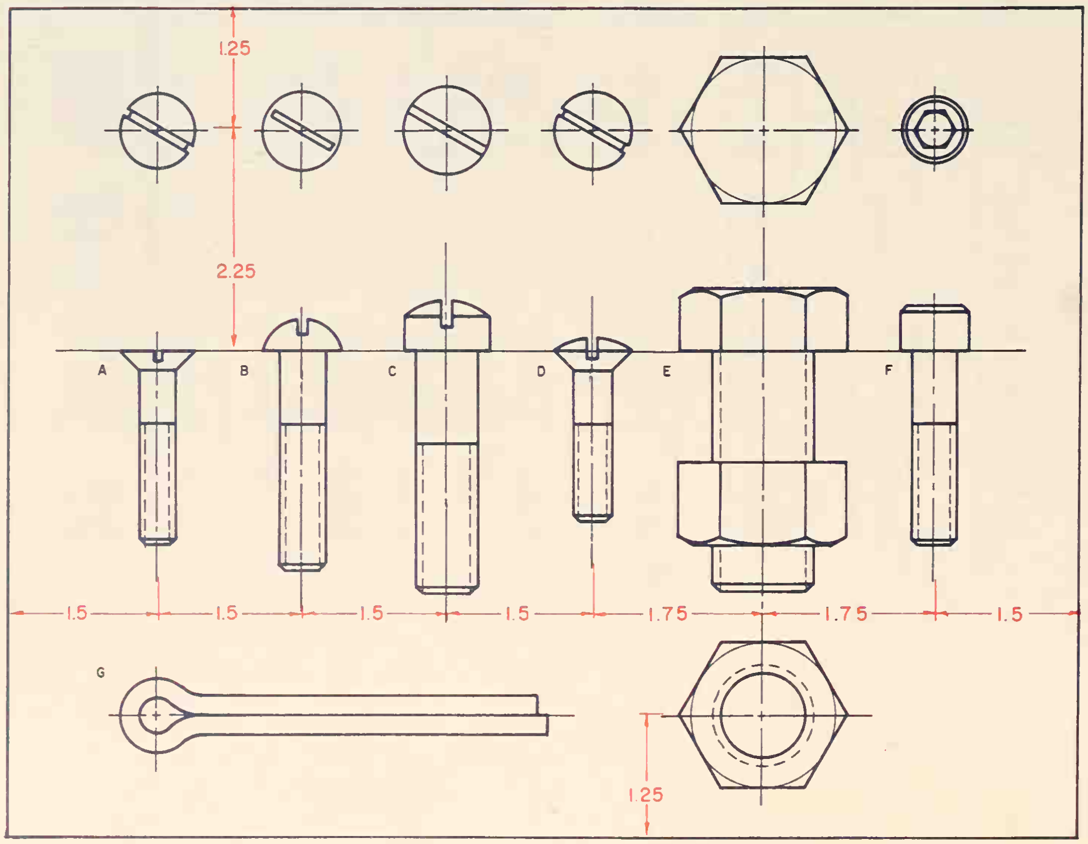
Problem 13-1

On an A-size, 8½ x 11 sheet of paper, lay out the center lines per given dimensions.

Calculate standard thread lengths.

Draw the following fasteners on the center lines as illustrated.

A. Flat-head cap screw – ⅜ – 16 UNC – 2A x 2.0 lg.
B. Round-head cap screw – ½ – 13 UNC – 2A x 2.25 lg.
C. Fillister-head cap screw – ⅝ – 11 UNC – 2A x 2.5 lg.
D. Oval-head cap screw – ⅜ – 24 UNF – 2A x 1.75 lg.
E. Hex-head cap screw with hex nut – 1 – 8 UNC – 2A x 2.5 lg.
F. Socket-head cap screw – ½ – 20 UNF – 2A x 2.0 lg.
G. Cotter pin – ⅜ dia. x 3.5 lg.



Problem 13-1

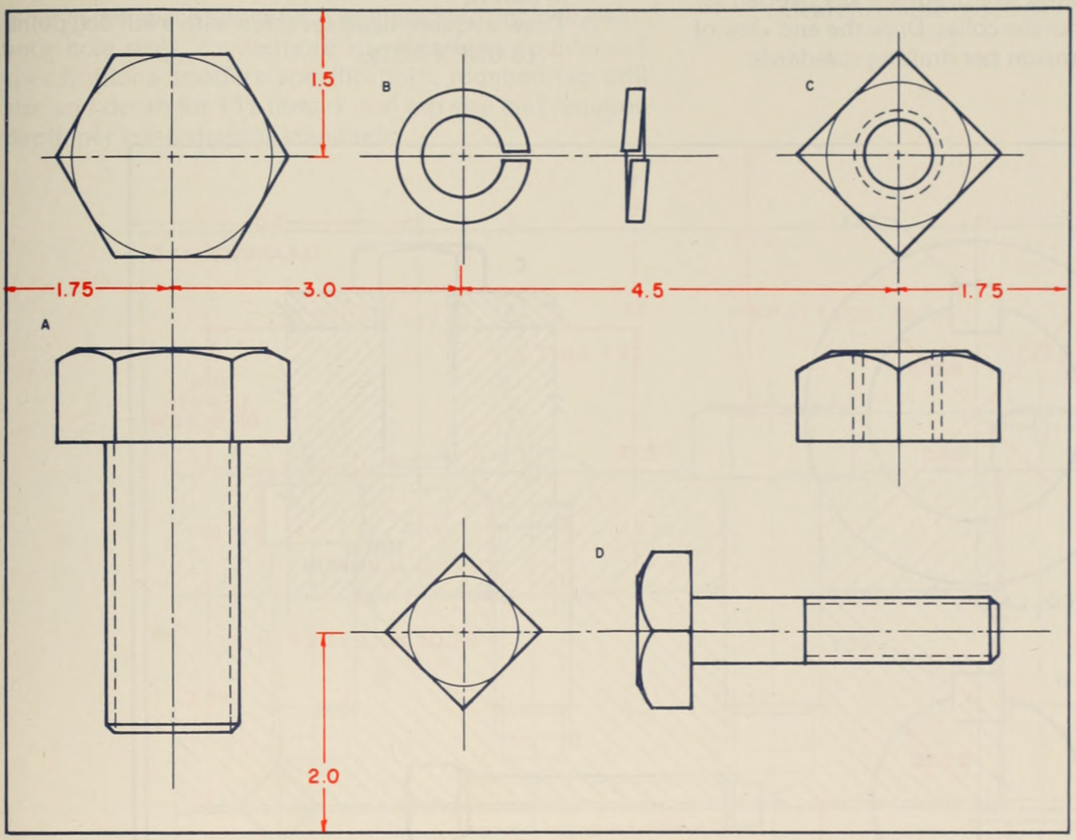
Problem 13-2

On an A-size, 8½ x 11 sheet of paper, lay out the center lines per given dimensions.

Calculate standard thread lengths.

Draw the following fasteners on the center lines as illustrated.

A. Hex-head bolt – 1⅜ – UNC x 3.0 lg.
B. Lock washer (For a ⅞ dia. cap screw).
C. Square nut – 1 – 12 UNF 2B.
D. Square-head cap screw – ¾ – 10 UNC x 3.0 lg.



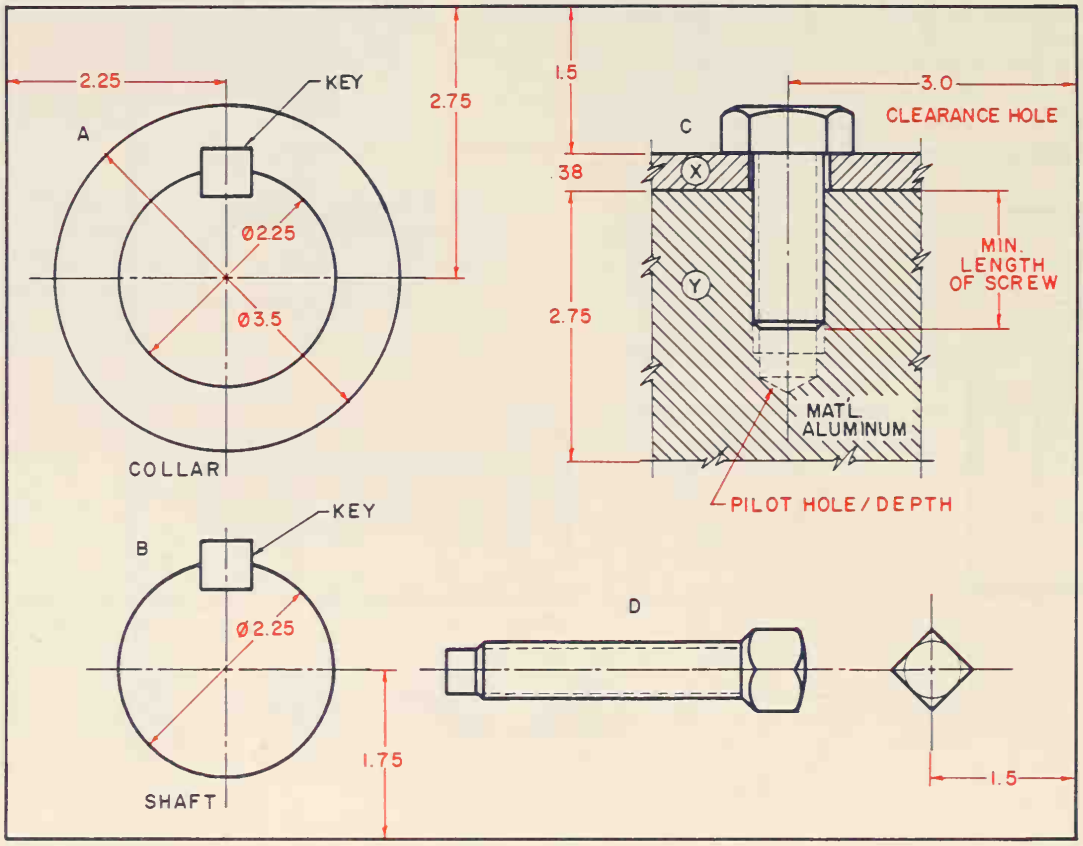
Problem 13-2

Problem 13-3

On an A-size, 8½ x 11 sheet of paper, lay out the center lines per given dimensions.

A. Calculate the required size of square key needed for a 2.25 ID collar. Draw collar and keyway, and dimension per drafting standards.
B. Calculate the required size of square key needed for the matching shaft of the collar. Draw the end view of the shaft and dimension per drafting standards.
C. Calculate the *minimum* length hex-head cap screw, ¾ – 10 UNC – 2A required to safely secure part X to part Y (material: aluminum). Illustrate and call-off the required pilot drill size and recommended depth into part Y. Illustrate and call-off the required size and depth of *full* threads for the hex-head cap screw.

   Illustrate and call-off the diameter for clearance hole in part X.
D. Draw a square-head set screw with a full dog point, ⅝ – 18 UNF x 3.0 lg.



Problem 13-3

Problem 13-4

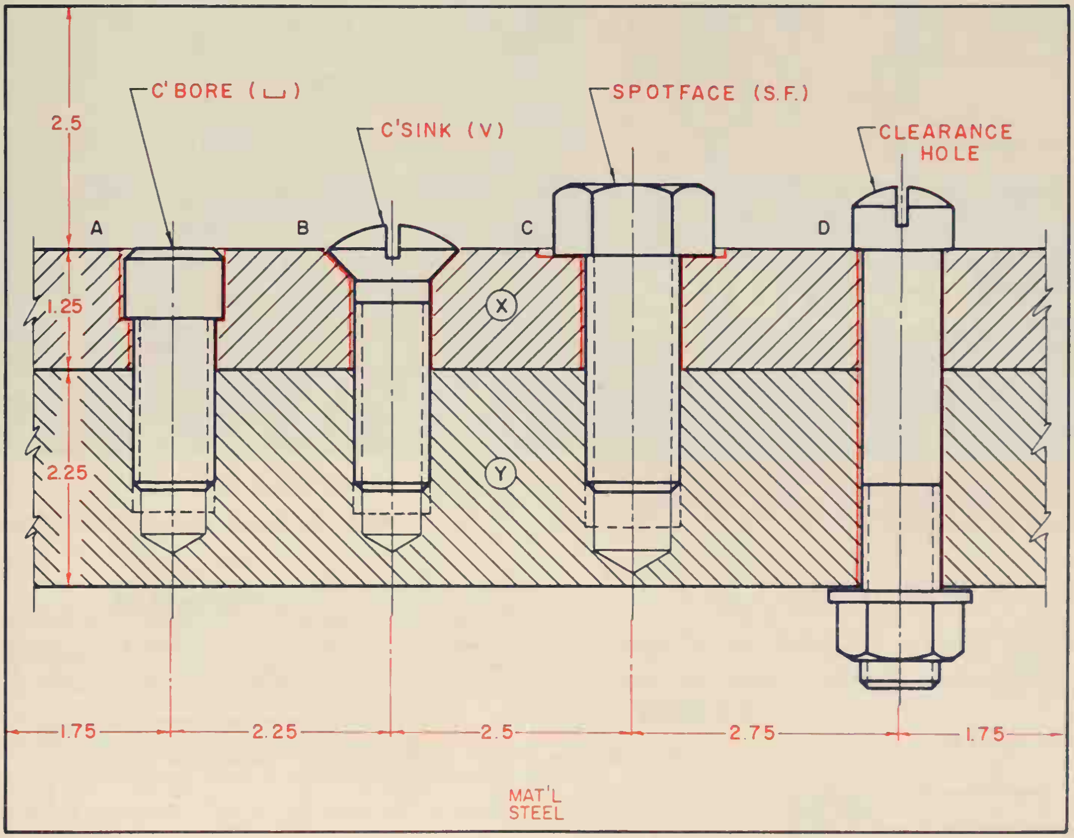
On an A-size, 8½ × 11 sheet of paper, lay out the center lines, part X, and part Y per given dimensions.

Calculate the standard thread lengths.

Draw the following fasteners on the center lines as illustrated.

Give *all* specific hole call-off information for each fastener in the space above each as illustrated (include clearance hole sizes, counterbore specifications, countersink specifications, spotface specifications, required tap drill size and depth for 75% thread; and tap size and required depth per latest drafting standards.

A. Socket-head cap screw – 7/8 – 9 UNC × 1.75 lg (calculate c'bore information).
B. Oval-head cap screw – ¾ – 10 UNC × 2.5 lg (calculate c'sink information).
C. Hex-head cap screw 1 – 12 UNF × 2.5 lg (calculate S.F. information).
D. Fillister-head cap screw with plain washer and hex-head nut – ¾ – 16 UNF × length to suit. (Calculate clearance hole required.)



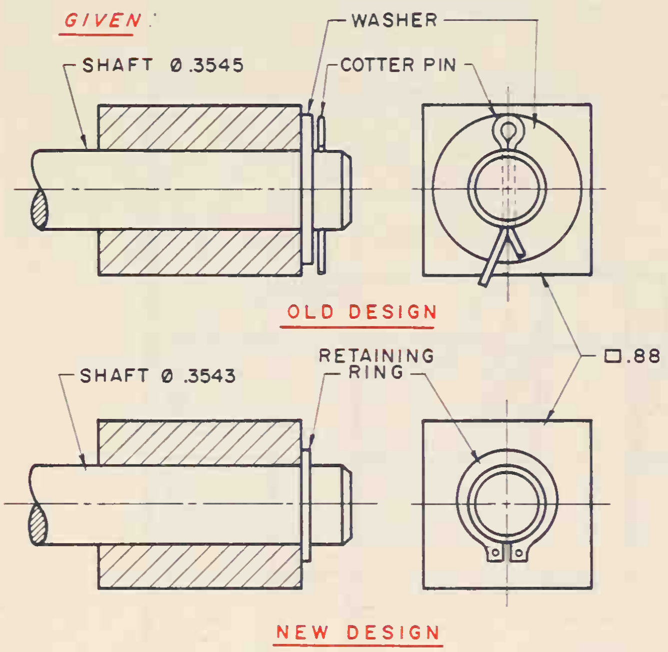
Problem 13-4

Problem 13-5

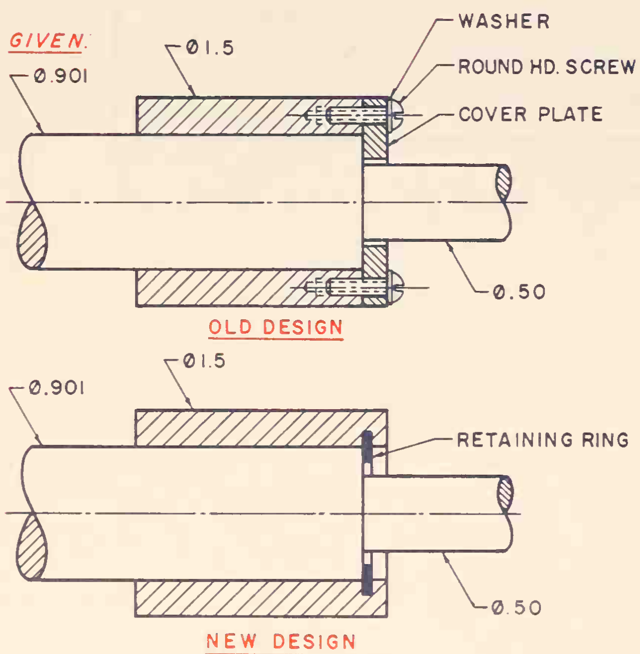
Given, an illustration of an old design (Figure 13-5A) that uses a washer and cotter pin to hold the .3543 dia. shaft in place. Using this design, it was necessary to locate and drill a hole for the cotter pin. The new design incorporated the use of one retaining ring to achieve the exact same function at a much lower cost. Choose the correct type and size retaining ring and fill in the required dimensions at A, B and C (see Figure 13-6A). Neatly letter all retaining ring data below the dimensioned shaft as illustrated.

Problem 13-6

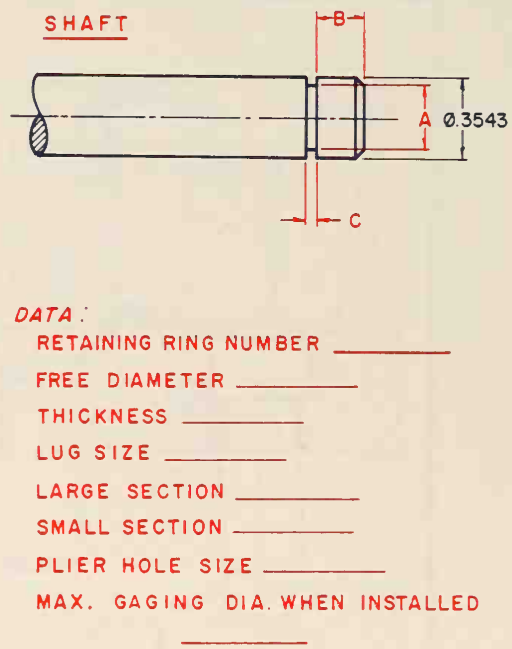
Given, an illustration of an old design (Figure 13-5B) that uses a cover plate with 4 holes for 4 washers and 4 round-head machine screws to hold the shaft in place. Using this design required drilling 4 blind tap-drill holes which had to be tapped for the 4 round-head screws. The new design incorporated the use of one retaining ring to achieve the exact same function at a much lower cost. Choose the correct type and size retaining ring and fill in the required dimensions at A, B and C (see Figure 13-6B). Neatly print all retaining ring data below the dimensioned collar as illustrated.



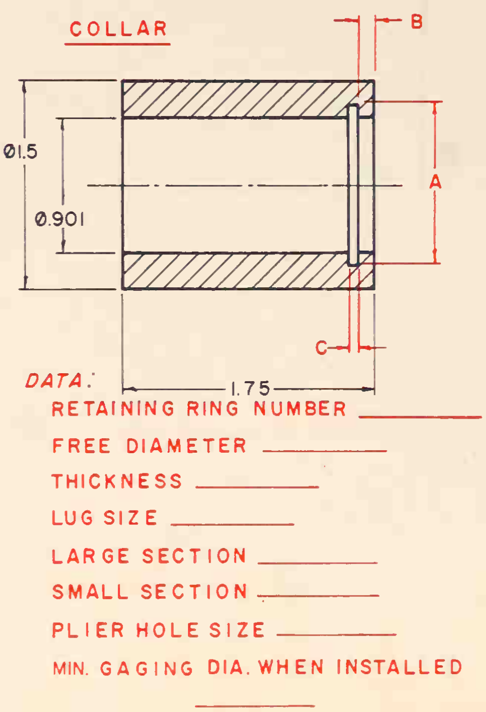
Problem 13-5A



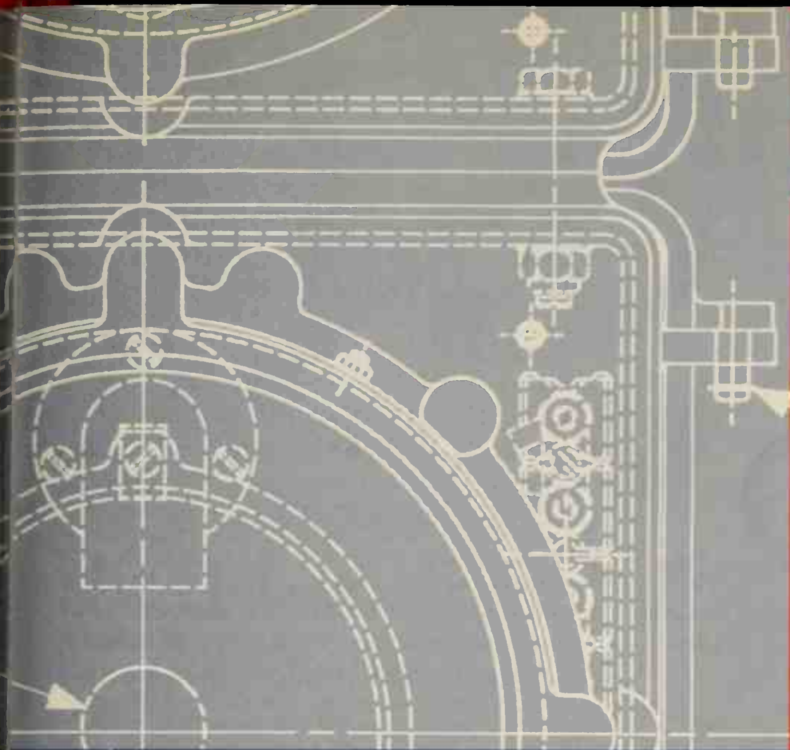
Problem 13-5B



Problem 13-6A



Problem 13-6B



CHAPTER 14

The most commonly used kinds of springs and the terminology associated with them are covered in this chapter. Extensive study of compression, extension, torsion and flat springs is fully covered, along with step-by-step study as to how to design and lay out a spring. Accuracy, line work, neatness, speed, correct dimensioning and required spring data should be stressed in all drawing problems at the the end of this chapter.

SPRINGS

A *spring* is a mechanical device that is used to store and apply mechanical energy. A spring can be designed and manufactured to apply a pushing action, a pulling action, a torque or twisting action, or a simple power action.

Product manufacturers usually use standard-size springs that are purchased from companies that specialize in making springs. These springs are usually mass produced and are, therefore, relatively inexpensive. Occasionally, however, a special spring must be designed to perform a special function. To be able to design special-function springs, the drafter or designer must know the many terms associated with springs, and how to design and construct special springs.

Spring Classification

A spring is generally classified as either a helical spring or a flat spring. *Helical springs* are usually cylindrical or conical; the *flat springs*, as their name implies, are usually flat.

Helical Springs

Three types of helical springs are compression springs, extension springs, and torsion springs, Figures 14-1A, 14-1B, and 14-1C.

Compression Spring

A *compression spring* offers resistance to a compressive force or applies a pushing action. In its free state, the coils of the compression spring do not touch. The types of ends of a compression spring are illustrated and described as follows.

Plain open end — *Figure* 14-2A. The plain open end spring is very unstable, has only point contact, and the ends are *not* perpendicular to the axis of the spring.

Plain closed end — *Figure* 14-2B. The plain closed end spring is a little more stable, and provides a round parallel surface contact perpendicular to the axis of the spring.

Ground open end — *Figure* 14-2C. The ground open end spring is much more stable, and provides a flat surface contact perpendicular to the axis of the springs.

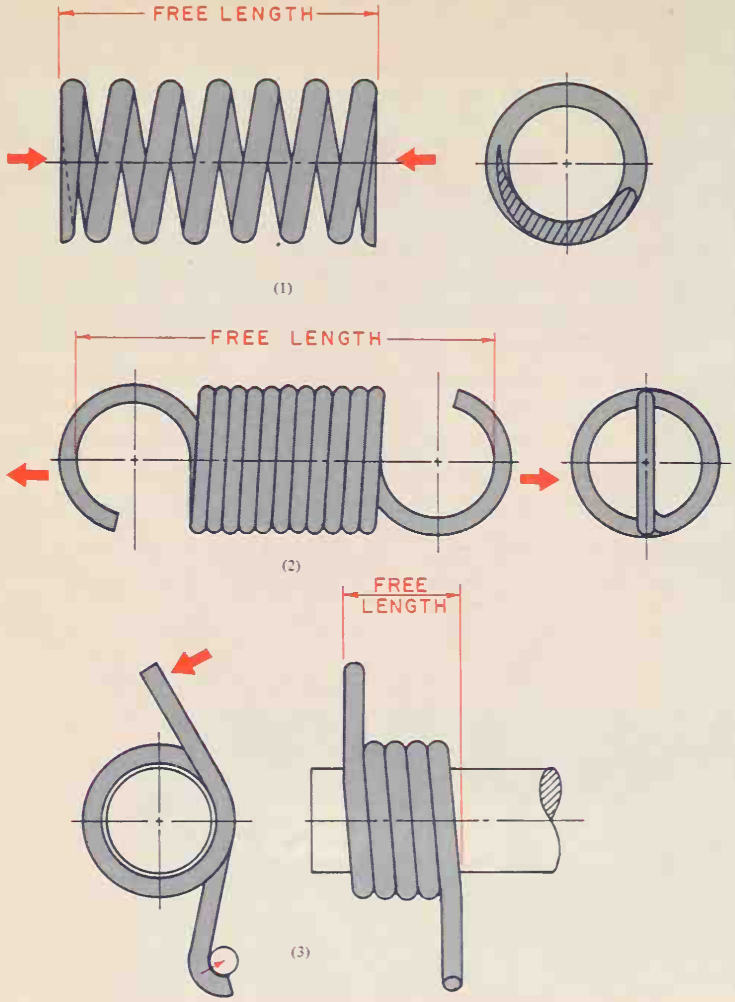


Figure 14-1A Types of helical springs: (1) compression spring, (2) extension spring, and (3) torsion spring

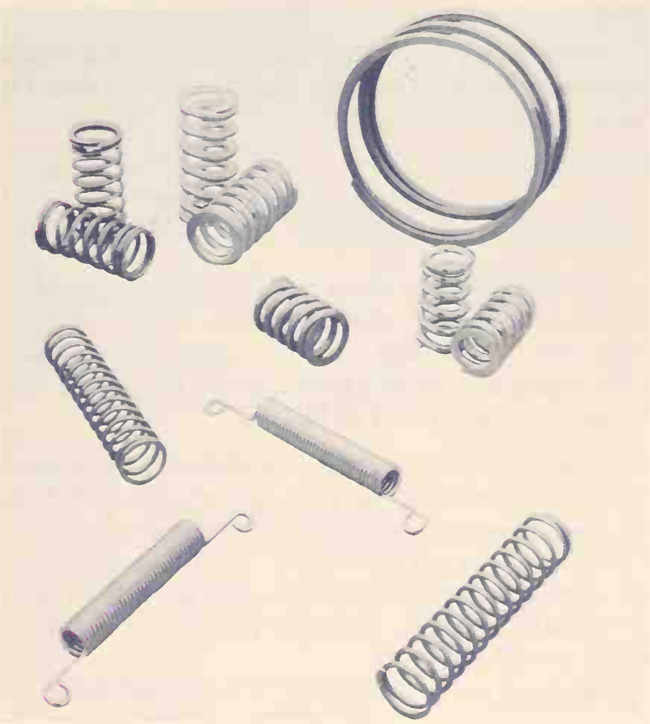


Figure 14-1B Varieties of compression and extension springs (*Courtesy* AMETEK, *Inc., Hunter Spring* Division)

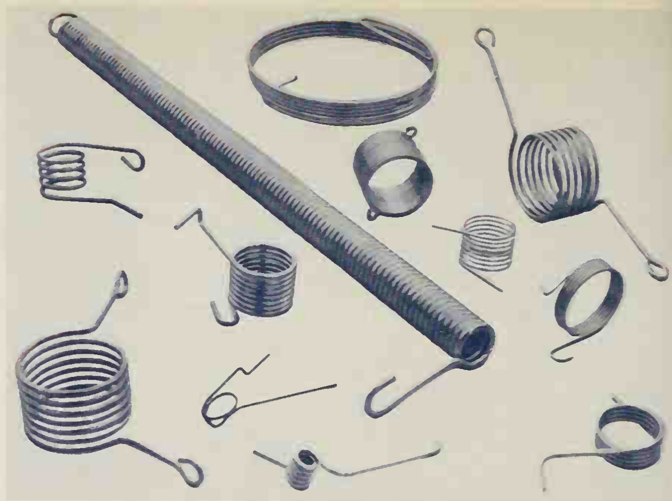


Figure 14-1C Varieties of torsion springs (*Courtesy* AMETEK, *Inc., Hunter Spring* Division)

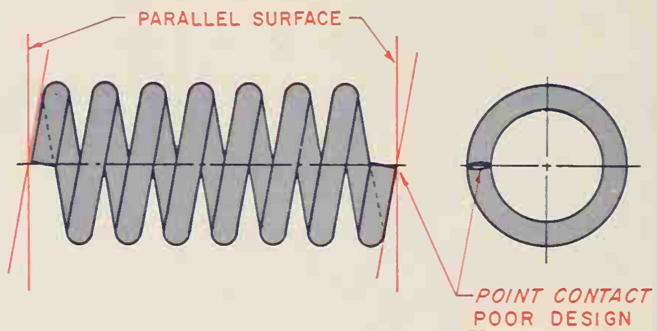


Figure 14-2A Plain open end compression spring

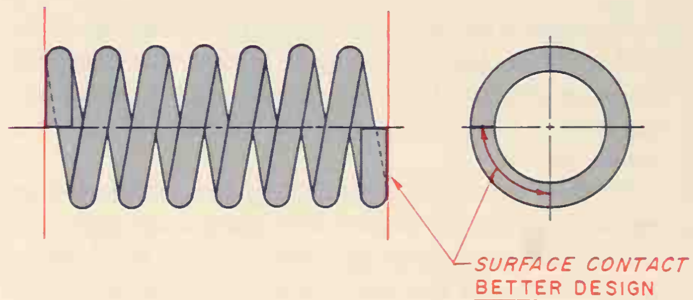


Figure 14-2B Plain closed end compression spring

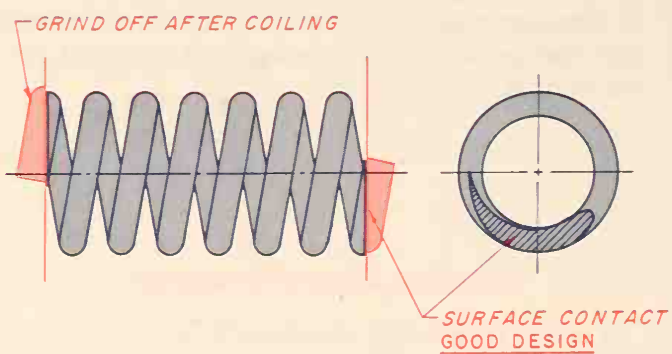


Figure 14-2C Ground open end compression spring

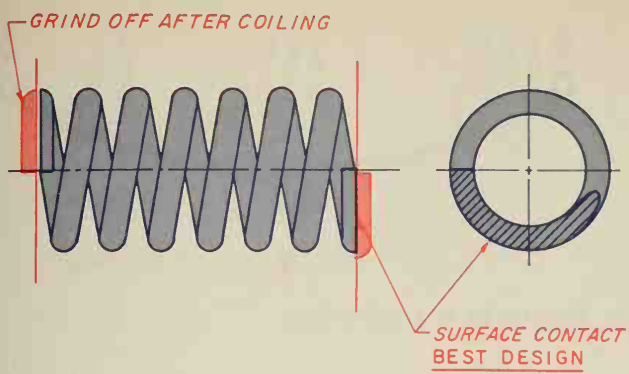


Figure 14-2D Ground closed end compression spring

Ground closed end – *Figure* 14-2D. The ground closed end spring is the most stable, and the best design. This design provides a large flat surface contact perpendicular to the axis of the spring.

A good example of a compression spring is the kind that is used in the front end of an automobile.

Extension Spring

An *extension spring* offers resistance to a pulling force. In its free state, the coils of the extension spring are usually either touching or very close. The ends of an extension spring are usually a hook or loop, Figure 14-3. Illustrated are a few of the many kinds of ends that are used. The loop or hook can be over the center or at the side. Each end is designed for a specific application or assembly. Regardless of the shape of the loop or hook, the overall length of an extension spring is measured from the *inside* of the loops or hook. A good example of an extension spring is the kind that is used to counterbalance a garage door.

Torsion Spring

A *torsion spring* offers resistance to a torque or twisting action. In its free state, the coils of a torsion spring are usually either touching or very close. The ends of a torsion spring are usually specially designed to fit a particular mechanical device. Figure 14-4. A good example of a torsion spring is the kind that is used to return a doorknob back to its original position.

Flat Springs

The other classification or type of spring is the flat spring. The *flat spring* is made of spring steel and is designed to perform a special function. Flat springs are not standard, and must be designed and manufactured to fit each particular need. The flat spring is considered a power spring, and it resists a pressure. A good example of a flat spring is the kind that is used for a door latch on a cabinet, Figure 14-5, or a

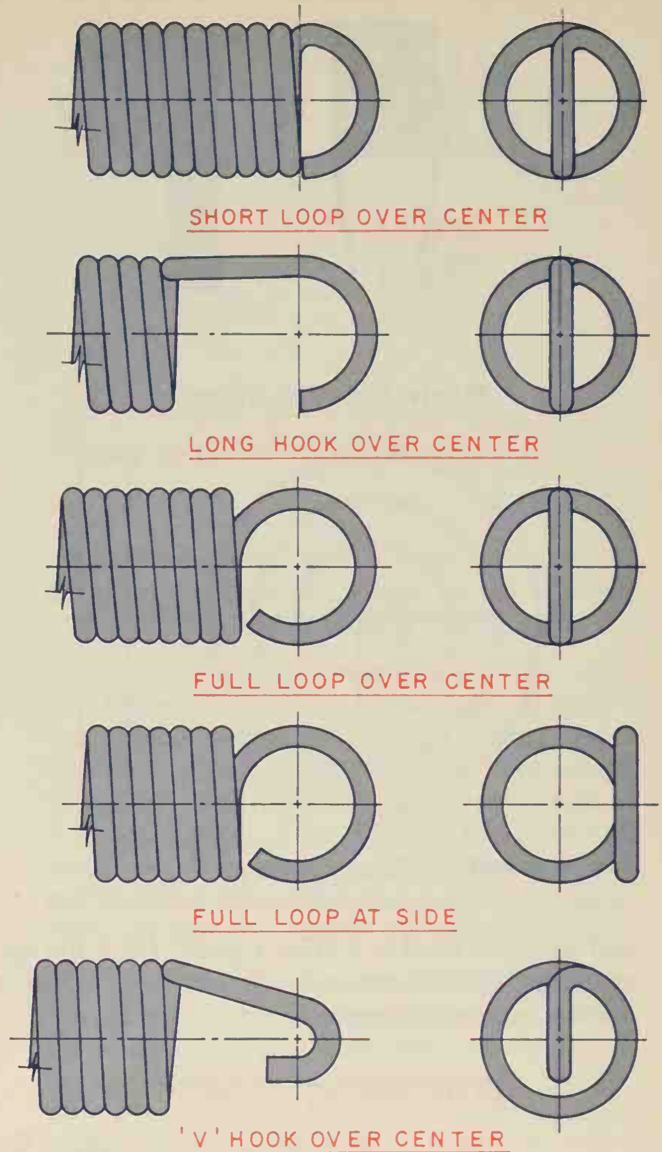


Figure 14-3 Ends of extension spring

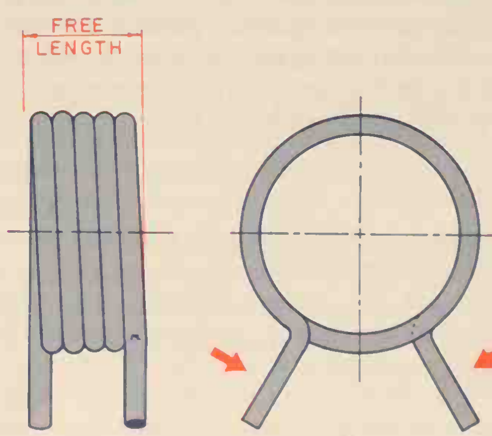


Figure 14-4 Torsion spring

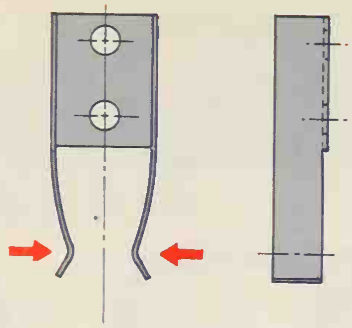


Figure 14-5 Flat spring

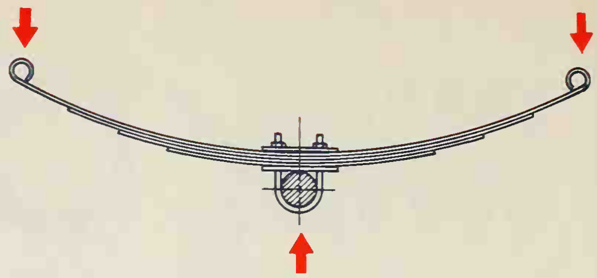


Figure 14-6 Leaf spring

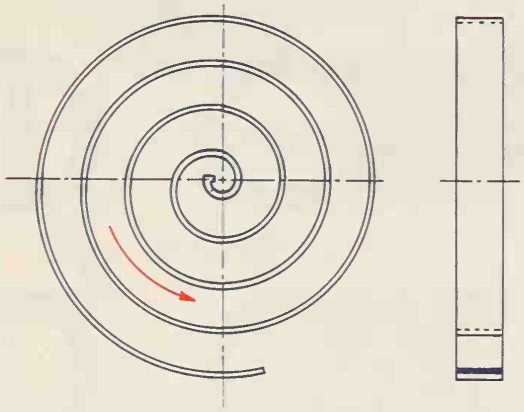


Figure 14-7 Special spring

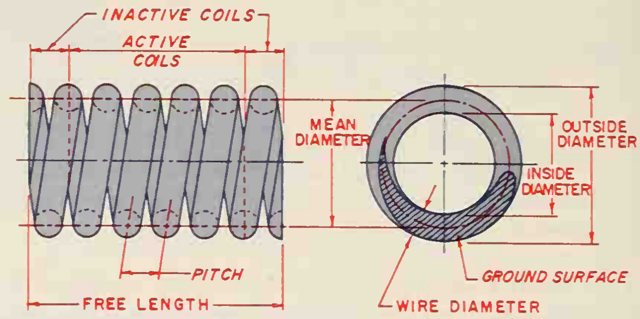


Figure 14-8 Spring terminology

leaf spring as used in a truck, Figure 14-6. A flat spiral spring used to power a windup clock or toy is another example, Figure 14-7.

Terminology of Springs

It is important to know and fully understand the various terms associated with springs and their design, Figure 14-8.

Free Length

Free length is the overall length of the spring when it is in its free state of unloaded condition. Free length of a compression spring is measured from the extreme ends of the spring. In an extension spring, the free length is measured inside the loops or hooks.

Solid Length

Solid length of a compression spring is the overall length of the spring when *all* coils are compressed together so they touch. This can be mathematically calculated. If the wire diameter is .500, the overall solid length is 3.25.

Outside Diameter

Outside diameter (O.D.) is the outside diameter of the spring (2 x wire size *plus* inside diameter).

Wire Size

Wire size is the diameter of the wire used to make up the spring.

Inside Diameter

Inside diameter (I.D.) is the inside diameter of the spring (2 x wire size *minus* outside diameter).

Active Coils

Active coils in a compression spring are usually the total coils minus the two end coils. In a compression spring, the coil at each end is considered nonfunctional. In an extension spring, active coils include *all* coils.

Loaded Length

Loaded length is the overall length of the spring with a special given or designed load applied to it.

Mean Diameter

Mean diameter is the theoretical diameter of the spring measured to the center of the wire diameter. This theoretical diameter is used by the drafter to lay out and draw a spring. To mathematically calculate the mean diameter, subtract the wire diameter from the outside diameter.

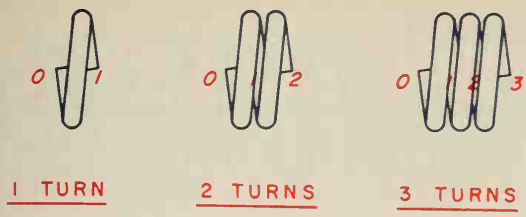


Figure 14-9 Coils or turns

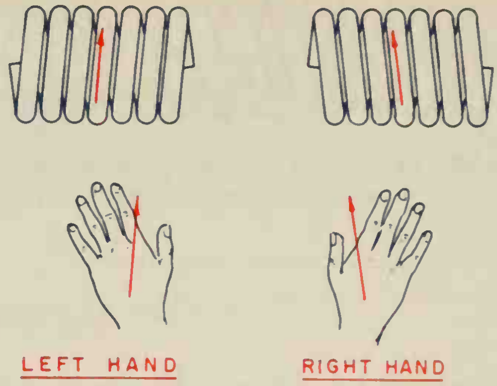


Figure 14-10 Direction of winding

Coil

Coil or *turn* is one full turn or 360° of the wire about the center axis, Figure 14-9.

Direction of Winding

Direction of winding is the direction in which the spring is wound. It can be wound right hand or left hand, Figure 14-10. The thumbs of your hands point toward the direction in which the coil windings are leaning. If the coil windings slant to the right, as the example to the left illustrates, it agrees with the direction of your left-hand thumb; thus, a left-hand winding. If the coil windings slant to the left as the example to the right illustrates, it agrees with the direction of your right-hand thumb; thus, a right-hand winding. If the coil winding direction is not called-off on the drawing, it will be manufactured with right-hand winding.

Required Spring Data

Each drawing must include complete dimensions and specific data. Besides the regular dimensions, i.e., outside diameter (O.D.) and/or inside diameter (I.D.) wire size; free length; and solid length (compression spring), the following data should be called-off at the lower right side of the work area:

- Material
- Number of coils (including active and inactive coils)
- Direction of winding (if not noted, it is assumed to be right hand)
- Torque data (if torsion spring)
- Finish
- Heat treatment specification
- Any other required data

How To Draw a Compression Spring

Given: Plain open ends, 1.50 outside diameter, .25 diameter wire size, 4.00 free length, oil tempered spring steel wire, 8 total coils (6 active coils), left-hand winding, heat treatment: heat to relieve coiling stresses, finish: black paint. Make a rough sketch of the spring using the given specifications, Figure 14-11A. A rough sketch is extremely important in developing a new spring design.

Step 1. Measure and construct two vertical lines the required overall length (front view). Divide the space between the two vertical lines into 17 equal spaces (front view) 2 x total coils plus 1; in this example, $2 \times 8 + 1 = 17$, Figure 14-11B. Measure and construct the mean diameter. To calculate the mean diameter, subtract the wire diameter from the outside diameter (end view).

Step 2. Determine the direction of windings; refer to sketch and lightly construct the wire diameter accordingly. (front view). The wire diameters are constructed on the mean diameter. Lightly draw the outside diameter and inside diameter (end view), Figure 14-11C.

Step 3. Lightly construct the near side of the spring. Add short, light tangent points, Figure 14-11D.

Step 4. Lightly construct the rear side of the spring. Add ends of spring; in this example, plain open ends. Check all work against given requirements, Figure 14-11E.

Step 5. Recheck all work. Darken in spring using the latest drafting standards. Add end of spring, right end, dimensions and add all required spring data, Figure 14-11F.
Notice: outside diameter, wire size, free length, and solid length are given as regular dimensions. The material, number of coils, direction of winding, heat treatment specifications and finish requirements are listed below and to the right as a note. In this example, the outside diameter is the controlling dimension; that is, the outside dimension is more important than the inside dimension. Both inside and outside dimensions should not be added in the same drawing.

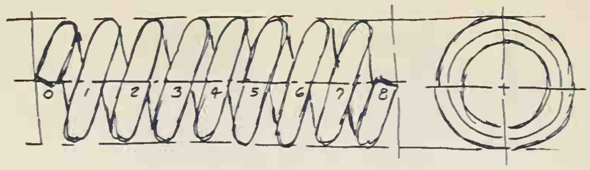


Figure 14-11A How to draw a compression spring with plain open ends

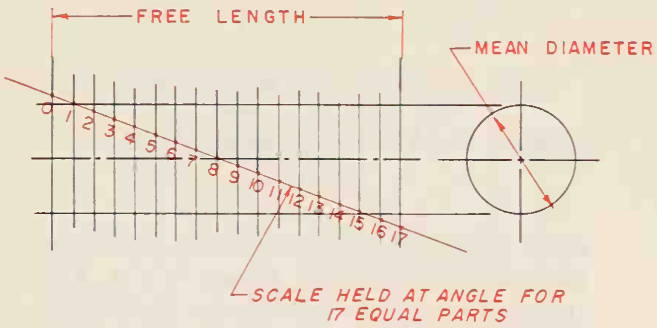


Figure 14-11B Step 1

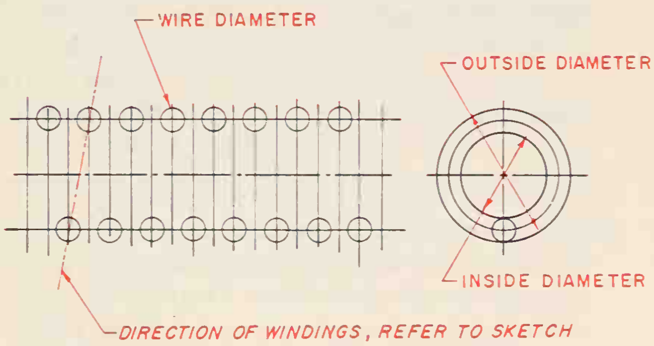


Figure 14-11C Step 2

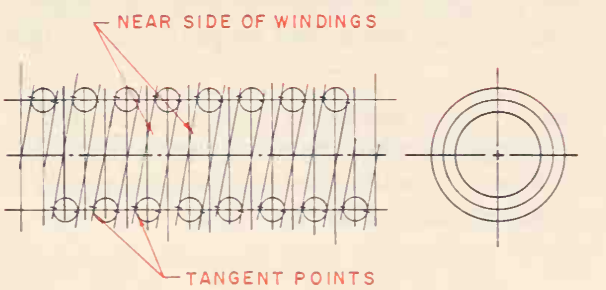


Figure 14-11D Step 3

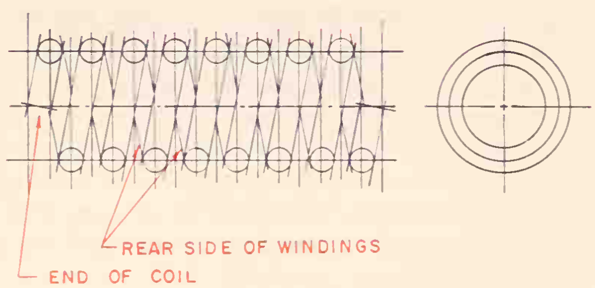


Figure 14-11E Step 4

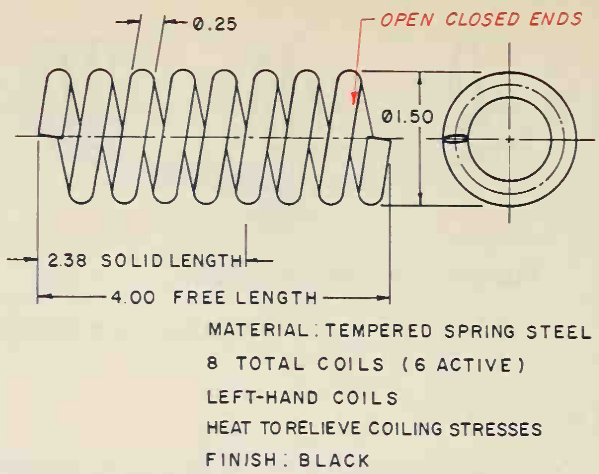


Figure 14-11F Step 5

How To Draw a Compression Spring (Plain Closed Ends)

Given: Plain closed ends, 20 mm inside diameter, 5 mm diameter wire size, 100 mm free length, material: hard drawn steel spring wire, 5 active coils (total 7 coils), left-hand winding, heat treatment: heat to relieve coiling stresses, finish: zinc plate. Make a rough sketch of the spring using the given specifications, Figure 14-12A.

Step 1. Measure and construct two vertical lines the required overall length (front view). Draw a line *inside* the two vertical lines equal to half the wire diameter from each end. Divide the space between the two vertical lines into 13 equal spaces (front view) 2 x total coils minus 1; in this example, $2 \times 7 - 1 = 13$, Figure 14-12B. Measure and construct the mean diam-

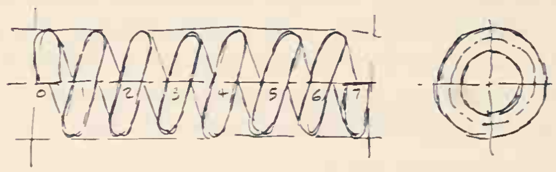


Figure 14-12A How to draw a compression spring with plain closed ends

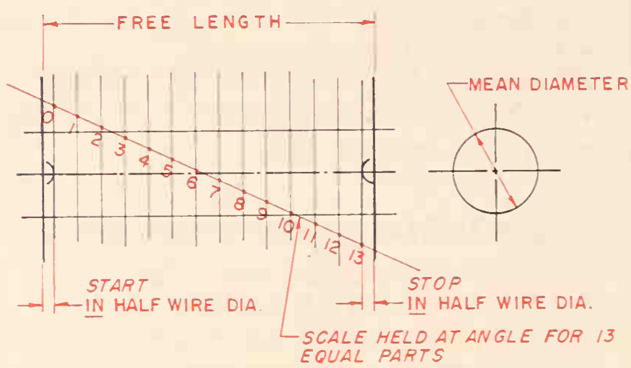


Figure 14-12B Step 1

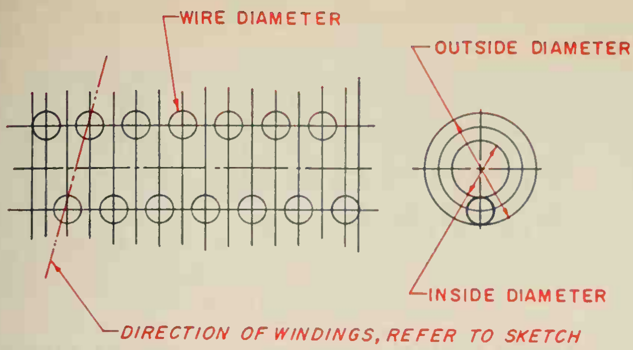


Figure 14-12C Step 2

eter. To calculate the mean diameter, add the wire diameter to the inside diameter (end view).

Step 2. Determine the direction of winding; refer to the sketch and lightly construct the wire diameter accordingly (front view). Lightly draw the outside diameter and inside diameter (end view), Figure 14-12C.

Step 3. Lightly construct the near side of the spring. Add short tangent points, Figure 14-12D.

Step 4. Lightly construct the rear side of the spring. Add ends of springs. In this example, plan closed ends. Check all work against given requirements, Figure 14-12E.

Step 5. Recheck all work. Darken in spring using the latest drafting standards. Add all required dimensions and spring data, Figure 14-12F.

How To Draw a Compression Spring (Ground Closed Ends)

(The following illustrations are for a ground closed end compression spring. The exact same steps can be used for a ground open end compression spring.)

Given: Ground closed ends, 1.125 outside diameter, .188 diameter wire size, 3.00 free length, material: hard drawn steel spring wire, 7 total coils (5 active coils), right-hand winding, heat treatment: heat to relieve coiling stresses, finish: zinc plate. Make a rough sketch of the spring using the given specifications, Figure 14-13A.

Step 1. Measure and construct two vertical lines the required free length (front view). Divide the space between the two vertical lines into 13 equal spaces (front view), 2 × total coils minus 1; in this example, 2 × 7 − 1 = 13, Figure 14-13B. Measure and construct the mean diameter. To calculate the mean diameter, subtract the wire diameter from the outside diameter (end view).

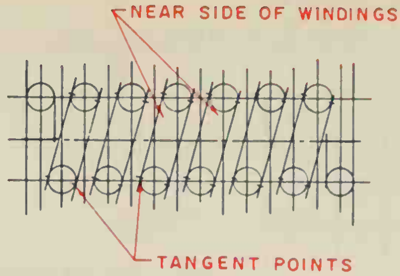


Figure 14-12D Step 3

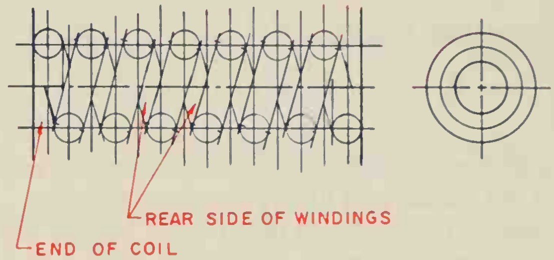


Figure 14-12E Step 4

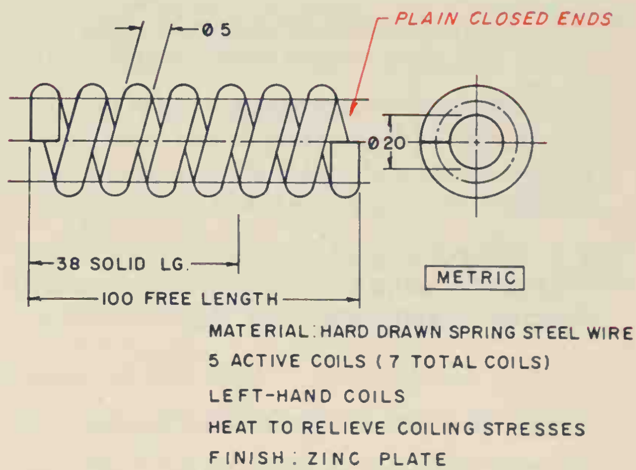


Figure 14-12F Step 5

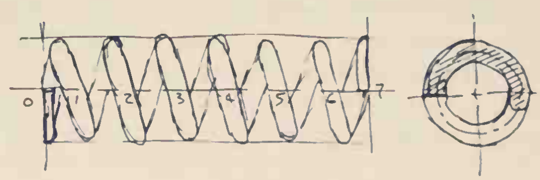


Figure 14-13A How to draw a compression spring with ground closed ends

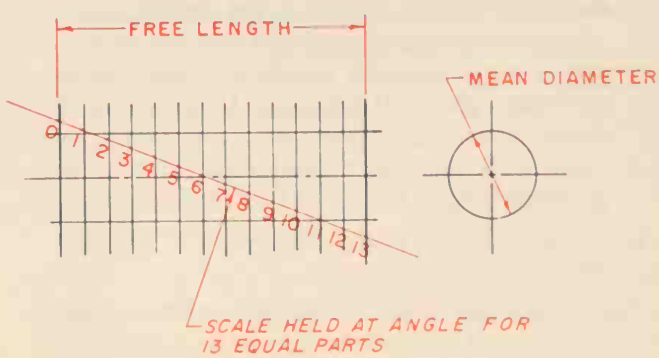


Figure 14-13B Step 1

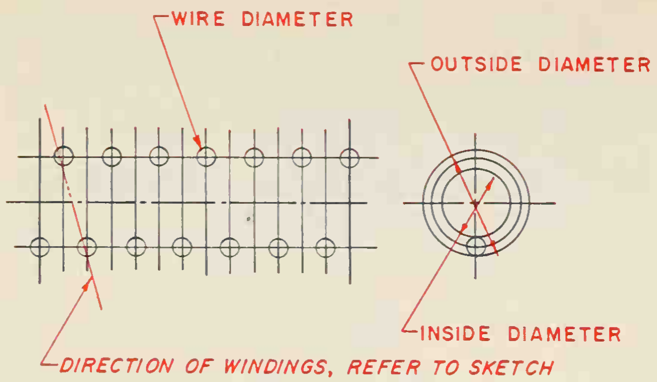


Figure 14-13C Step 2

Step 2. Determine the direction of winding; refer to the sketch and lightly construct the wire diameter accordingly (front view). Lightly draw the outside diameter and inside diameter (end view), Figure 14-13C.

Step 3. Lightly construct the rear side of the spring. Add short tangent points, Figure 14-13D.

Step 4. Lightly construct the rear side of the spring. Add ends of spring; in this example, ground closed end. Check all work against given requirements, Figure 14-13E.

Step 5. Recheck all work. Darken in spring using the latest drafting standards. Add all required dimensions and spring data, Figure 14-13F.

How To Draw an Extension Spring

Given: Full loop, over center each end 1.625 outside diameter, .188 diameter wire size, 4.750 approximate free length, material: hard drawn spring steel wire, heat treatment: heat to relieve coiling stresses, finish: black paint, windings as tight as possible. Make a rough sketch of the spring using the given specifications, Figure 14-14A.

Step 1. Draw the outside diameter, inside diameter and mean diameter (end view). Lightly draw the required free length. In the design of an extension spring, it is almost impossible to arrive at the *exact* free length. In designing an extension spring, it is best to design it slightly *shorter* than actually required. Construct the end loops with the *inside* diameter within the specified free length, Figure 14-14B. Note in this example the loops are the exact diameter as the spring itself.

Step 2. Starting at the intersection of the mean diameter of the right end loop, and the mean diameter of the spring, lower side, locate and

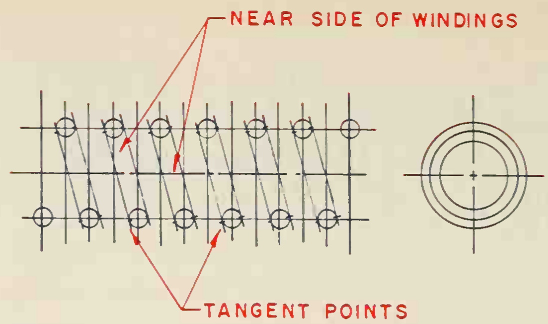


Figure 14-13D Step 3

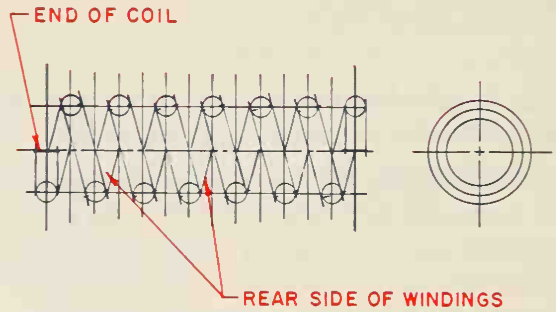


Figure 14-13E Step 4

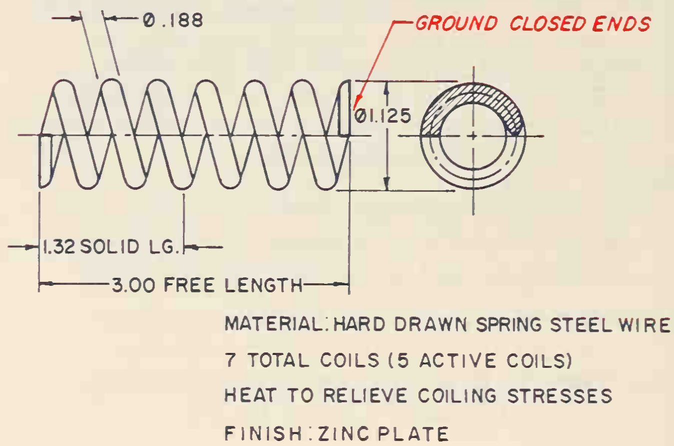


Figure 14-13F Step 5

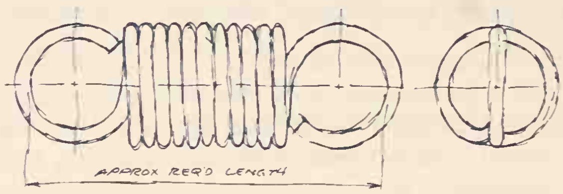


Figure 14-14A How to draw an extension spring with full loop ends

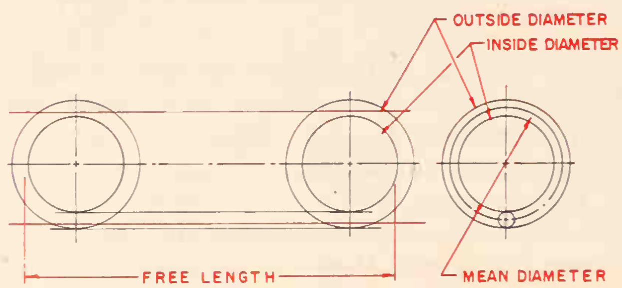


Figure 14-14B Step 1

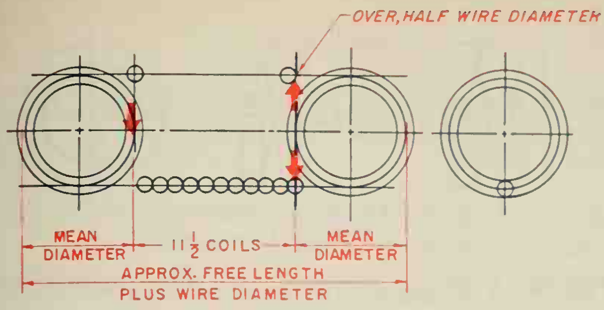


Figure 14-14C Step 2

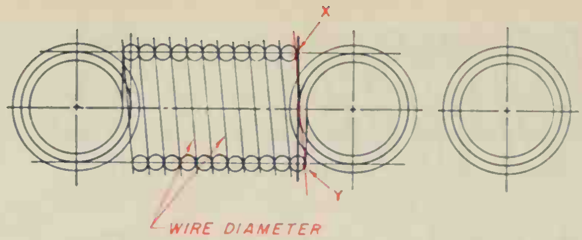


Figure 14-14D Step 3

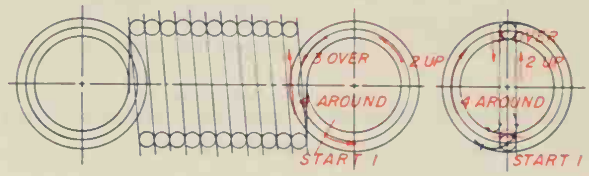


Figure 14-14E Step 4

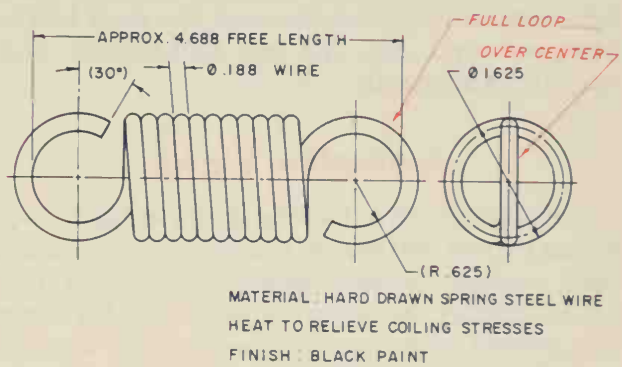


Figure 14-14F Step 5

draw the first lower wire diameter, Figure 14-14C. Project directly up to the mean diameter of the spring, upper side, and draw the first upper wire diameter *over* to the left, half a wire diameter as illustrated. Lay out, side-by-side, wire diameters touching, as illustrated; in this example, 10½ coils. Notice the coils must end on the mean diameter, left end. This may mean adjusting slightly the location of the left end loop. It is best to bring it *in* slightly, if necessary.

Step 3. Locate points X and Y, as illustrated in Figure 14-14D, and adjust the drafting machine at this angle and lock on this angle. Draw the wire loops.

Step 4. Lightly draw the loop in the right-side view. To calculate just what the loop will actually look like, number various points along the loop in the front view; in this example, point 1, starting point; point 2, up; point 3, over; and point 4, around. Project these points to the end view, as illustrated in Figure 14-14E.

Step 5. Recheck all work. Darken in spring using the latest drafting standards. Add all required dimensions and spring data, Figure 14-14F.

Other Spring Design Layout

When drawing any specially designed spring for a particular function, it is recommended to make a rough sketch of it, including all required specifications. A torsion spring is developed in a manner very similar to an extension spring with its tight coils. Usually, the required torque pressure is included in the given spring data. The actual designed deflection of the torsion spring is illustrated by phantom lines, and the angle is noted.

Standard Drafting Practices

Some company standards specify that the drafter not draw the complete spring because of the time and cost involved. A shortcut method to draw a spring is shown in Figure 14-15. At top is the conventional method of representing a compression spring; below it is the same spring drawn by the schematic drawing system.

Another method of drawing a spring, especially a long spring, is illustrated in Figure 14-16. The incompleted coils are illustrated by phantom lines. If the company does not have a standard method of drawing springs it is the drafter's decision as to which method of representation is used. In most cases, it is best to draw the object, in this case the spring, in such a way that there is no question whatsoever as to exactly what is required. Of course, regardless of which system is used, full dimensions and specification data must be included.

Section View of a Spring

If a cutting plane line passes through the axis of a spring, the spring is drawn in one of two ways. A small spring is drawn with the back coils showing, as illustrated in Figure 14-17, Part A, with the section lining of the coils filled in solid. A larger spring is drawn

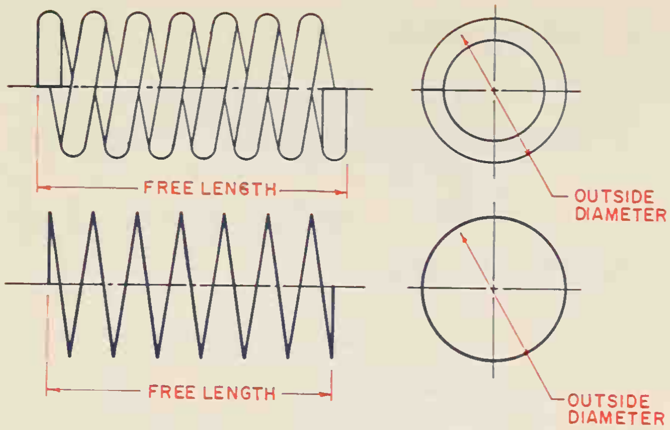


Figure 14-15 Schematic system of representing a compression spring

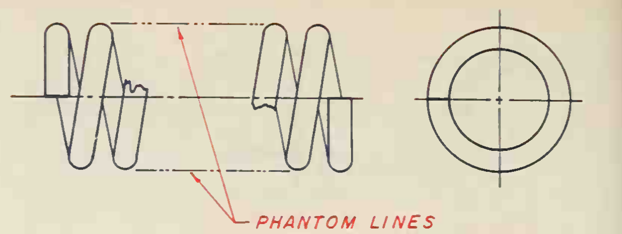


Figure 14-16 Incompleted coils with phantom lines

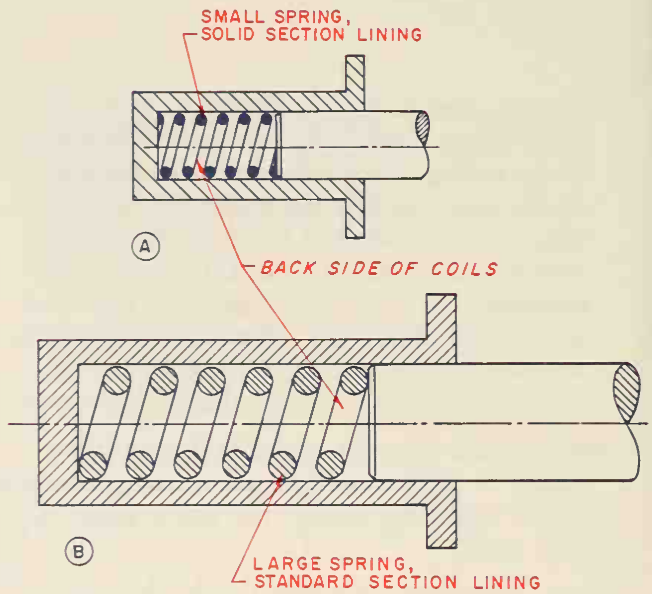


Figure 14-17 Section view of a spring

the same way, but uses standard section lining, Figure 14-17, Part B. Notice that both illustrations are right-hand springs, but, because the front half has been removed, only the rear half is seen which appears as left hand.

Isometric Views

A template, such as the one shown in Figure 14-18, makes it quick and simple to draw isometric views of light, medium, or heavyweight open springs. Lightweight springs are slightly smaller than the dimension printed on the template because they are drawn with the two smallest cutouts in any set. The thick lower edge and pinpoint centers ensure precise positioning to repeat each loop for any length spring.

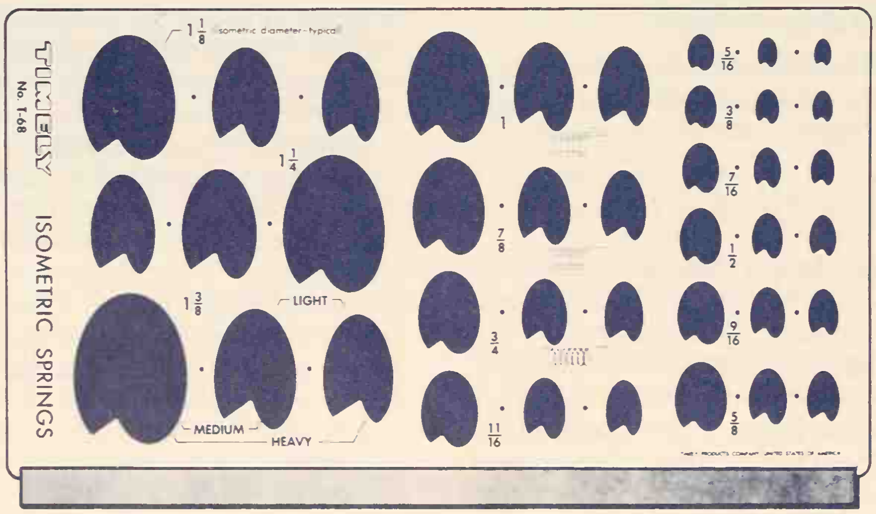


Figure 14-18 Isometric spring template (*Courtesy Timely Products Co.*)

Review

1. List two reasons why the schematic method of illustrating coils is sometimes used in industry.
2. List four major kinds of ends used on a compression spring. Which is the most stable?
3. Why is it incorrect to dimension both the inside diameter and the outside diameter of a spring on the same drawing? Which dimension should be given?
4. Other than the required dimensions, outside and/or inside diameter, wire size, free length, solid length (compression spring), what spring data must be noted below and to the right?
5. List two general classifications of springs.
6. What is the solid length of a compression spring with 8 active coils, a wire size of .375 diameter, mean diameter of 2.00, closed ground ends?
7. List three types of helical springs. Make a rough sketch of each illustrating how pressure is applied to each.
8. How is the section lining illustrated in a small spring where the cutting plane line passes through the center axis of the spring?
9. What is meant by the free length of a spring?
10. List three common uses for a torsion spring.

Chapter Fourteen Problems

The following problems are intended to give the beginning drafter practice in drawing various kinds of springs with special required specifications.

The steps to follow in laying out springs are:

Step 1. Study all required specifications.

Step 2. Make a rough sketch of the spring, incorporating *all* required specifications and required dimensions.

Step 3. Calculate the size of the basic shape of the front and end views.

Step 4. Center the two views within the work area with correct spacing for dimensions between views.

Step 5. Starting with the end view, or the view that contains the diameter, lightly draw the spring adhering to *all* specific required specifications. Take care to show correct direction of winding, correct type of ends, and total count of windings.

Step 6. Check to see that both views are centered within the work area.

Step 7. Check all dimensions in both views.

Step 8. Darken in both views, starting first with all diameters and arcs.

Step 9. Neatly add all dimensioning as required to fully describe the object using the latest drafting standards.

Step 10. Neatly add all required specifications under the two views. The drawing must include the following:

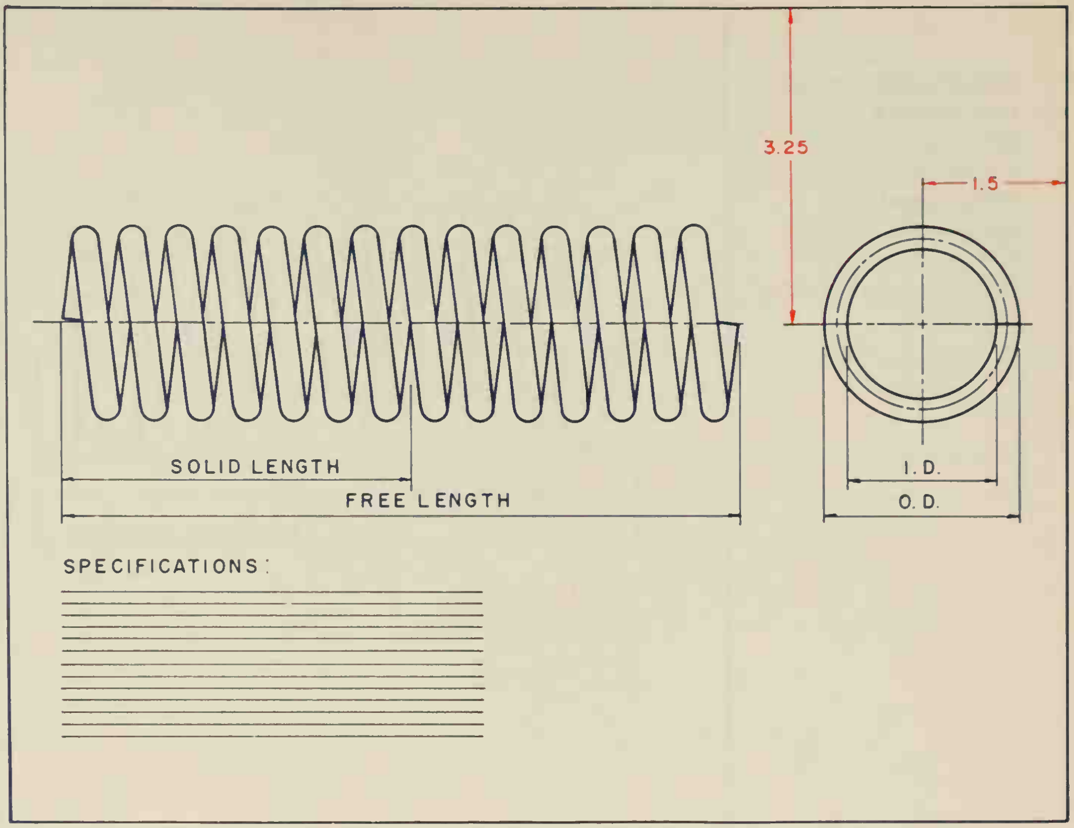
- Free length
- Wire size
- Total number of coils
- Type of ends
- Solid length
- Outside diameter
- Inside diameter
- Direction of windings
- Material (usually, hard drawn steel, spring wire)
- Required heat treating process (usually, heat to relieve coiling stresses)
- Any other special requirements

Step 11. For torsion-type springs, illustrate *working location* and travel with phantom lines and dimension.

Problems 14-1 through 14-7

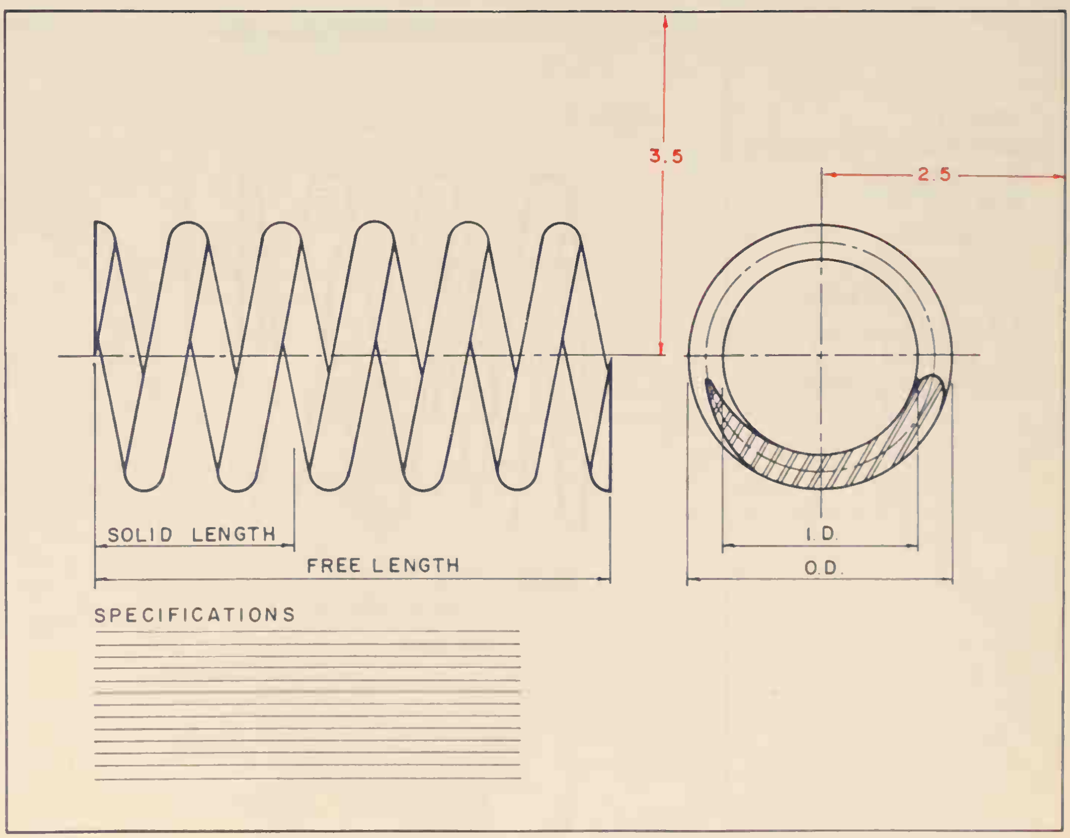
Construct a 2-view drawing of each spring using the listed steps. Center the views on an A-size, $8\frac{1}{2} \times 11$ sheet of paper with a 1″(25 mm) space between views. Use correct line thicknesses and all drafting standards. Add all required dimensions and specifications per the latest drafting standards.

Compression-type spring
Free length 7.00
Wire size .25
12 active coils
(14 *total* coils)
Plain open ends
O.D. 2.00/I.D. 1.50
R.H. winding
Calculate solid length



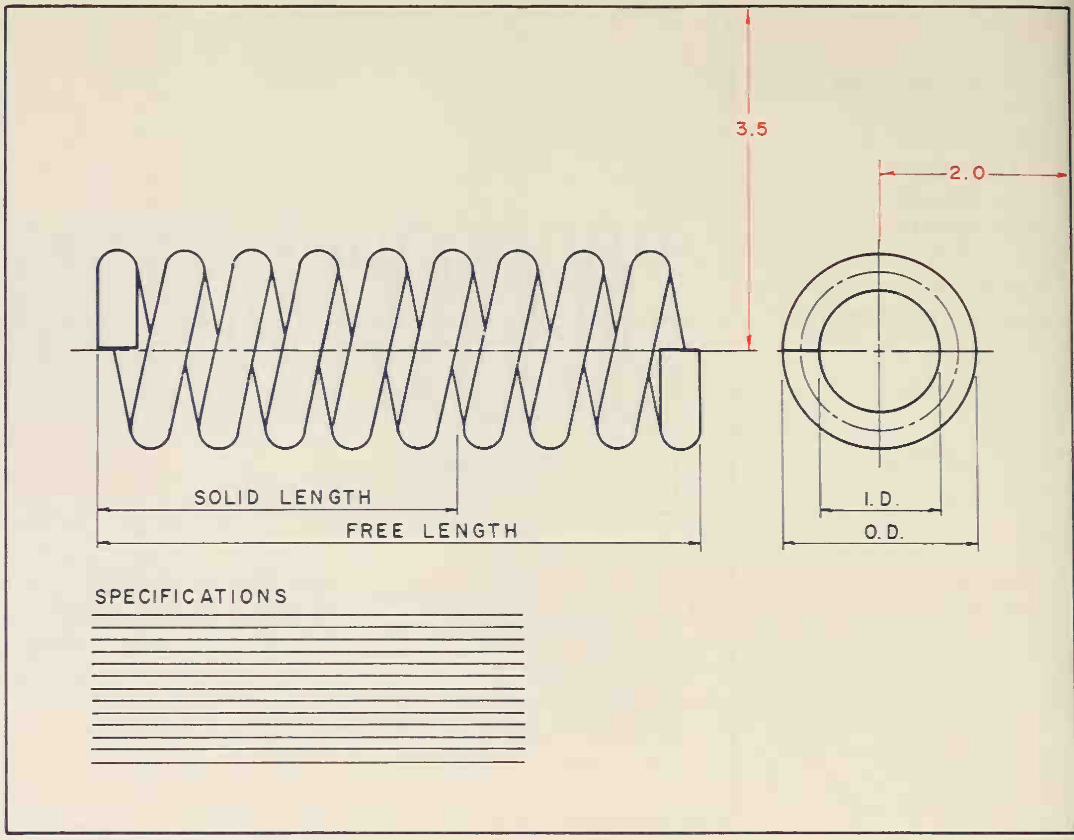
Problem 14-1

Compression-type spring
Free length 5.25
Wire size .375
4 active coils (6 *total* coils)
Ground open ends
O.D. 2.75/I.D. 2.00
L.H. winding
Calculate solid length



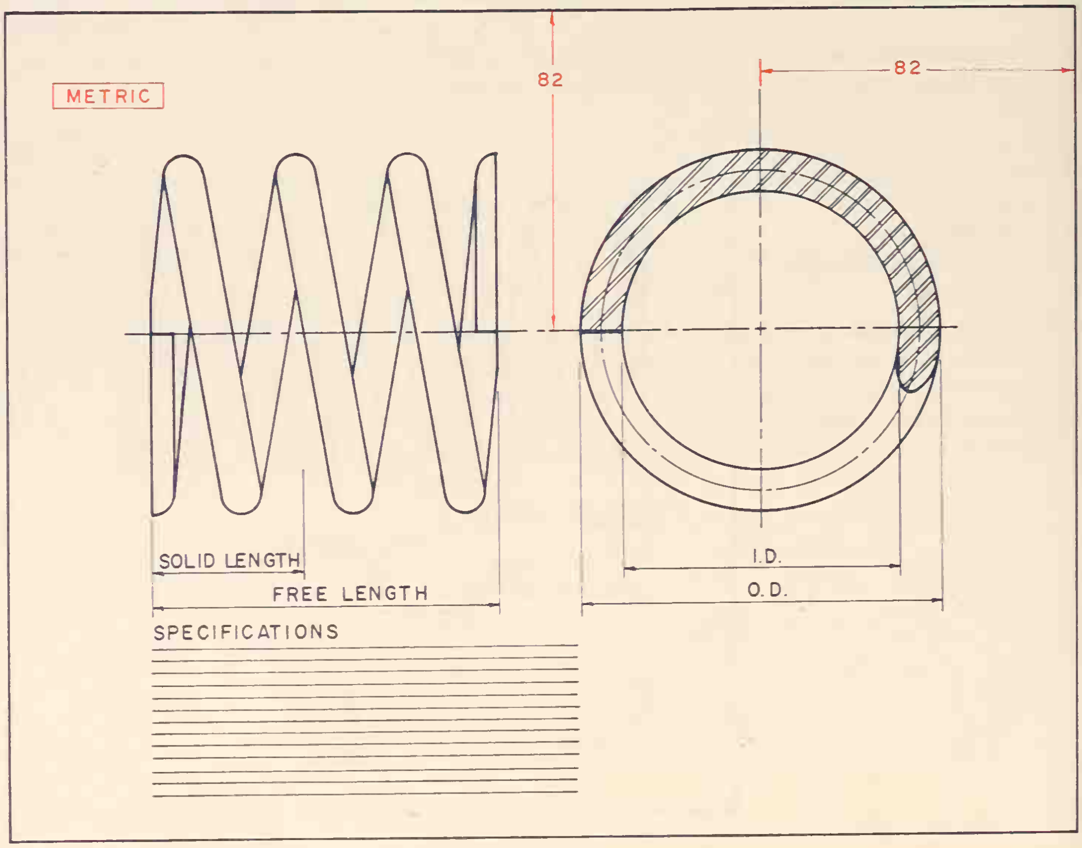
Problem 14-2

Compression-type spring
Free length 6.25
Wire size .375
9 total coils (7 *active* coils)
Plain closed ends
O.D. 2.00/I.D. 1.25
L.H. winding
Calculate solid length



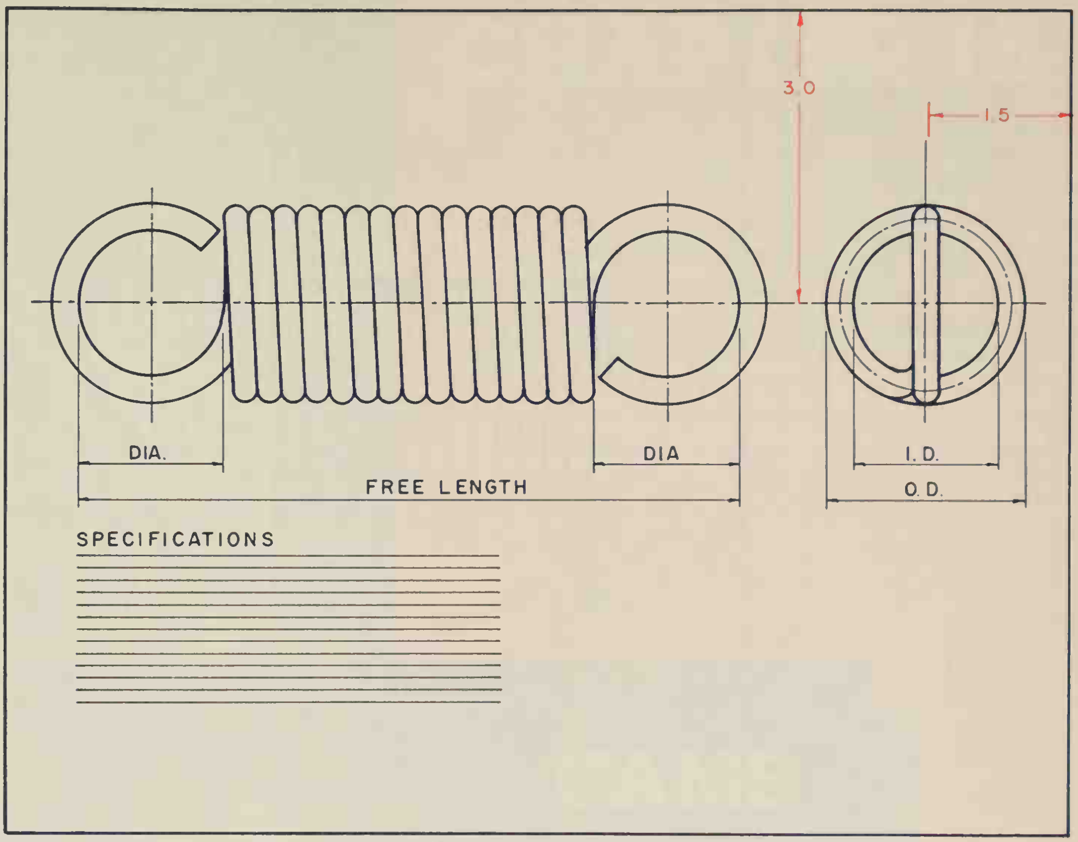
Problem 14-3

(Metric)
Compression-type spring
Free length 90
Wire size 12
4 total coils
(2 active coils)
Ground closed ends
O.D. 96/I.D. 72
R.H. winding
Calculate solid length



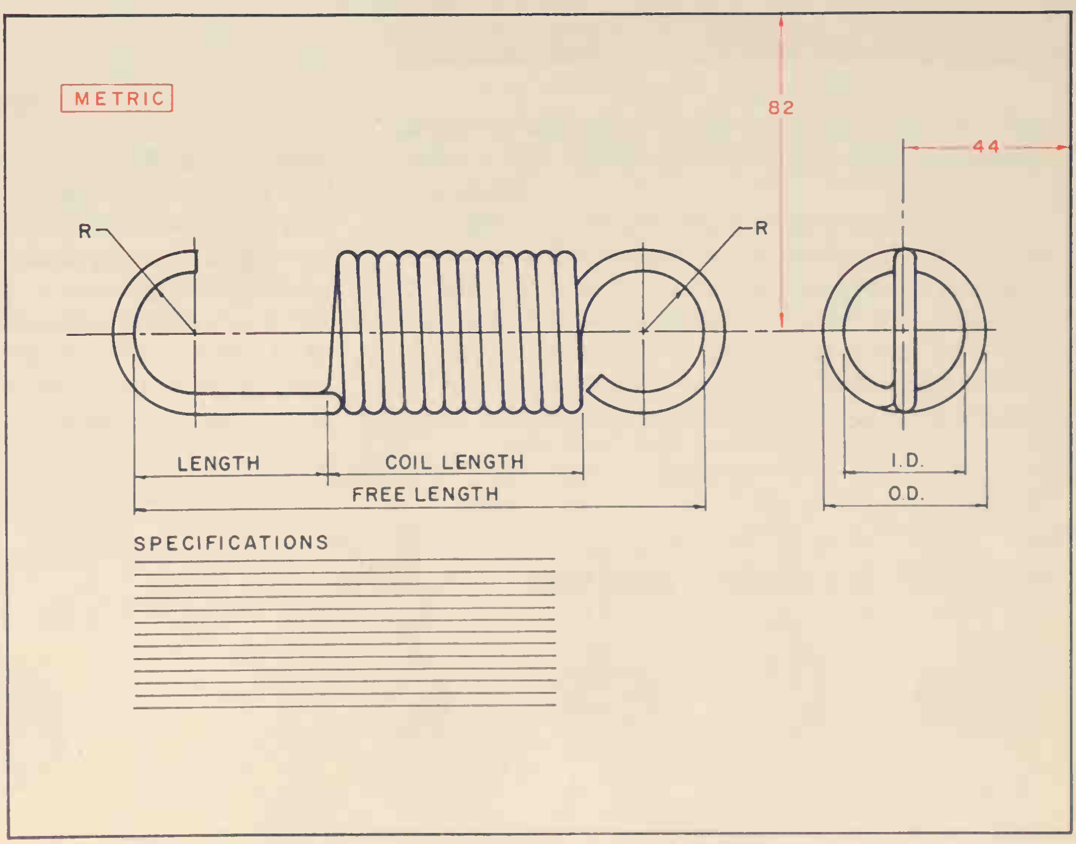
Problem 14-4

Extension-type spring
Full loop over center, both ends
Approx. free length 7.0
Wire size .25
O.D. 2.0/I.D. 1.50
R.H. winding (This is *standard* for all extension springs)



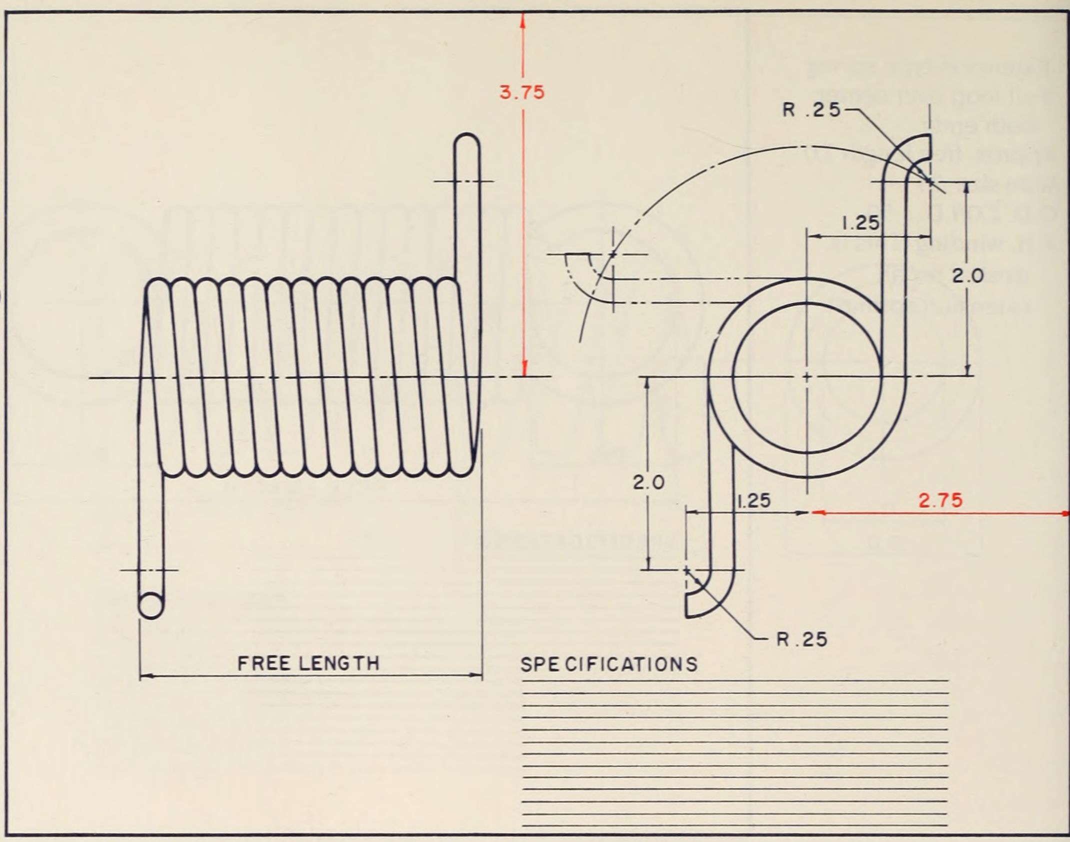
Problem 14-5

(Metric)
Extension-type spring
Full loop over center (right end)
Long hook over center (left end)
Free length 150
Wire size 5
12 total coils
65 coil length
O.D. 42/I.D. 32
Standard R.H. winding

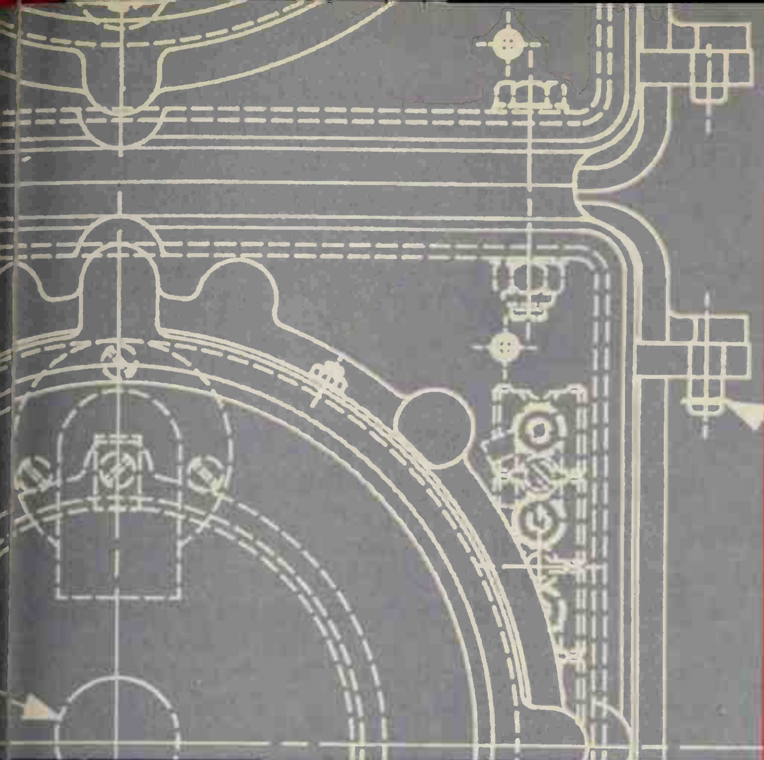


Problem 14-6

Torsion-type spring
Free length 3.625
Wire size .25
13 total coils
O.D. 2.0/I.D. 1.50
R.H. standard winding
90° maximum working flex (counterclockwise)
Arm lengths 2.0 (as shown)



Problem 14-7



CHAPTER 15

Various kinds of standard cam motions are studied in this chapter, including uniform velocity, modified uniform velocity, harmonic motion, and uniform acceleration. The terminology associated with cams, and how to dimension them are also covered. Cam designing with the aid of a displacement diagram is discussed. This material will provide the beginning designer with the required information to achieve any required cam motion.

CAMS

Cam Principle

A *cam* produces a simple means to obtain irregular or specified predictable designed motion. These motions would be very difficult to obtain in any other way.

Figure 15-1 illustrates the basic principle and terms of a cam. In this example, a rotating shaft has an irregularly shaped disc attached to it. This disc is the cam. The follower, with a small roller attached to it, pushes against the cam. As the shaft is rotated the roller follows the irregular surface of the cam, rising or falling according to the profile of the cam. The roller is held tightly against the cam either by gravity or a spring.

Figure 15-2 illustrates a simple cam in action. Notice how the rotation of the shaft converts into an up and down motion of the follower. A cam using a flat-faced follower is shown in Figure 15-3. This type of cam, for example, is used to raise and lower the valve in an automobile engine. A modified cam follower is used to change the rotary motion of shaft A

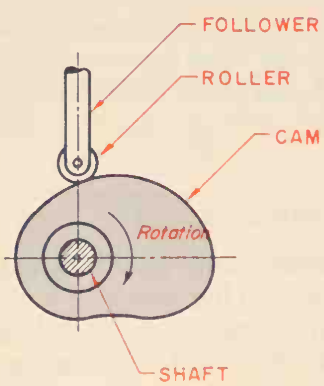


Figure 15-1 Basic cam principle and terms

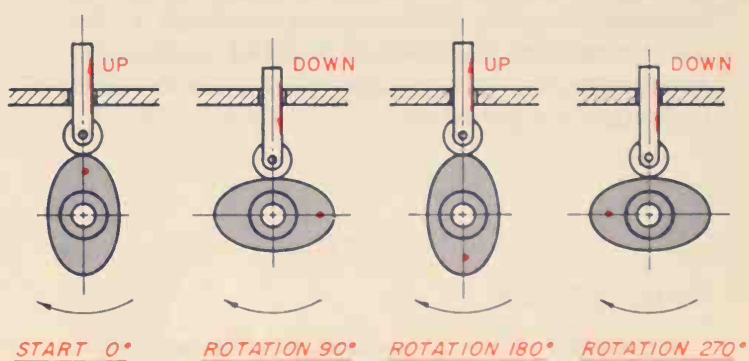


Figure 15-2 Simple cam in action

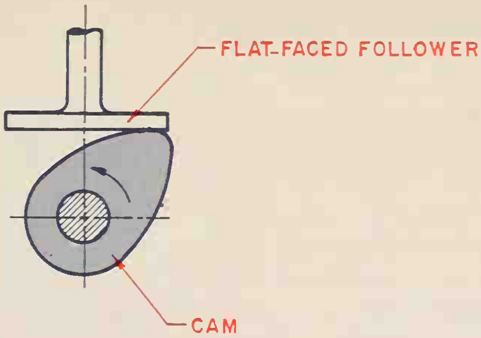


Figure 15-3 Flat-faced follower

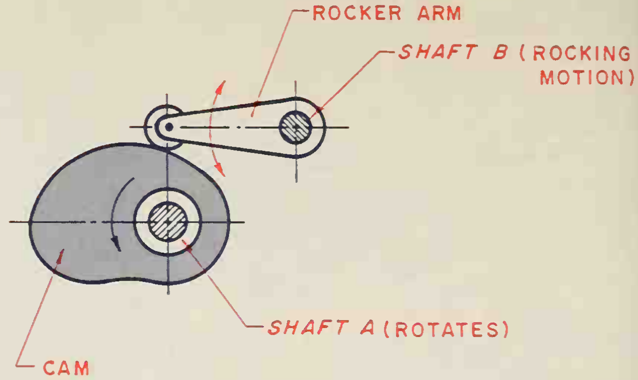


Figure 15-4 Rocker arm follower with wheel

into an up and down of the rocker arm, and then into a rocking motion of shaft B, Figure 15-4.

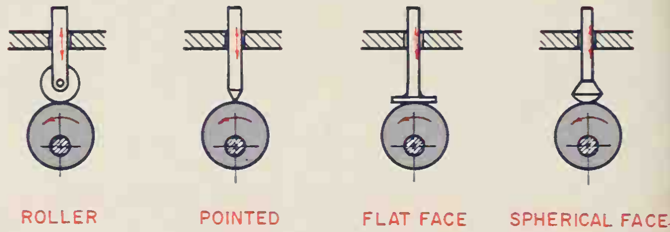


Figure 15-5 Basic types of followers

Basic Types of Followers

Speed of rotation and the actual load applied upon the lifter determines the type of follower to be used. There are various basic types of followers: roller, pointed, flat faced and spherical faced, Figure 15-5.

Cam Mechanism

Two major kinds of cams are used in industry: radial arm design and cylindrical design. The *radial arm* design changes a rotary motion into either an up and down motion or a rocking action as discussed previously. In the *cylindrical* design, a shaft rotates exactly as it does in the radial design, but the action or direction of the follower differs greatly. In the radial arm design, the follower operates *perpendicular* to the cam shaft. In the cylindrical design, the follower operates *parallel* to the cam shaft. See Figure 15-6 for a simplified example of a cylindrical design cam. Shaft A has an irregular groove cut into it. As the cam rotates, the follower traces along the groove. The follower is directly attached to a shaft that moves to the left and right. Notice, this shaft does *not* rotate; the motion is *parallel* to the axis of the rotating cam shaft.

Cams produce one of three kinds of motion: uniform velocity, harmonic, or uniform acceleration. Each is discussed in full later.

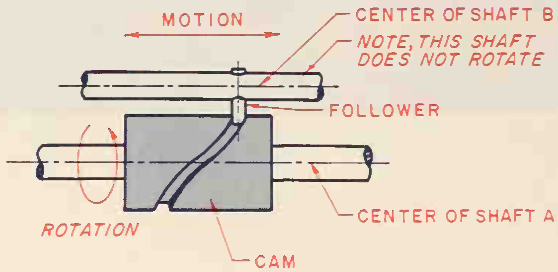


Figure 15-6 Cylindrical cam mechanism

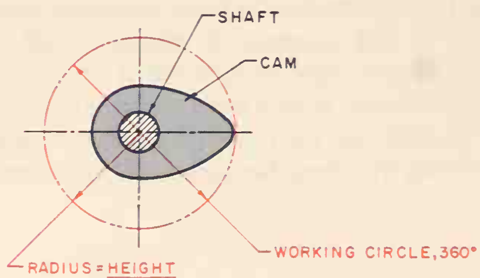


Figure 15-7 Cam terms and working circle

Cam Terms

Working Circle

The *working circle* is considered a distance equal to the distance from the center of the cam shaft to the highest point on the cam, Figure 15-7.

Displacement Diagram

The *displacement diagram* is a designed layout of the required motion of the cam. It is laid out on a grid, and its length represents one complete revolution of the cam. The length of the displacement diagram is usually drawn equal in length to the circumference of the working circle. This is not absolutely neces-

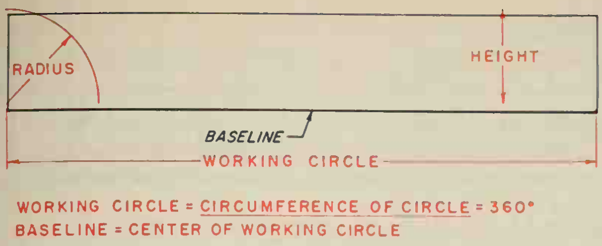


Figure 15-8 Displacement diagram – basic layout

sary, but it will give an in-scale idea of the cam's profile. The height of the displacement diagram is equal to the radius of a working circle, Figure 15-8. The bottom line of the displacement diagram is the *baseline.* All dimensions should be measured upward from the baseline. On the cam itself, think of the center of the cam as the baseline.

The length of the displacement diagram is divided into equal lines or grid, each of which represents degrees around the cam. These divisions can be 30°, 15° or even 10°. The finer the divisions, the more accurate is the final cam profile, Figure 15-9.

Dwell

Dwell is the period of time during which the follower does not move. This is shown on the displacement diagram by a straight horizontal line throughout the dwell angle. On the cam, the dwell is drawn by a radius.

Time Interval

The *time interval* is the time it takes the cam to move the follower to the designed height.

Rotation

Rotation of the cam is either clockwise or counterclockwise. The actual cam profile is laid out *opposite* of the rotation.

Base Circle

The *base circle* is used to lay out an offset follower which is illustrated in detail later. The base circle is a circle with a radius equal to the distance from the center of the shaft to the center of the follower wheel

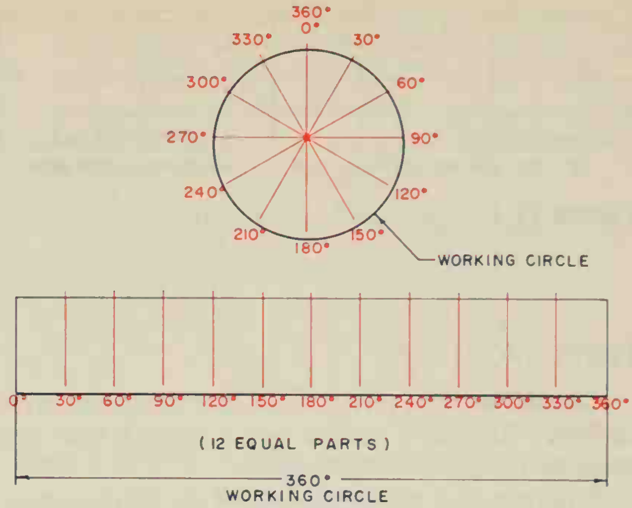


Figure 15-9 Displacement diagram with 30° increments

at its lowest position. On an offset follower, the base circle replaces the working circle.

Cam Motion

Four major types of curves are usually employed. Special irregular curves other than the four major types can be designed to meet a specific movement, if necessary.

The four types are: uniform velocity, modified uniform velocity, harmonic motion, and uniform acceleration. For comparison, the following four examples use the same working circle, same shaft, and same rise.

Uniform Velocity

In this type of motion, the cam follower moves with a *uniform velocity*; that is, it rises and falls at a constant speed, but the start and stop is very abrupt and rough, Figure 15-10.

Modified Uniform Velocity

Because of the abrupt and rough start and stop of the uniform velocity, it is modified slightly. *Modified uniform velocity* smoothes out the roughness slightly by adding a radius at the ends of the high and low points. This radius is equal to 1/3 the rise or fall, Figure 15-11. This radius smooths out the start and stop somewhat, and is good for slow speed.

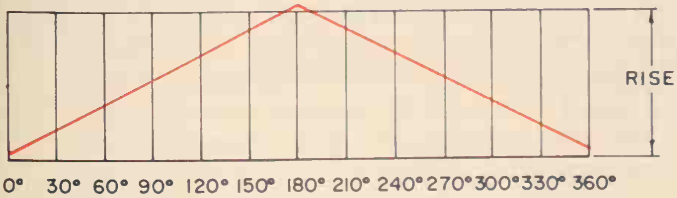


Figure 15-10 Uniform velocity cam

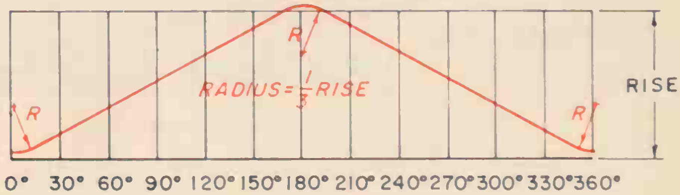


Figure 15-11 Modified uniform velocity cam

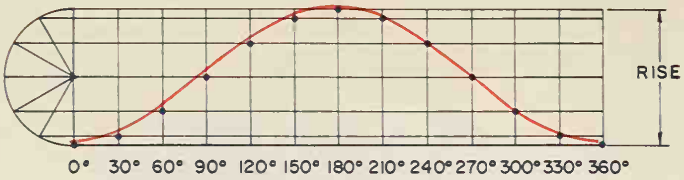


Figure 15-12 Harmonic motion cam

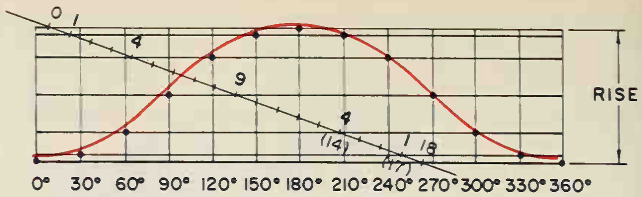


Figure 15-13 Uniform acceleration cam

Harmonic Motion

Harmonic motion is very smooth, but the speed is not uniform. Harmonic motion has a smooth start and stop, and is good for fast speed.

To lay out a harmonic motion on the displacement diagram, draw a semicircle whose diameter is equal to the designed rise or fall. Divide the semicircle into equal divisions; in this example, 30°. Divide the overall horizontal distance of the rise or fall equally into increments of the same number as the semicircle; in this example, 6 equal divisions. Projection points on the semicircle are projected horizontally to the corresponding vertical lines. For example, the first point on the semicircle is projected to the first vertical line, the second point on the semicircle is projected to the second vertical line, and so forth. Connect the curve with an irregular curve. This completes the harmonic curve, Figure 15-12.

Uniform Acceleration

Uniform acceleration is the smoothest motion of all cams, and its speed is constant throughout the cam travel. The uniform acceleration curve is actually a parabolic curve; the first half of the curve is exactly the reverse of the second half. This form is best for high speed.

To lay out a uniform acceleration motion on the displacement diagram, divide the designed rise or fall into 18 equal parts. To do this, place the edge of a scale with its "0" on the starting level of the rise or fall, and equally space 18 units of measure on the high or low elevation of the rise or fall, Figure 15-13. Mark off points 1, 4, 9, 4 (14), and 1 (17), and draw horizontal lines. Note that 14 is actually 4, and 17 is actually 1. Divide the overall horizontal distance of the rise or fall into 12 equal increments. From points 1, 4, 9, 4 (14), and 1 (17), project points to the corresponding vertical lines. For example, the first point is from point 1 on the division line to the first vertical line, and then from point 4 on the division line to the second vertical, and so forth. Connect the curve with an irregular curve. This completes the uniform acceleration curve.

Combination of Motions

The illustrations thus far have covered the four major types of cams: uniform velocity, modified uniform velocity, harmonic motion, and uniform acceleration. Any combinations of these can be designed for a particular function or requirement. Figure 15-14 illustrates a displacement diagram with a 90° fall using a harmonic motion, followed by a 30° dwell. The cam then falls again 90° using a modified uniform velocity followed by a 30° dwell. The cam then rises using uniform acceleration motion followed by another 30° dwell.

Laying Out the Cam from the Displacement Diagram

Regardless of which type of motion is used, the layout process is exactly the same. The working circle is drawn equal to the height of the displacement

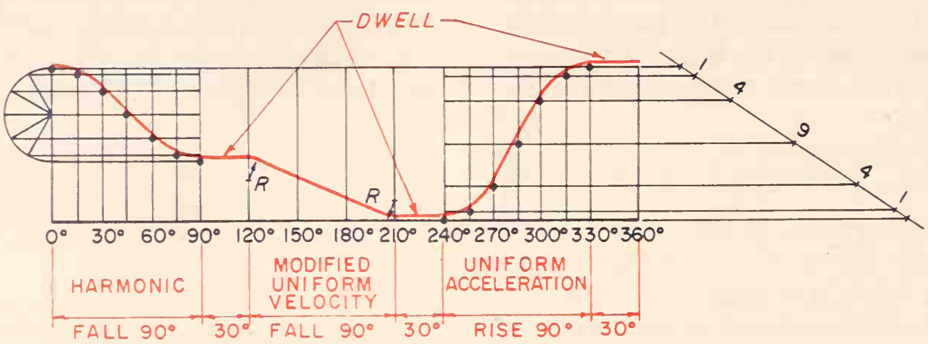


Figure 15-14 Combination of motions

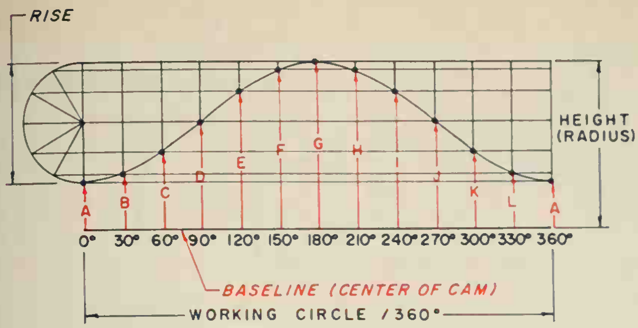


Figure 15-15A Displacement diagram example

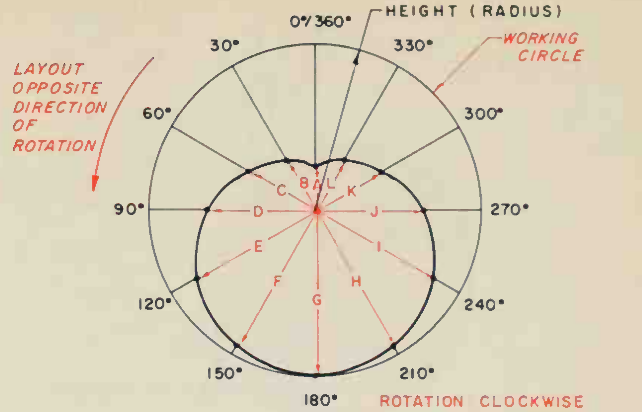


Figure 15-15B Heights transferred from displacement diagram

diagram. The circle of the cam must be divided into the exact same number of equal divisions as the displacement diagram, Figure 15-15A. Label the increments on both the displacement diagram and the working circle of the cam; in this example, harmonic motion is illustrated.

Notice that the even increment on the cam layout is labeled *opposite* of the rotation of the cam. In this example, rotation is clockwise; therefore, the labeling of the radial lines should be counterclockwise. Transfer each distance from the displacement diagram to the corresponding radial line, Figure 15-15B. Using an irregular curve, complete the cam layout.

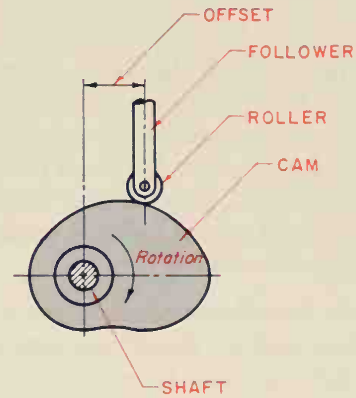


Figure 15-16 Associated cam terms

Offset Follower

The cam follower is usually in line with the same center line as the cam (see Figure 15-1). Occasionally, however, when position or space is a problem, the follower can be designed to be on another center line, or offset as illustrated in Figure 15-16. In order to lay out an offset follower, it is necessary to use slightly different steps than those used for a regular cam.

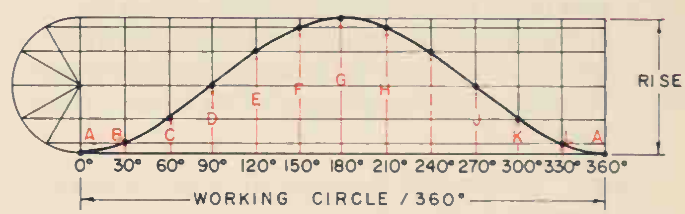


Figure 15-17A Drawing a cam with an offset follower design layout – Step 1

How To Draw a Cam with an Offset Follower

Given: Cam data: harmonic motion cam, follower offset .625, base circle .88 radius, rise of 1.50, shaft diameter .375, direction of rotation: counterclockwise.
Follower data: Follower width .250, roller .375 diameter.

Step 1. Design and lay out a displacement diagram exactly as with any cam, Figure 15-17A.

Step 2. From the center of the shaft of the cam, construct the offset circle. The offset circle has a radius equal to the required follower offset. From the same swing point, lay out the base circle. The radius of the base circle is equal to the distance from the center of the shaft to the center of the follower *wheel* at its *lowest* position, Figure 15-17B.

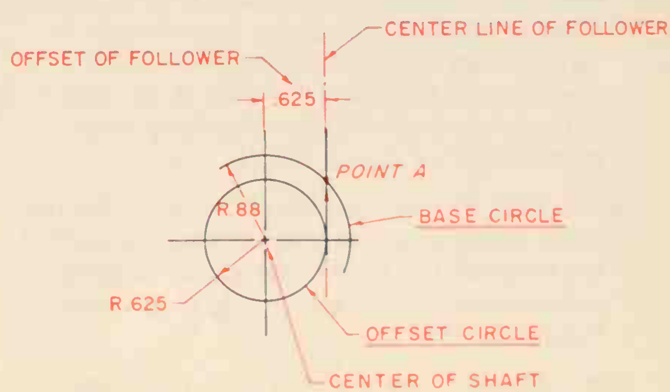


Figure 15-17B Step 2

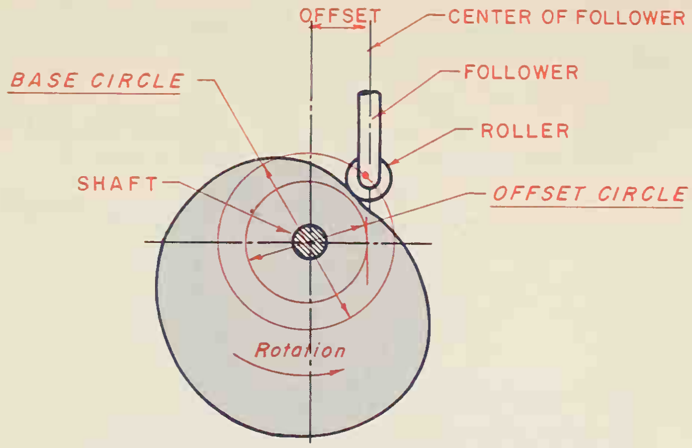


Figure 15-17C Step 3

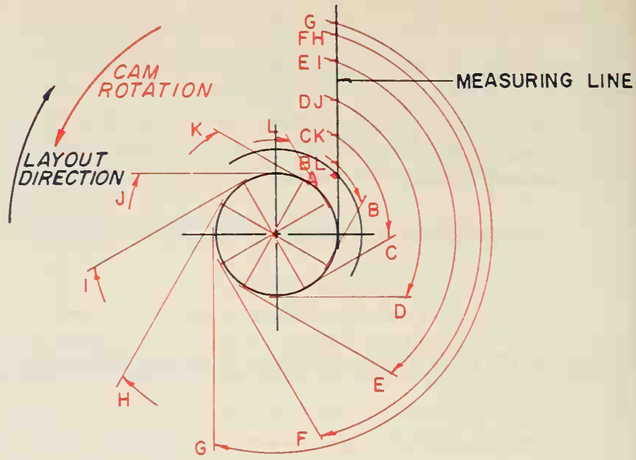


Figure 15-17D Step 4

Step 3. The point where it crosses a constructed vertical line from the center line of the follower is point A on the displacement diagram, Figure 15-17C. This represents the *lowest* position of the follower wheel. This vertical line is the measuring line and will be used to lay out the other points around the cam.

Step 4. Divide the offset circle into the same equal divisions as used on the displacement diagram; in this example, 12 equal parts. Lightly, consecutively, letter or number the divisions on the offset circle. Start at the lowest point of the cam; in this example, point A. Letter or number in a direction *opposite* of the cam rotation. Note that point A is the exact location where the center line of the follower is tangent with the offset circle. Construct a layout projection line 90° from the tangent point of the circle, Figure 15-17D.

Step 5. Transfer the distances from the displacement diagram to the measuring line, lightly letter or number each point. With the compass point on the center of the shaft of the cam, swing these distances to the corresponding radial lines (refer back to Figure 15-17D). Lightly letter or number each point. Do not forget to *lay out the cam opposite to the direction of rotation.* These points represent the path of the center of the follower wheel. Lightly connect these points together, Figure 15-17E.

Step 6. With the compass set at the radius for the roller, lightly draw the roller around the path of the follower. The inside, high points of these arcs represent the actual profile of the cam, Figure 15-17F.

Step 7. Check all construction work. If correct, darken and complete the cam, Figure 15-17G.

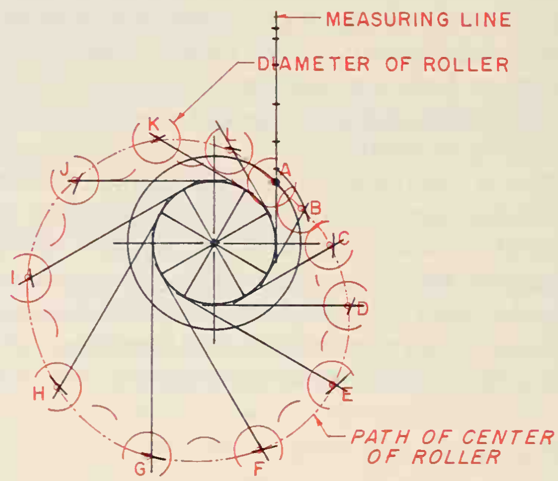


Figure 15-17E Step 5

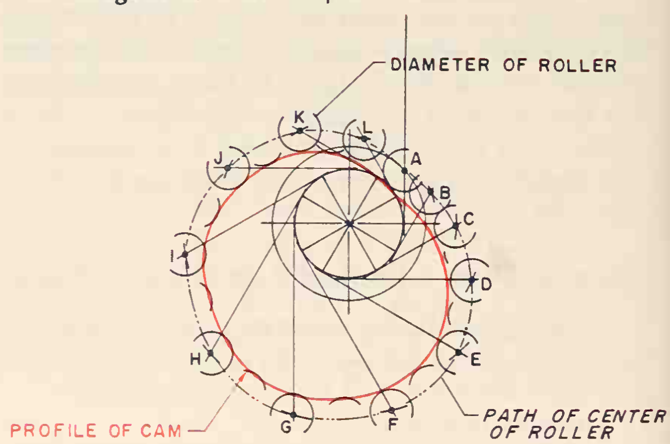


Figure 15-17F Step 6

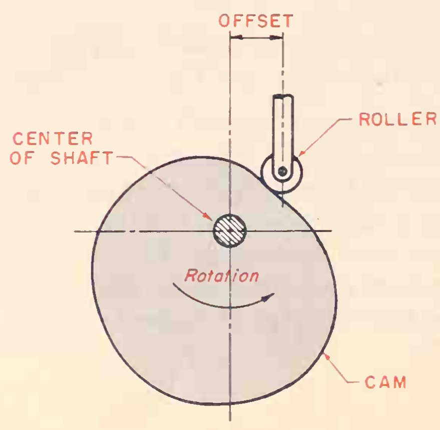


Figure 15-17G Step 7

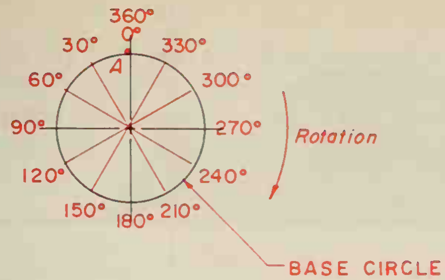


Figure 15-18A Drawing a cam with a flat-faced follower – Step 1

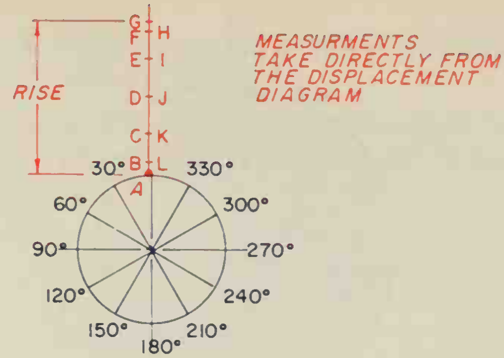


Figure 15-18B Step 2

How To Draw a Cam with a Flat-faced Follower

Given: Cam data: harmonic motion cam, base circle .75 radius, rise of 1.50, shaft diameter .375., direction of rotation: clockwise.
Follower data: flat-faced follower, 1.25 diameter distance across the flat surface.
Design and lay out a displacement diagram exactly as with any cam. In this example, the displacement diagram in Figure 15-17A will be used.

Step 1. Construct the base circle. The base circle is drawn with a radius equal to the distance from the center of the shaft to the face of the follower in its *lowest* position. Divide the base circle into the same equal divisions as used on the displacement diagram. Lightly consecutively letter or number the divisions on the base circle, Figure 15-18A.

Step 2. Locate point A which represents the location of the flat-faced follower at its lowest point. Construct a measuring line starting from the base circle and transfer the distances from the displacement diagram to the measuring line. Letter or number each point, Figure 15-18B. Do not forget to lay out the *cam opposite to the direction of rotation.*

Step 3. Swing these distances to the corresponding radial lines, Figure 15-18C.

Step 4. From these distances, construct lines perpendicular from these radial lines at the point of intersection, Figure 15-18D.

Step 5. Lightly construct the cam within these perpendicular lines, Figure 15-18E.

Step 6. Check all construction work. If correct, darken and complete the cam, Figure 15-18F. Notice the position of the flat-faced follower at the 0°, 90°, and 150° positions.

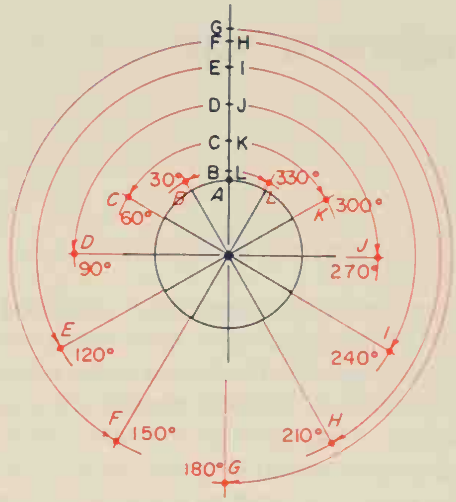


Figure 15-18C Step 3

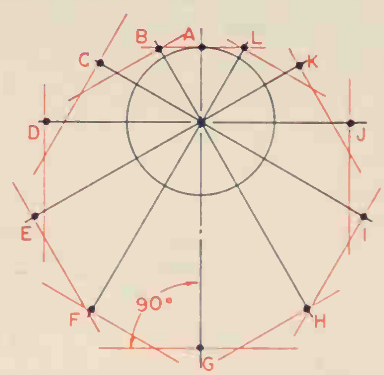


Figure 15-18D Step 4

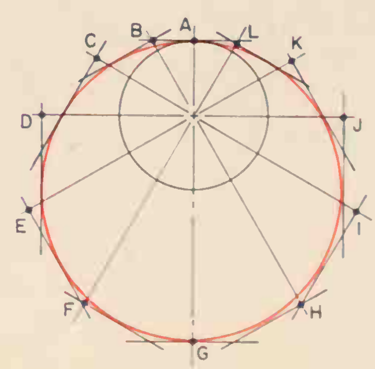


Figure 15-18E Step 5

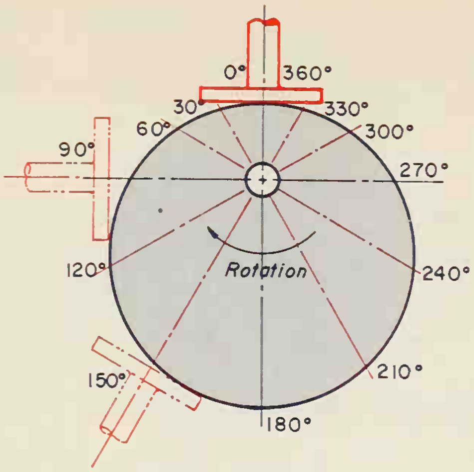


Figure 15-18F Step 6

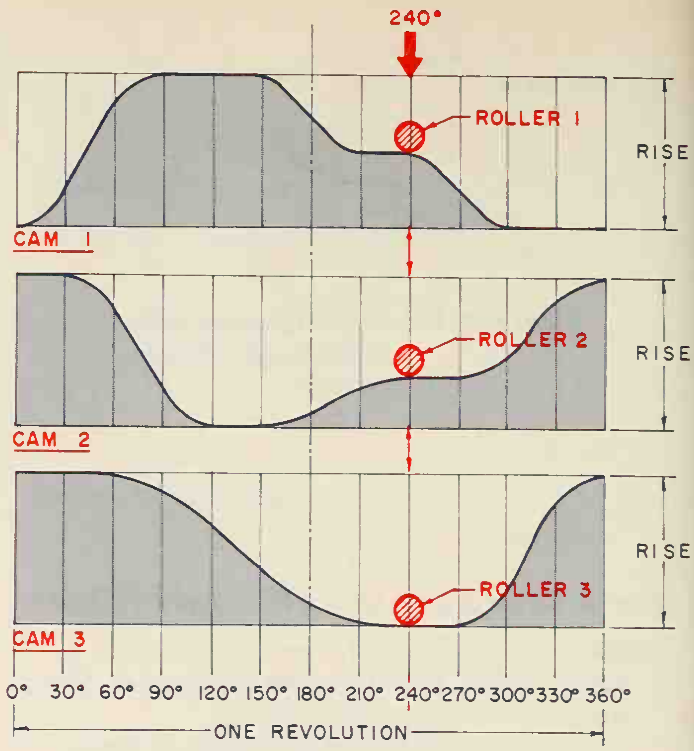


Figure 15-19 Timing diagram

Timing Diagram

Many times, more than one cam is attached to the same shaft. In this case, each cam works independently but must function in relation to the other cams. In order to be able to visualize graphically and study the interaction of the cams on the same shaft, place the various displacement diagrams in a column with the starting points and ending points in line, as illustrated in Figure 15-19. This represents one full revolution and is referred to as a *timing diagram*. For example, at 240° it is easy to visualize the exact position of each cam roller.

Dimensioning a Cam

A cam must be fully dimensioned. The cam size dimensions are constructed radiating from the center of the shaft by both radii length and degrees from the starting point, as illustrated in Figure 15-20. Other important dimensions pertain to the shaft hole size

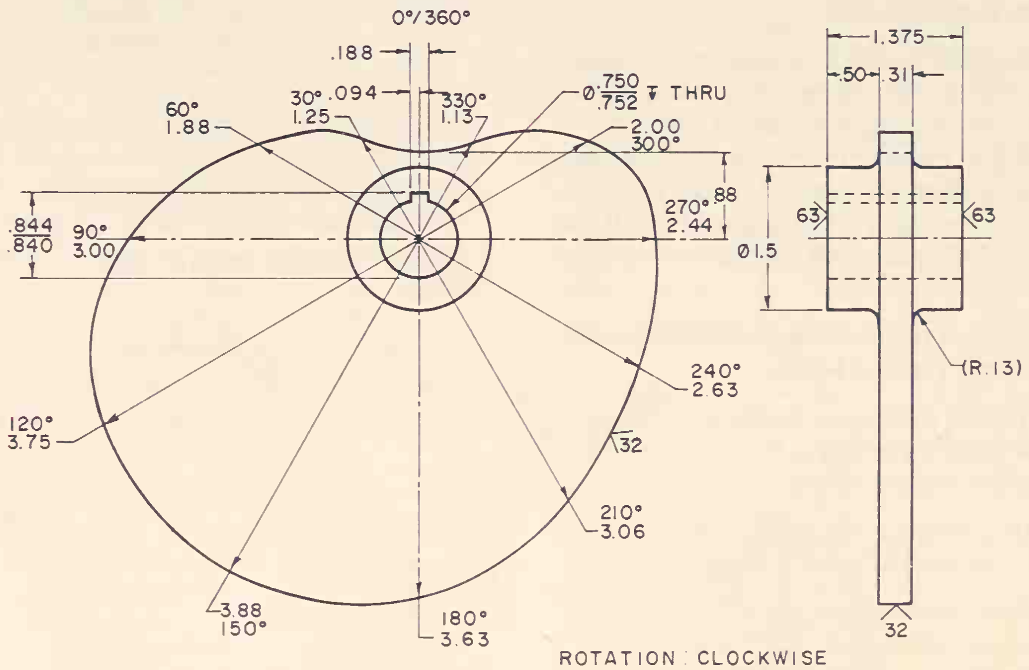


Figure 15-20 Dimensioning a cam

and keyway size, and are dimensioned according to most recent drafting standards.

Try not to place dimensions on the cam itself; place them around the perimeter, if possible.

Review

1. List three examples of uses of a simple cam.
2. What determines the type of follower to be used?
3. List the two major kinds of cams used in industry. Explain the function of each.
4. What is the working circle?
5. Explain what the displacement diagram is and why it is used.
6. What do the length and height of the displacement diagram represent on the actual cam?
7. List the four major types of curves usually used in the design and layout of the cam displacement diagram. Which one gives the smoothest motion?
8. What is meant by an offset follower?
9. Explain why a timing diagram is used.
10. Why is the cam laid out opposite of the direction of rotation?

Chapter Fifteen Problems

The following problems are intended to give the beginning drafter practice in designing and laying out cam displacement diagrams according to the required specifications to do a particular function. The cam displacement diagram will then be transferred to an actual cam profile layout. The drafter will practice laying out uniform velocity, harmonic motion, and uniform acceleration motions.

The steps to follow in laying out cams are:

Step 1. Study all required specifications.

Step 2. Make a rough sketch of the cam displacement diagram incorporating *all* required specifications and required dimensions.

Step 3. Lightly lay out the displacement diagram. Space out horizontally as far as possible.

Step 4. Break down the area into equal spaces that correspond to degrees around the cam. L*abel* each line indicating the degrees.

Step 5. Following the required specifications, lightly develop the cam's travel on the displacement diagram. (Show all light layout work – do not erase.)

Step 6. Check all work.

Step 7. Darken in displacement diagram.

Step 8. To lay out the cam profile, locate the center of the cam.

Step 9. Draw the shaft, hub, working circle, and key, if required, in place.

Step 10. Divide the working circle into equal degrees as required.

Step 11. Note *direction of travel*. Lightly letter the degrees around the working circle *opposite* of direction of travel.

Step 12. Locate the starting elevation and draw the cam follower *from* the starting point.

Step 13. Lightly draw in the rest of the cam, following details as required.

Step 14. Transfer all distances *from* the cam displacement diagram to the corresponding degree line *around* the cam layout.

Step 15. Lightly connect all points using an irregular curve.

Step 16. Check all work.

Step 17. Darken in all work.

Step 18. Neatly add all required specifications and dimensions to the drawing.

The drawing must include the following:

Shaft diameter
Hub size
Key or set screw size
Direction of rotation
Working circle size
All dimensions according to the most recent drafting standards. (For these problems, dimension only the front view.)

Problems 15-1A and 15-1B

Construct a cam displacement diagram on a A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications:

1. Working circle 5.0 dia.
2. Shaft dia. .75
3. Hub dia. 1.25
4. Square key .18
5. Rotation: counterclockwise
6. Follower dia. – 1.0
7. Start 1.0 from center

Required motion:

1. Rise 90°, modified uniform velocity 1.5
2. Dwell 60°
3. Fall 60°, modified uniform velocity .75
4. Dwell 30°
5. Fall 60°, modified uniform velocity .75
6. Dwell 60°

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

Check all work and add all required dimensions and specifications according to the most recent drafting standards.

Problems 15-2A and 15-2B

Construct a cam displacement diagram on an A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications:

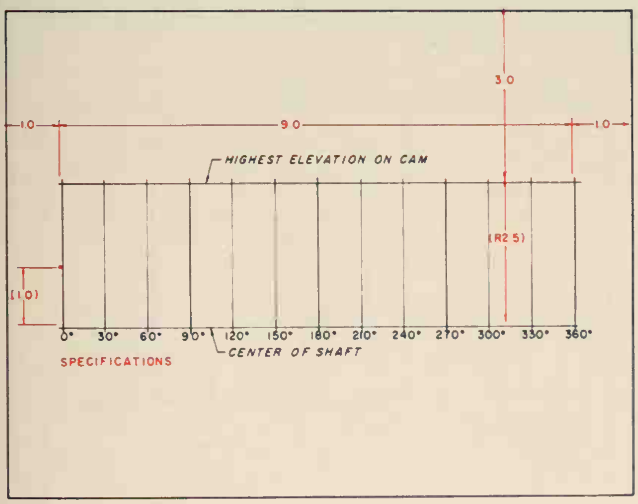
1. Working circle 5.0 dia.
2. Shaft dia. .75
3. Hub dia. 1.25
4. Square key .18
5. Rotation: clockwise
6. Follower dia. 1.0
7. Start 1.0 from center

Required motion:

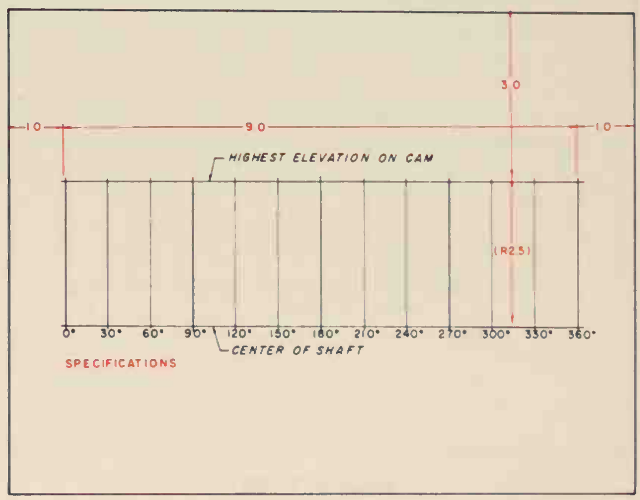
1. Rise 90°, harmonic motion 1.00
2. Dwell 30°
3. Rise 90°, harmonic motion .50
4. Dwell 30°
5. Fall 90°, harmonic motion 1.50
6. Dwell 30°

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

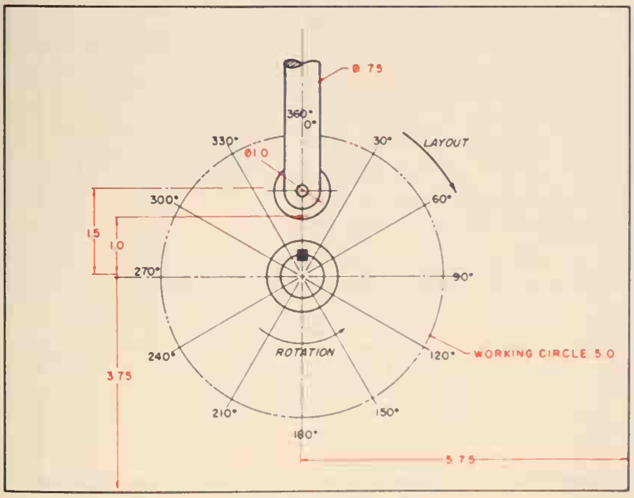
Check all work and add all required dimensions and specifications according to the most recent drafting standards.



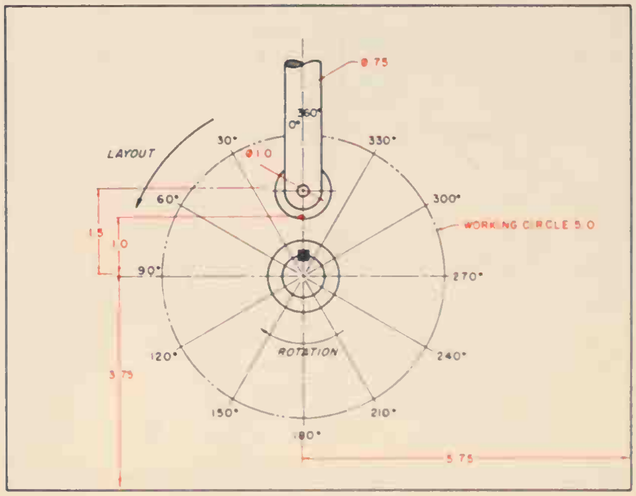
Problem 15-1A



Problem 15-2A



Problem 15-1B



Problem 15-2B

Problems 15-3A and 15-3B

Construct a cam displacement diagram on an A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications:

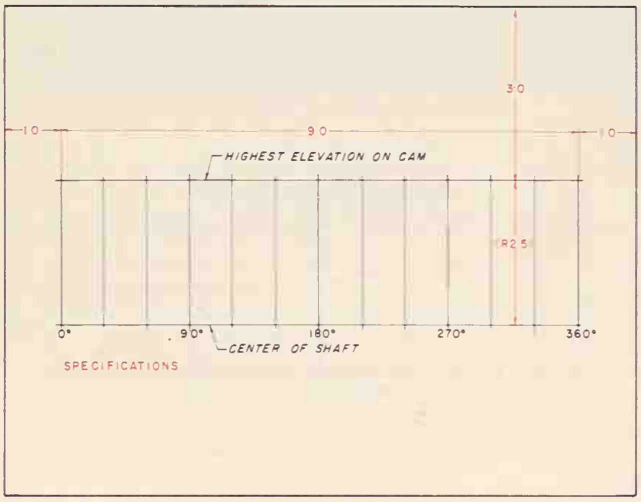
1. Working circle 5.0
2. Shaft dia. .63
3. Hub dia. 1.0
4. Square key to suit
5. Rotation: clockwise
6. Follower dia. .75
7. Start 2.5 from center

Required motion:

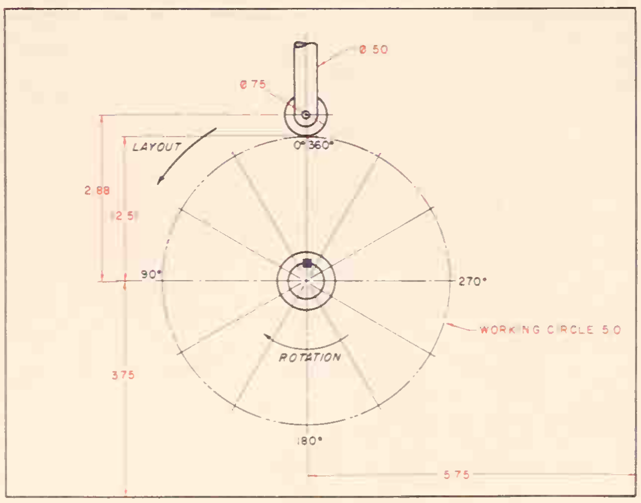
1. Fall 180°, uniform acceleration 1.50
2. Dwell 45°
3. Rise 90°, uniform acceleration 1.50
4. Dwell 45°

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

Check all work and add all required dimensions and specifications according to the most recent drafting standards.



Problem 15-3A



Problem 15-3B

Problems 15-4A and 15-4B

Construct a cam displacement diagram on an A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications (metric):

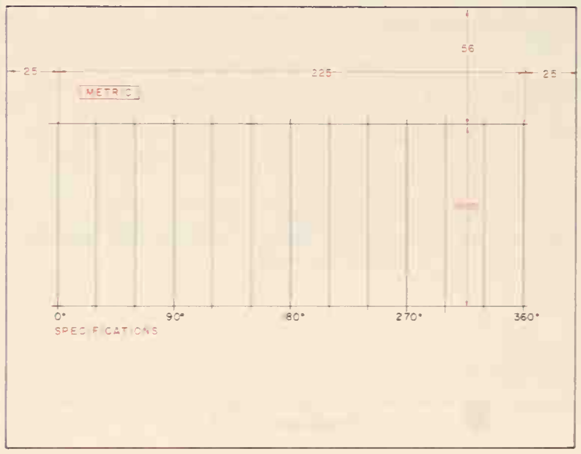
1. Working circle 245
2. Shaft dia. 28
3. Hub dia. 44
4. Square key to suit
5. Rotation: clockwise
6. Follower dia. 22
7. Start 32 from center

Required motion:

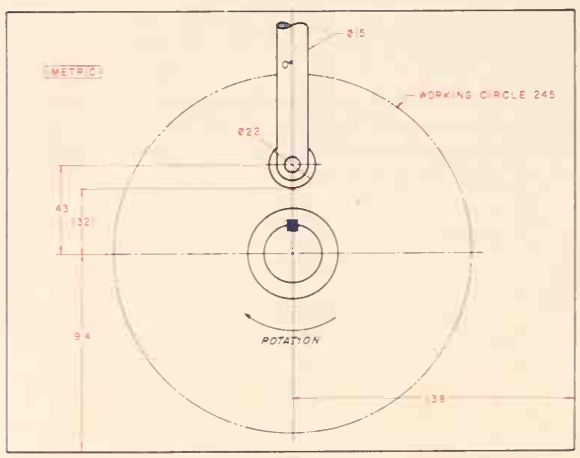
1. Rise 60°, harmonic motion 25
2. Dwell 15°
3. Rise 90°, harmonic motion 38
4. Dwell 15°
5. Fall 45°, harmonic motion 44
6. Dwell 15°
7. Rise 30°, harmonic motion 18
8. Dwell 15°
9. Fall to starting level 75°, harmonic motion 38

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

Check all work and add all required dimensions and specifications according to the most recent drafting standards.



Problem 15-4A



Problem 15-4B

Problems 15-5A and 15-5B

Construct a cam displacement diagram on an A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications:

1. Working circle 7.0
2. Shaft dia. .625
3. Hub dia. 1.0
4. Square key to suit
5. Rotation: counterclockwise
6. Follower dia. 1.0
7. Start 1.0 from center

Required motion:

1. Rise 120°, modified uniform velocity 2.5
2. Dwell 60°
3. Fall 30°, modified uniform velocity .75
4. Dwell 30°
5. Fall to starting level 90°, modified uniform velocity 1.75
6. Dwell 30°

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

Check all work and add all required dimensions and specifications according to the most recent drafting standards.

Problems 15-6A and 15-6B

Construct a cam displacement diagram on an A-size, 8½ × 11 sheet of paper per dimensions given.

Lay out a cam with the following specifications:

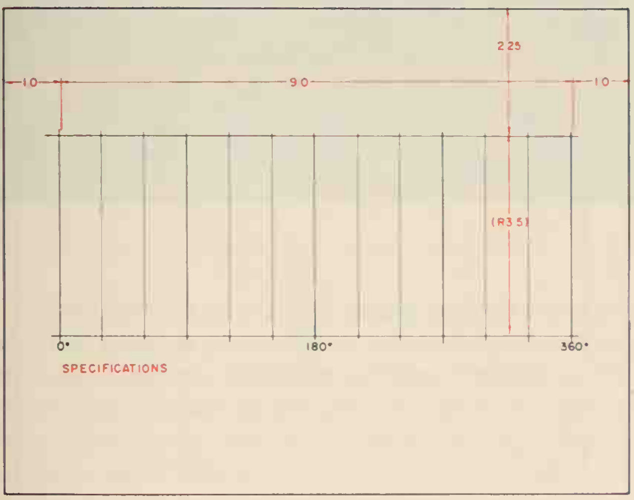
1. Working circle 7.75
2. Shaft dia. .56
3. Hub dia. .88
4. Square key to suit
5. Rotation: clockwise
6. Follower dia. .375
7. Start 1.625 from center

Required motion:

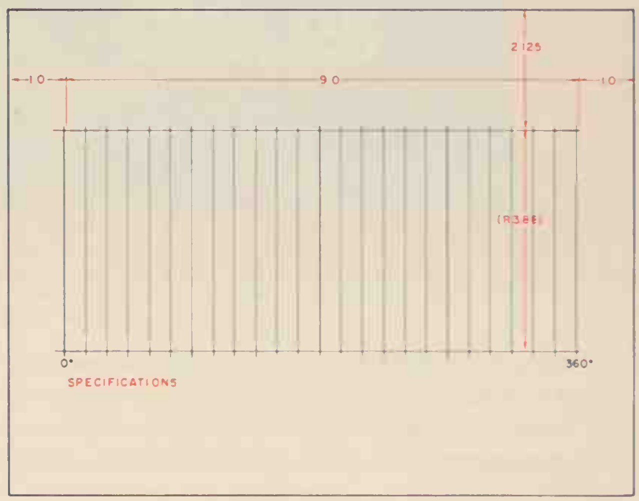
1. Fall 90°, uniform acceleration 3.0
2. Dwell 15°
3. Rise 60°, uniform acceleration 2.0
4. Dwell 105°
5. Rise 90°, uniform acceleration to starting level (1.0)

Construct the cam and follower on an A-size, 8½ × 11 sheet of paper per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

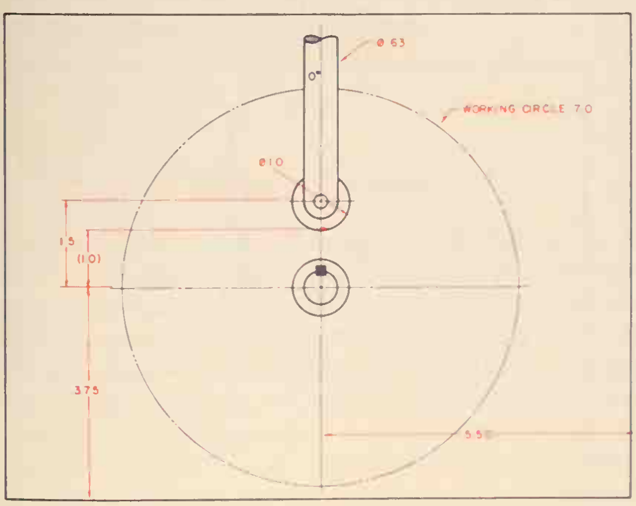
Check all work and add all required dimensions and specifications according to the most recent drafting standards.



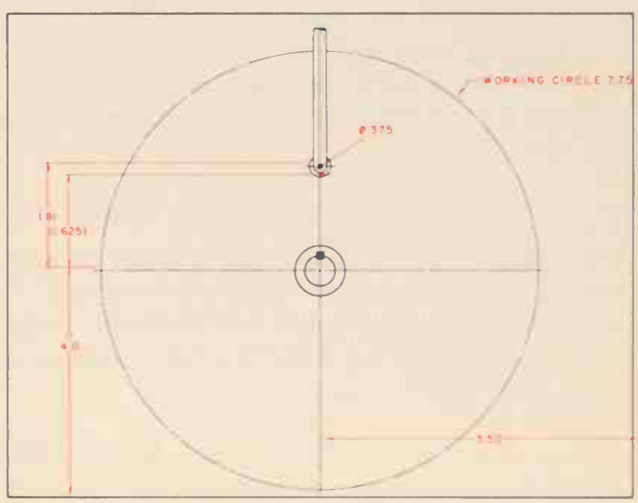
Problem 15-5A



Problem 15-6A



Problem 15-5B



Problem 15-6B

Problems 15-7A and 15-7B

Construct a metric cam displacement diagram per dimensions given:

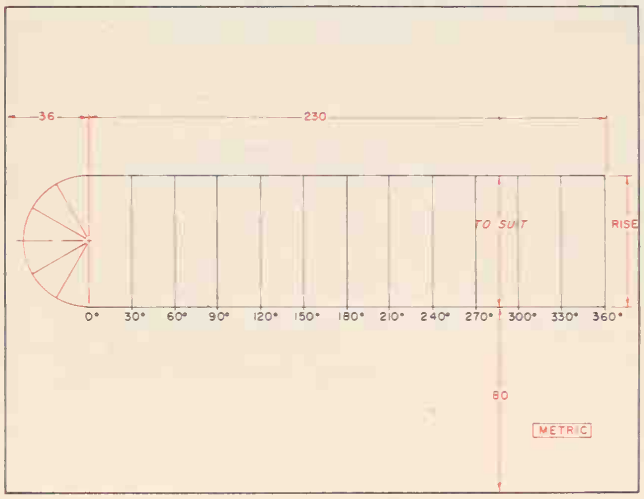
Lay out a cam with the following specifications:

1. Rise/fall 56
2. Shaft dia. 16
3. Hub dia. 32
4. Square key to suit
5. Rotation: clockwise
6. Follower: *flat-faced (34 dia.)
7. Base circle 26 radius
8. Harmonic motion/one full turn

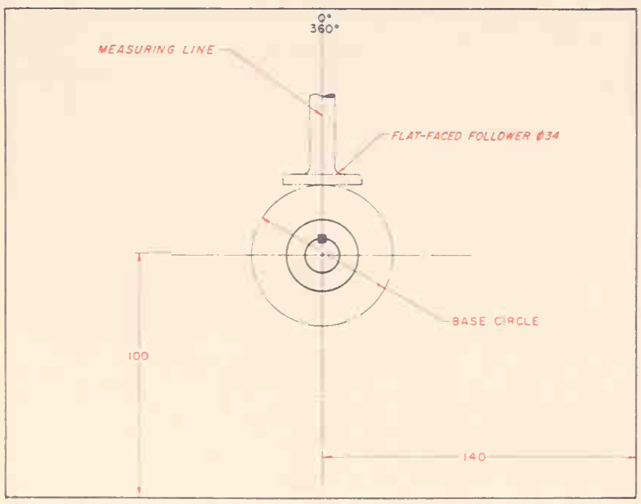
Construct the cam and flat-faced follower per dimensions given.

Check all work and add required dimensions and specifications according to the most recent drafting standards, and using the metric system.

*Design the flat-faced follower to suit.



Problem 15-7A



Problem 15-7B

Problems 15-8A and 15-8B

Construct a cam displacement diagram per dimensions given.

Lay out an offset cam with the following specifications:

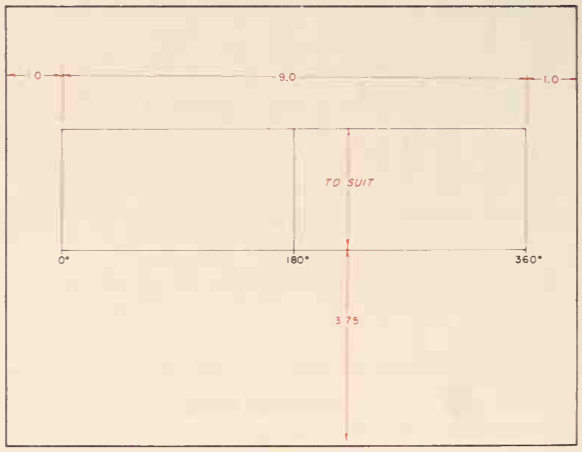
1. Offset circle dia. 2.00
2. Shaft dia. .75
3. Hub dia. 1.25
4. Square key to suit
5. Rotation: clockwise
6. Follower dia. .75
7. Follower offset 1.00
8. Base circle 1.375 radius

Required motion:

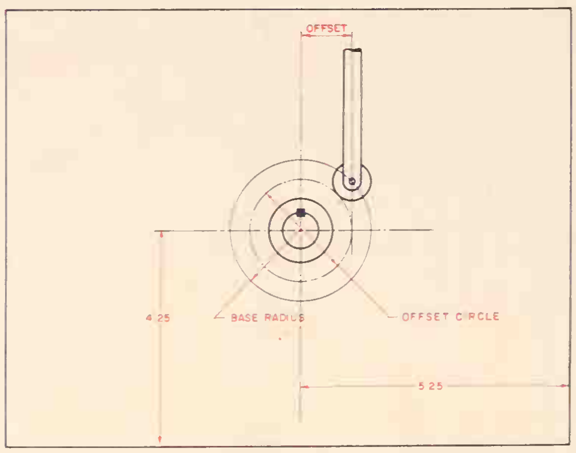
1. Fall 75°, uniform acceleration 1.75
2. Dwell 10°
3. Rise 35°, harmonic motion .75
4. Dwell 5°
5. Fall 70°, modified uniform velocity 1.25
6. Dwell 15°
7. Rise 45°, harmonic motion .75
8. Dwell 15°
9. Rise 60°, uniform acceleration 1.50
10. Dwell 30°

Construct the cam and offset follower per dimensions given, and transfer all dimensions from the displacement diagram to the cam layout.

Check all work and add all required dimensions and specifications according to the most recent drafting standards.



Problem 15-8A



Problem 15-8B

CHAPTER 16

The major kinds of standard gears are explained in this chapter, along with the terms and formulas associated with gears. The major gear types included are: spur gears, pinion gears, helical gears, ring gears, bevel gears, worm gears, and rack and pinion gears. The study of gear ratios and gear chains is covered in order to give the beginning designer the required information to achieve the required ratios.

GEARS

Gears transmit or transfer rotary motion from one shaft to another shaft. Gears can change the direction of rotation, speed up or slow down rotation, increase or reduce power, and change rotary motion into a reciprocating motion. There are various kinds of gears, each with their own function, Figure 16-1.

The drafter must be able to identify each kind of gear, know the various functions of each and be able to design and draw the various gears using correct terminology associated with gears.

Kinds of Gears

Gears are usually classified by the position or location of the shafts they connect. A spur gear, pinion gear or helical gear is usually used to connect shafts that are parallel to each other. Intersecting shafts at 90° are usually connected by a beveled gear or angle gear. Shafts that are not parallel to each other and that do not intersect use a worm and worm gear. In order to connect rotary motion into a reciprocating or back and forth motion, a rack gear and pinion would be used.

Spur Gear

The *spur gear* is the most commonly used gear, Figure 16-2. It is cylindrical in form, with teeth that are cut straight across the face of the gear. All teeth are parallel to the axis of the shaft. The spur gear is usually considered the *driven gear.*

Pinion Gear

The *pinion gear* is exactly like a spur gear but it is usually smaller, and has fewer teeth, Figure 16-2. The pinion gear is normally considered the *drive gear.*

Rack Gear

The *rack gear* is a type of spur gear, but its teeth are in a straight line or flat instead of in a cylindrical form, Figure 16-3. The rack gear is used to transfer circular motion into straight-line motion.

Ring Gear

The *ring gear* is similar to the spur, pinion, and rack gears, except that the teeth are internal, Figure 16-4.

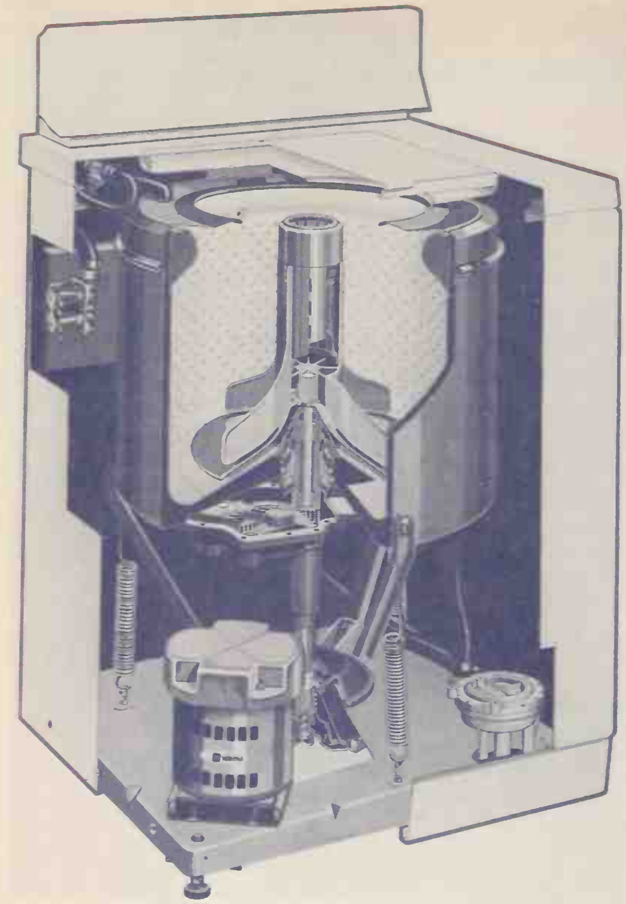


Figure 16-1 Example of gears in use (*Courtesy The Maytag Company*)

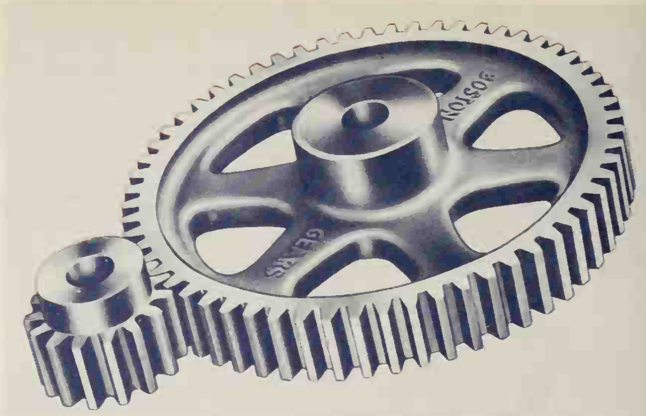


Figure 16-2 Spur gear/pinion gear (*Courtesy Boston Gear*)

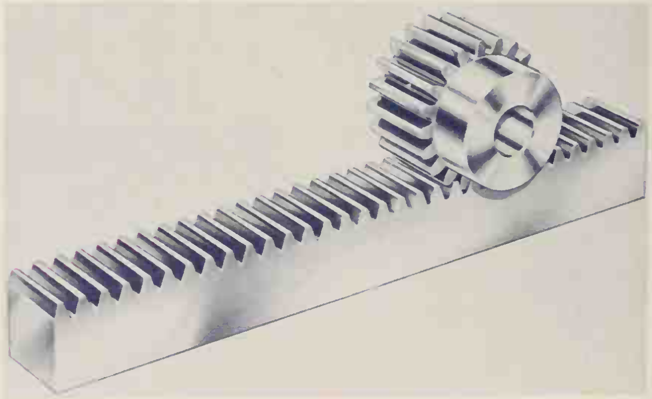


Figure 16-3 Rack gear (*Courtesy Boston Gear*)

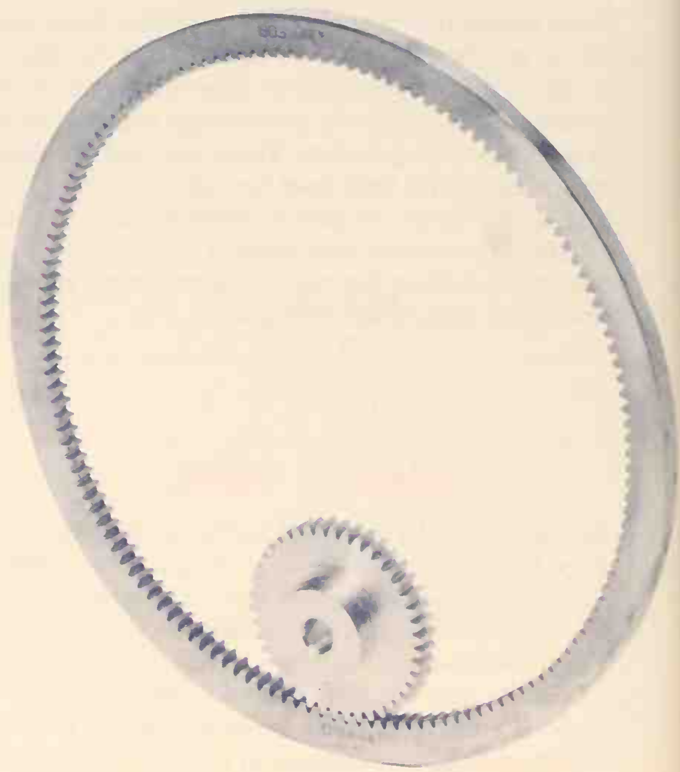


Figure 16-4 Ring gear (*Courtesy Boston Gear*)

Bevel Gear

A bevel gear is another gear commonly used, Figure 16-5. A *bevel gear* is cone shaped in form with straight teeth that are on an angle to the axis of the shaft. Bevel gears are used to transmit power and motion between intersecting shafts that are at 90° to each other.

Angle Gear

The *angle gear* is similar to a bevel gear, except that the angles are at other than 90° to each other.

Miter Gear

The *miter gear* is exactly the same as a bevel gear, except that both mating gears have the same number of teeth. The shafts are at 90° to each other, Figure 16-6.

Spiral Bevel or Miter Gears

Any bevel gears with curved teeth are called *spiral bevel gears*, Figure 16-7.

Worm Gear

Worm gears are used to transmit power and motion at a 90° angle between nonintersecting shafts, Figure 16-8. They are normally used as a speed reducer.

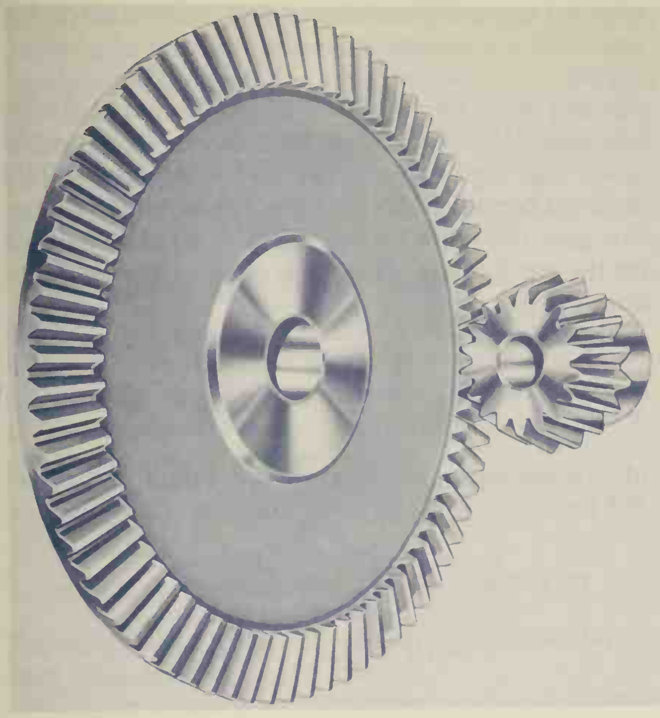


Figure 16-5 Bevel gear (*Courtesy Boston Gear*)

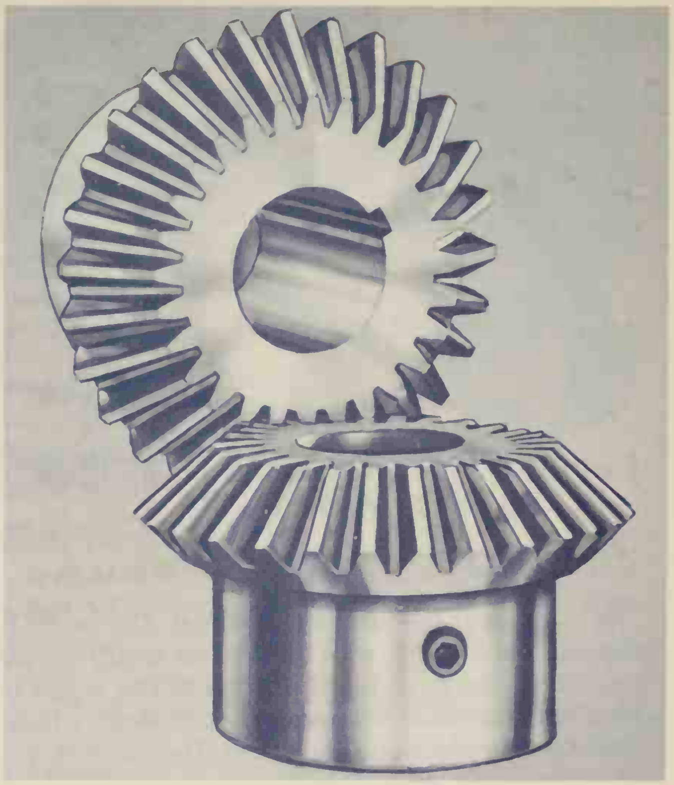


Figure 16-6 Miter gear (*Courtesy Boston Gear*)

Figure 16-7 Spiral bevel gear (*Courtesy Boston Gear*)

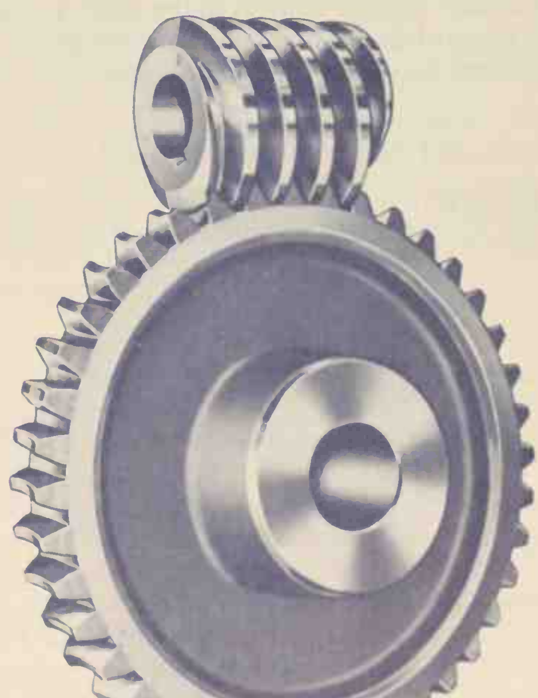


Figure 16-8 Worm gear (*Courtesy Boston Gear*)

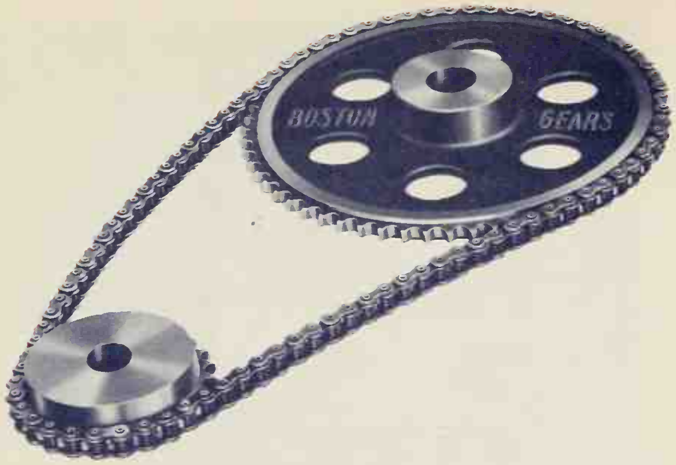


Figure 16-9 Chain and sprockets (*Courtesy Boston Gear*)

The worm gear is round like a wheel. The worm is shaped like a screw, with threads (or teeth) wound around it. Because one full turn of the worm is required to advance the worm gear one tooth, a high-ratio speed reduction is achieved. The worm drives the larger worm gear.

Chain and Sprockets

A *chain and sprockets* are used to transmit motion and power to shafts that are parallel to each other, Figure 16-9. Sprockets are similar to spur and pinion gears, as the teeth are cut straight across the face of the sprocket and are parallel to the shaft. There are many types of chains and sprockets, but all use the same terms, formulas, ratios, and so forth.

Velocity of Feet Per Minute (F.P.M.)

A gear is very similar to a simple wheel. In the field of horology (the science of measuring time), a gear is referred to as a wheel. In making calculations for a gear, it is sometimes easier to think of it as a wheel. Figure 16-10 illustrates the relationship of the diameter of a wheel to given revolutions per minute (R.P.M.) and time. Velocity is calculated by recording the distance that a given point on a wheel or gear travels during a certain period of time. To calculate velocity of a gear, the point is usually assumed to be located on the pitch circle. The pitch circle is discussed in detail later.

The formula is:

$$\pi \text{Dia.} \times \text{R.P.M.} \times \text{Time} = \text{Distance}$$

In this example, point a on the wheel will travel 785 feet.

$$\pi 2.0 \text{ Dia.} \times 500 \text{ R.P.M.} \times 3 \text{ Min.} = \text{Distance}$$
$$6.28 \times 500 \times 3 = 9420 \text{ inches}$$
$$9420 \text{ inches} = 785 \text{ feet}$$

If two wheels of the exact same diameter are placed together, as illustrated in Figure 16-11, and assuming there is no slippage, point a on wheel A will travel the exact same distance as point b on wheel B. Notice, wheel a is rotating clockwise, and wheel B is rotating counterclockwise. If wheel A is rotated at 500 R.P.M. for 3 minutes point a will travel 785 feet.

Gear Ratio

If two friction wheels of different diameters are placed together, Figure 16-12, and assuming there is no slippage, point a on wheel A will travel the same distance as point b on wheel B. In this example, wheel A is the driver.

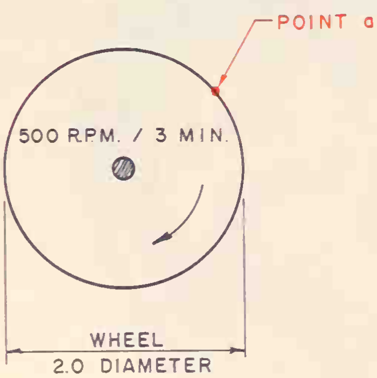


Figure 16-10
Relationship of diameter of a wheel to given revolutions per minute and time

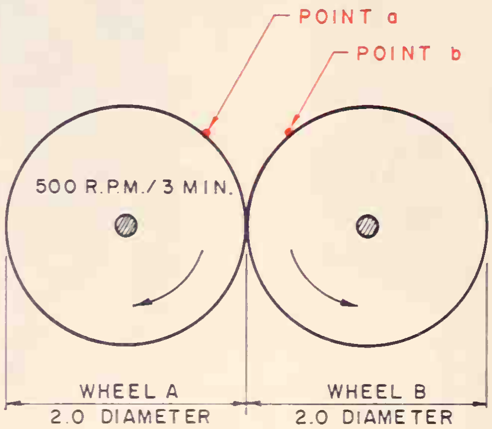


Figure 16-11
Relationship of two wheels of the exact same diameters

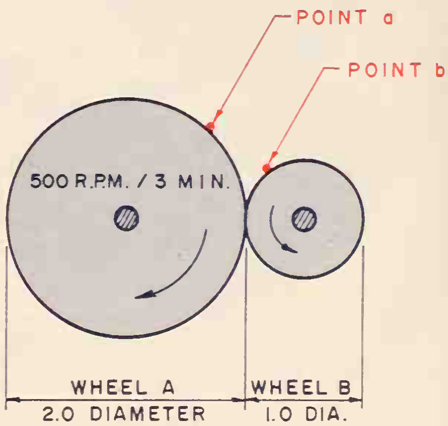


Figure 16-12
Relationship of two wheels of different diameters

π Diameter × revolutions per minute × time = distance

WHEEL A	**WHEEL B**
πDia. × R.P.M. × time =	πDia. × R.P.M. × time
π2.0 Dia. × 500 R.P.M. × 3 min. =	π1.0 Dia. × ? R.P.M. × 3 min.
6.28 × 500 × 3 = 9420 =	3.14 × 3 = 9.42

9420 ÷ 9.42 = 1000 R.P.M. of Wheel B

Wheel A has a 2.0 diameter and turns at 500 R.P.M. Wheel B has a diameter of half of wheel A, but turns twice as fast, thus point a and point b travel the exact same distance. Note that both wheel A and wheel B travel at the same velocity.

The *ratio* between gears is:

$$\frac{\text{Diameter, wheel A}}{\text{Diameter, wheel B}} = \frac{2}{1} = 2{:}1$$

The ratio of 2:1 means that wheel B rotates two times each time wheel A rotates once.

The ratio of one gear to another can be calculated by using any of three different methods: the number of teeth of corresponding gears, pitch diameters of corresponding gears, or the R.P.M. between the gears.

Method 1

To find the ratio, divide the number of teeth on the spur gear by the number of teeth on the pinion gear:

$$\frac{\text{Number of teeth (spur gear)}}{\text{Number of teeth (pinion gear)}} = \text{Ratio}$$

Example:

If a spur gear has 60 teeth and a pinion gear has 30 teeth, the ratio would be:

$$\frac{\text{Number of teeth (spur gear)}}{\text{Number of teeth (pinion gear)}} = \frac{60}{30} = 2{:}1$$

The pinion gear will rotate two times for each full revolution of the spur gear.

Method 2

To find the ratio, divide the pitch diameter (D) of the spur gear by the pitch diameter (D) of the pinion gear:

$$\frac{\text{Pitch Diameter (D) (spur gear)}}{\text{Pitch Diameter (D) (pinion gear)}} = \text{Ratio}$$

Example:

If a spur gear has a pitch diameter (P.D.) of 4.000 and a pinion gear has a pitch diameter (P.D.) of 1.000, the ratio would be:

$$\frac{\text{P.D. (spur gear)}}{\text{P.D. (pinion gear)}} = \frac{4.000}{1.000} = 4{:}1$$

The pinion gear will rotate four times for each full revolution of the spur gear.

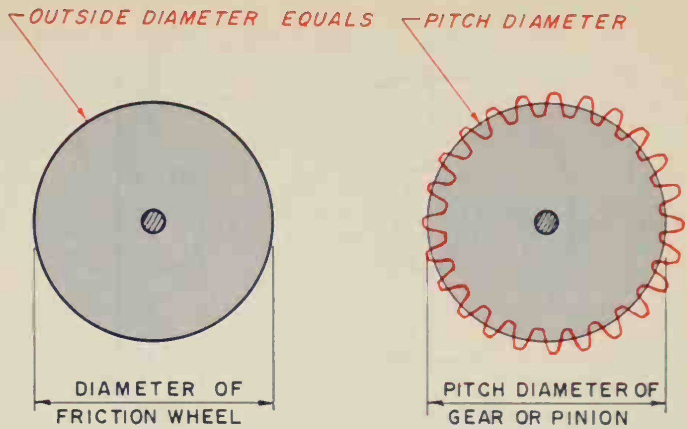


Figure 16-13 Pitch diameter of a gear

Method 3

To find the ratio, divide the revolutions per minute (R.P.M.) of the pinion gear by the R.P.M. of the spur gear:

$$\frac{\text{R.P.M. (pinion gear)}}{\text{R.P.M. (spur gear)}} = \text{Ratio}$$

Example:

If a pinion gear rotates at 1000 R.P.M. and a spur gear rotates at 200 R.P.M., the ratio would be:

$$\frac{\text{R.P.M. (pinion gear)}}{\text{R.P.M. (spur gear)}} = \frac{1000}{200} = 5{:}1$$

The pinion gear will rotate five times for each full revolution of the spur gear.

Pitch Diameter

Think of the pitch diamter of a gear as the outside diameter of the friction wheel, Figure 6-13. All ratios as discussed so far with the friction wheel apply also to gears. To apply formulas, substitute the outside diameter of the friction wheel for the pitch diameter of the gear.

Gear Blank

Gears are usually cut from a gear blank. The gear blank must allow sufficient space for the gears and a method to attach the gear to the shaft. Illustrated in Figure 16-14 is a common gear blank with an outside diameter and face width for the gears to be cut into, a hub, and a hole for the set screw to secure the gear blank to the shaft. A half-section is used to illustrate the gear blank in this example. Two complete sets of dimensions must be applied to the gear drawing: those relating to the gear blank, as illustrated, and those relating to the teeth. Gear dimensions do not hold tight tolerancing, but all gear tooth dimensions must hold very tight tolerancing.

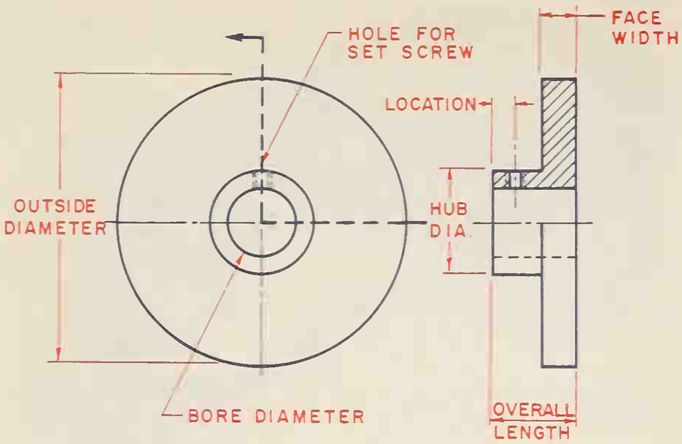


Figure 16-14 Gear blank

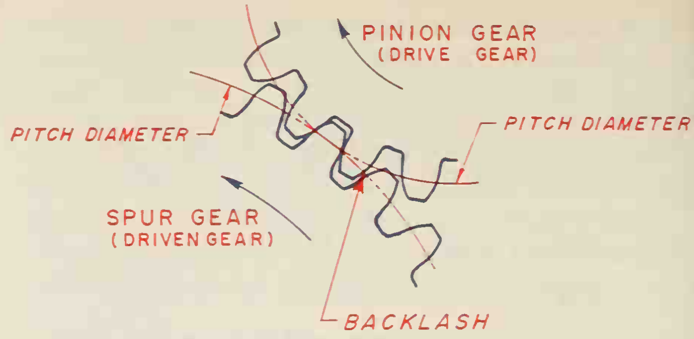


Figure 16-15 Backlash

Backlash

Backlash is the amount by which the gear tooth is less than the tooth space. It is measured by locking one gear and rocking the other back and forth, and measuring that rock at a known radius, usually the pitch diameter. The amount of backlash is the shortest distance between mating teeth as measured between the nondriving surfaces of adjacent teeth. Figure 16-15.

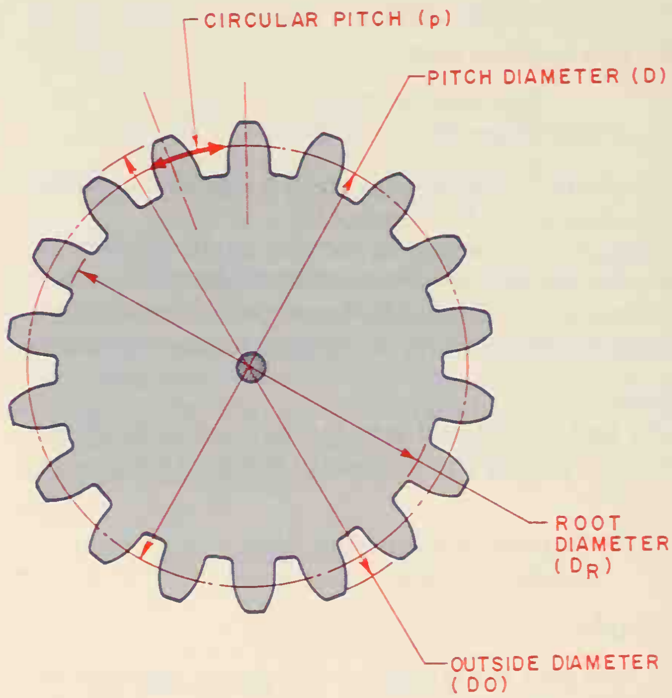


Figure 16-16 Basic gear terminology

Basic Terminology

The drafter must know and understand all major terms associated with various kinds of gears used today in industry. Illustrated in Figure 16-16 are the basic terms associated with most gears, regardless of type.

Pitch Diameter (D)

The *pitch diameter* is the theoretical circle on which the teeth of mating gear mesh. Think of the pitch diameter on the gear as being the same as the outer diameter on the friction wheel. Note: The pitch diameter is considered the *nominal* size of the gear.

Root Diameter (DR)

The *root diameter* is the measurement over the extreme inner edges of teeth. It is equal to the pitch diameter minus 2 times the dedendum (b).

Outside Diameter (OD)

The *outside diameter* is the measurement over the extreme outer edge of teeth. It is equal to the pitch diameter, plus 2 times the addendum (a).

Circular Pitch (p)

Circular pitch is the distance between corresponding points of adjacent teeth measured on the circumference of the pitch diameter.

Figure 16-17 illustrates the major terms associated with individual gears. There are many more technical terms associated with the actual form and cutting of gear teeth, but the following terms are the ones the drafter should be familiar with.

Working Depth (hk)

The *working depth* is the distance that a tooth projects into the mating space. It is equal to gear addendum (a) plus pinion addendum (a).

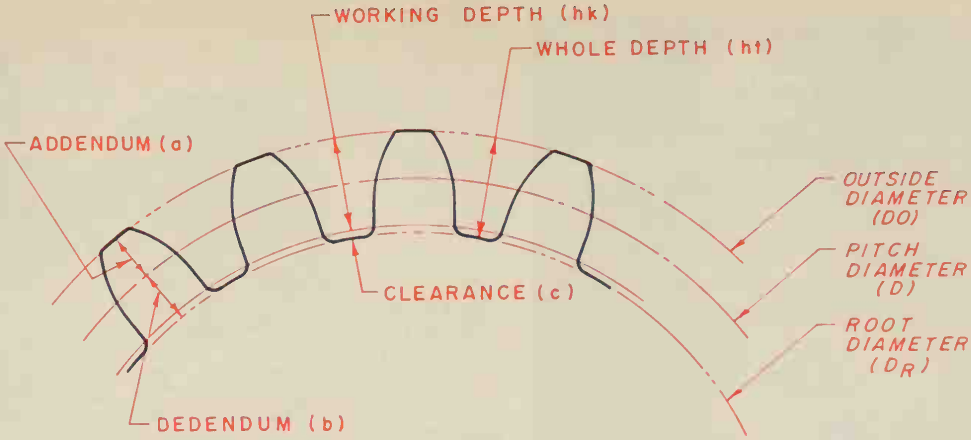


Figure 16-17 Major gear terms

Addendum (a)

The *addendum* is the radial distance from the pitch diameter to the top of the tooth. It is equal to $\frac{1}{P}$.

Dedendum (b)

The *dedendum* is the radial distance from the pitch diameter to the bottom of the tooth. It is equal to $\frac{1.157}{P}$.

Clearance (c)

Clearance is the space between the working depth and the whole depth. It is equal to dedendum (b) minus addendum (a).

Whole Depth (ht)

The *whole depth* is the total depth of a tooth space. It is equal to the addendum (a), plus the dedendum (b), plus the clearance (c).

Note: All notations in parentheses ( ) correspond to those used in the most recent edition of *Machinery's Handbook* so that they agree if a more detailed formula is required by the drafter.

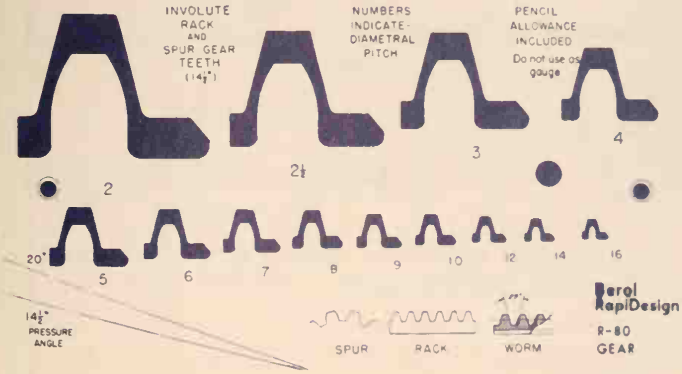


Figure 16-18 Gear template – spur/rack/worm (*Courtesy Modern School Supply*)

Diametral Pitch (P)

Diametral pitch (P) is a ratio equal to the number of teeth on the gear per inch of pitch diameter (D).

$$\text{Diametral pitch (P)} = \frac{\text{Number of teeth (N)}}{\text{Pitch diameter (D)}}$$

Example:

A gear with 48 teeth on a 3.0 pitch diameter (D) would have a diametral pitch (P) of 16.

$$P = \frac{N}{D} = \frac{48}{3.0} = 16$$

Gear Template

A quick and efficient method of illustrating teeth is by using a gear template, Figure 16-18. When using a gear template, the drafter must first calculate the diametral pitch (P). The numbers next to each tooth indicate the diametral pitch. The *lower* part of the template opening is used to draw spur gear *teeth*. The *top* portion of the opening is used to draw teeth of a *rack* or *worm*.

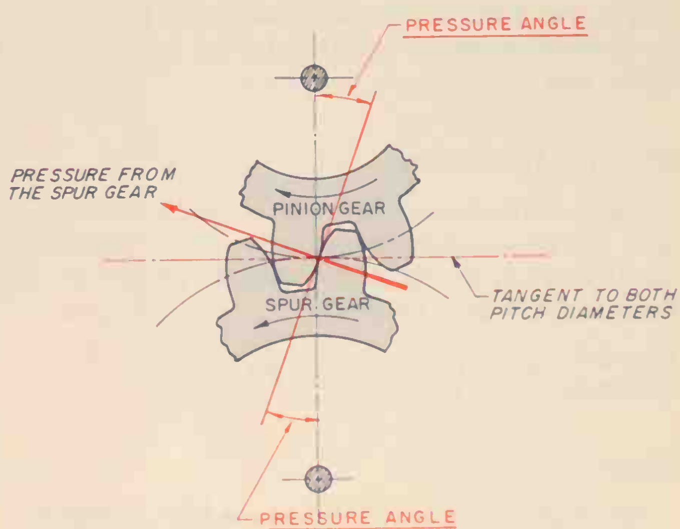


Figure 16-19 Pressure angle

Pressure Angle

The pressure angle determines the tooth form, Figure 16-19. The *pressure angle* is the angle at which pressure from the driver gear tooth passes to the tooth of the driven gear. The standard pressure angle is either 14½° or 20°. The 14½° pressure angle is still popular, especially when replacing old machinery, and because it is quiet. The 20° pressure angle is stronger, due to the heavier tooth section at the base of the tooth form.

Center-to-Center Distances

Calculating the center-to-center distance between two friction wheels is a simple math problem, Figure 16-20.

$$\text{Center-to-center distance} = \frac{\textbf{Outside diameter of wheel A} + \textbf{Outside diameter of wheel B}}{2}$$

In this example, $\frac{2.0 + 1.0}{2} = 1.5$ center-to-center distance

The exact same formula applies to a gear and pinion, except that the pitch diameter (D) is used in place of the outside diameter (OD). Refer to Figure 16-21.

$$\text{Center-to-center distance} = \frac{\textbf{Pitch diameter of gear} + \textbf{Pitch diameter of pinion}}{2}$$

Measurements Required to Use a Gear Tooth Caliper

A *gear tooth caliper* is used to check and measure an individual gear tooth. In order to use a gear tooth caliper, two parts of the individual tooth are used: the chordal thickness and the chordal addendum, Figure 16-22.

Chordal Thickness

The *chordal thickness* is the length of the chord measured straight across at the pitch diameter. It is measured straight across tooth, not along the pitch diameter as is the circular thickness.

$$\textbf{Chordal thickness} = \text{Sin}\left(\frac{90°}{N}\right) \times \text{Pitch dia.}$$

Chordal Addendum

The *chordal addendum* is the distance from the top of the tooth to the point at which the chordal thickness is measured.

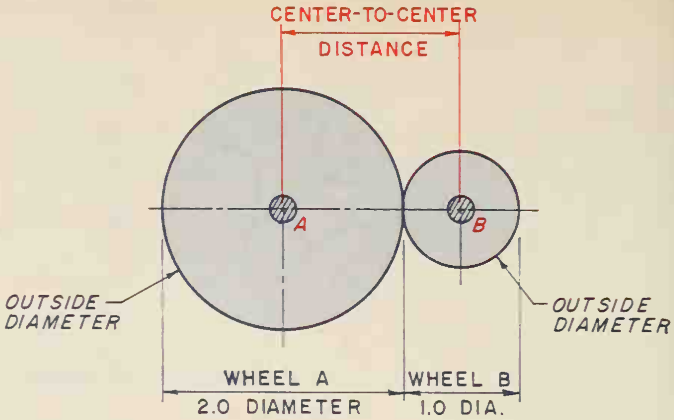


Figure 16-20 Center-to-center distances of two wheels

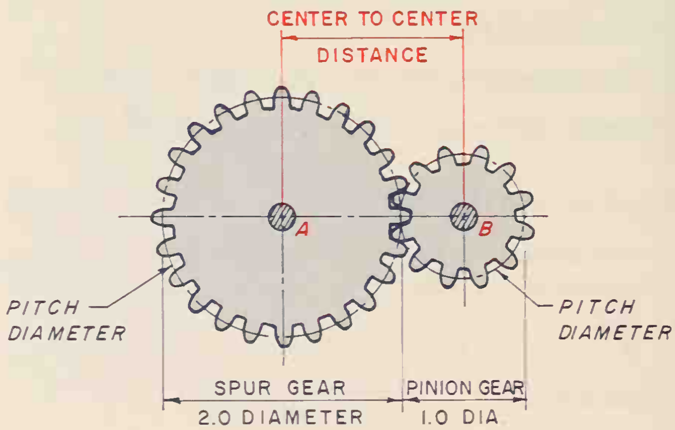


Figure 16-21 Center-to-center distances of two gears

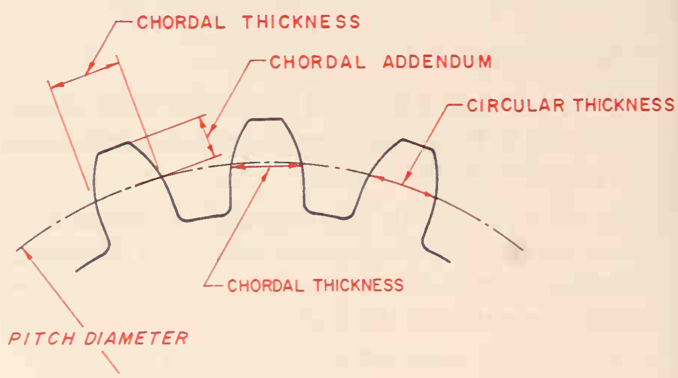


Figure 16-22 Measurements required to use a gear tooth caliper

$$\textbf{Chordal addendum} = \left[1 - \text{Cos}\left(\frac{90°}{N}\right)\right] \times \frac{\text{Pitch dia.}}{2} + \text{addendum}$$

Figures 16-23 and 16-24 show a gear tooth vernier caliper and how it is used.

Required Tooth-Cutting Data

Overall gear blank dimensions are shown on the detail drawing (as illustrated in Figure 16-15) and can

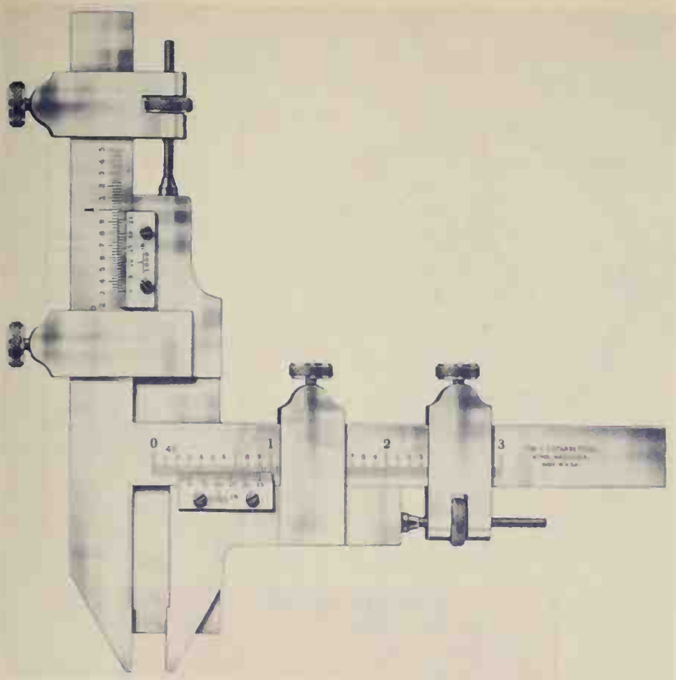


Figure 16-23 Gear tooth caliper (*Courtesy* L. S. *Starrett Co.*)

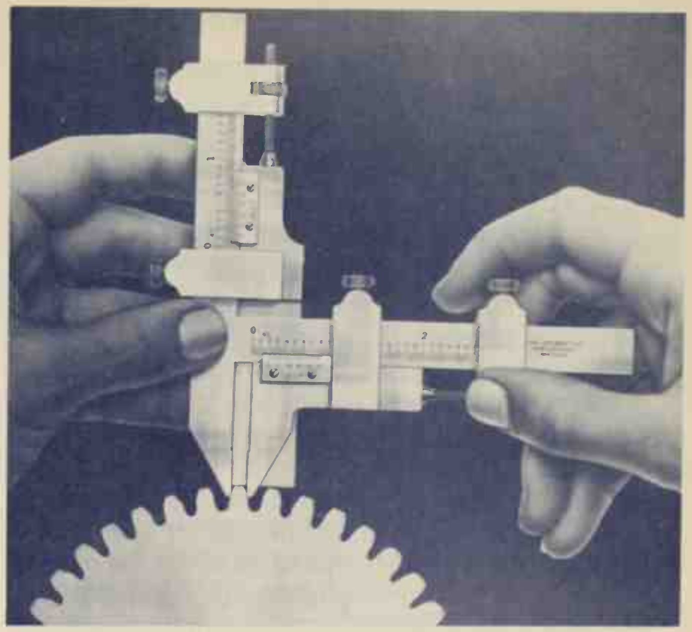


Figure 16-24 Using a gear tooth caliper (*Courtesy* L. S. *Starrett Co.*)

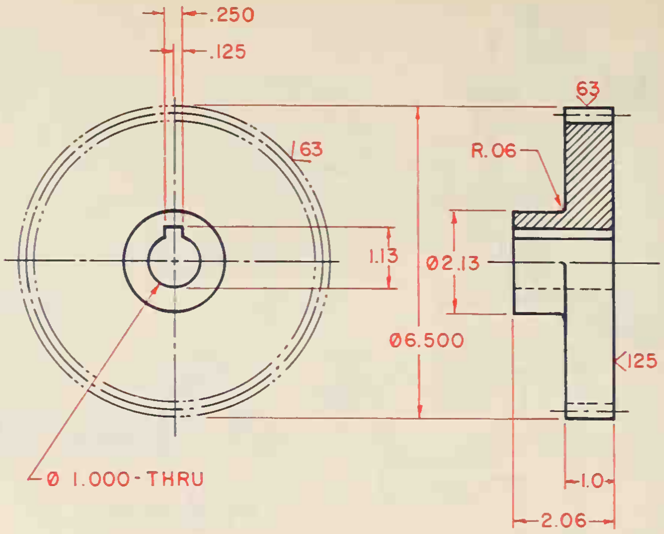
REQUIRED CUTTING DATA			
ITEM	TO FIND:	HAVING	FORMULA
1	Number of teeth (N)	D & P	D x P
		DO & P	(DO x P) - 2
2	Diametral pitch (P)	p	$\frac{3.1416}{p}$
		D & N	$\frac{N}{D}$
		DO & N	$\frac{N+2}{DO}$
3	Pressure angle (Ø)	–	20° STANDARD 14°-30' OLD STANDARD
4	Pitch diameter (D)	N & P	$\frac{N}{P}$
		N & DO	$\frac{N \times DO}{N+2}$
		DO & P	$DO - \frac{2}{P}$
5	Whole depth (ht)	a & b	a + b
		P	$\frac{2.157}{P}$
6	Outside diameter (DO)	N & P	$\frac{N+2}{P}$
		D & P	$D + \frac{2}{P}$
		D & N	$\frac{(N+2) \times D}{N}$
7	Addendum (a)	P	$\frac{1}{P}$
8	Working depth (hk)	a	2 x a
		P	$\frac{2}{P}$
9	Circular thickness (t)	P	$\frac{3.1416}{2 \times P}$
10	Chordal thickness	N,D & a	$\sin\left(\frac{90°}{N}\right) \times D$
11	Chordal addendum	N,D & a	$\left[1 - \cos\left(\frac{90°}{N}\right)\right] \times \frac{D}{2} + a$
12	Dedendum (b)	P	$\frac{1.157}{P}$

Figure 16-25 Required tooth-cutting data for spur and pinion gears

hold loose tolerancing. The actual gear dimensions must hold tight tolerancing.

Twelve essential items of information must be calculated and listed on the gear detail drawing. This list is usually located at the lower right-hand side of the drawing, and generally consists of the data in Figure 16-25, but these items may vary slightly from company to company. The required material, heat-treating process, and other important information must also be included, usually in the title block.

In actual practice, the gear teeth are *not* drawn as it takes too much drawing time. A simplified method is used to illustrate the actual gear tooth, similar to that used to illustrate threads of a fastener, Figure 16-26. The outside diameter and the root diameter are illustrated by a thin phantom line. The pitch diameter is illustrated by a thin center line. Actual teeth are not drawn, except to illustrate some special feature in relationship to a tooth, a spline, a keyway or a locating point. In this example, all dimensions in color are related to the gear blank only. All gear dimensions are called-off in the cutting data box underneath.



CUTTING DATA	
NUMBER OF TEETH	24
DIAMETRAL PITCH	4
PRESSURE ANGLE	20°
PITCH DIAMETER	6.000
WHOLE DEPTH	0.5393
OUTSIDE DIAMETER	6.500
ADDENDUM	.250
WORKING DEPTH	.500
CIRCULAR THICKNESS	.3925
CHORDAL THICKNESS	.2566
CHORDAL ADDENDUM	.3924
DEDENDUM	.289

Figure 16-26 Example of a spur gear detail drawing

Rack

A *rack* is simply a gear with teeth formed on a flat surface, Figure 16-27. A rack changes rotary motion into reciprocating motion. All terms and formulas associated with spur and pinion gears apply to the rack. The sides of the teeth are *straight*, not involute as on a spur gear. The teeth are inclined at the same angle as the pressure angle of the mating pinion gear. Note that the circular pitch of the pinion gear is the same as the linear pitch of the rack. All dimensions for heights of depth, pitch, and addendum lines are calculated from a datum or reference line. The rack is usually manufactured out of rectangular stock but, occasionally, is manufactured out of round stock to meet a specific design.

Two methods can be used to obtain full meshing of the pinion and the rack:

1. The rack is cut down so that it has less backlash.
2. The outside diameter of the pinion is increased slightly so that the pinion is *not* a standard size. If a spur gear is meshed with the oversized pinion gear, its outside diameter is manufactured slightly undersize.

Both methods maintain the standard shaft center-to-center distances between the gear and the pinion. Standard tabulated charts are available to calculate these amounts of increased or decreased outside diameters.

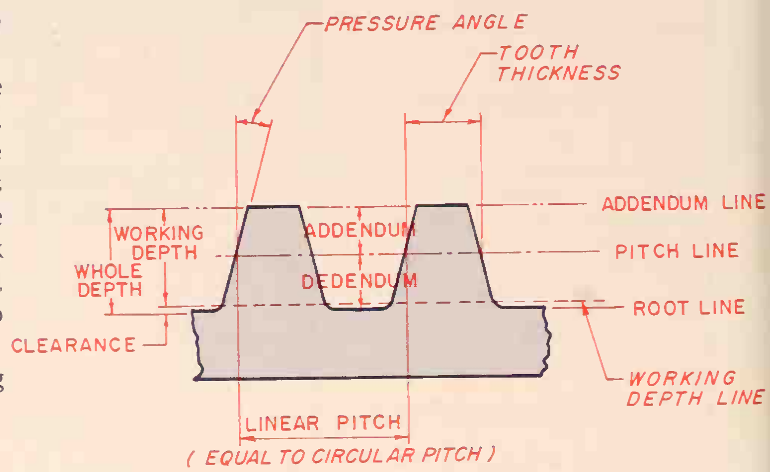
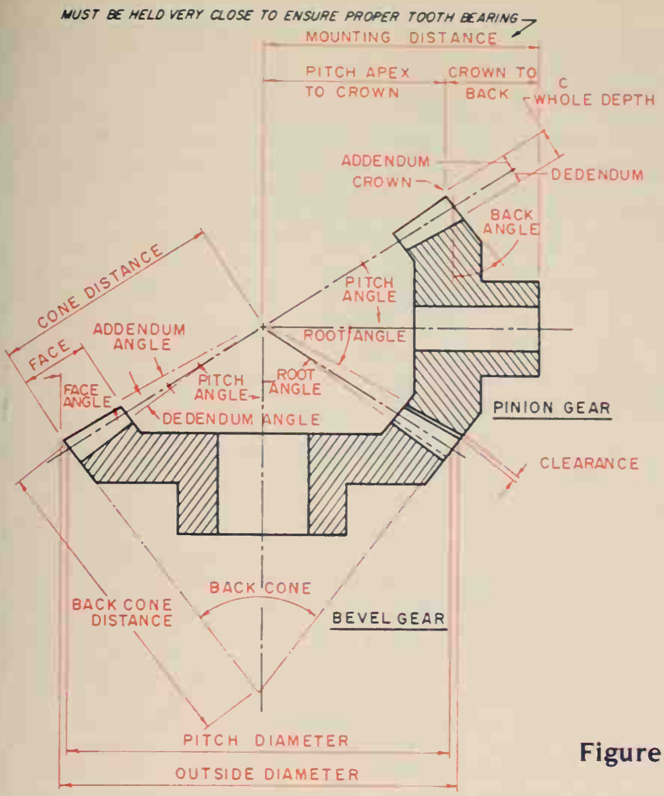


Figure 16-27 Gear terminology for a rack

The required tooth-cutting data for a rack are:

- Pressure angle (same as mating pinion gear)
- Tooth thickness at pitch line (same as mating pinion gear)
- Whole depth (same as mating pinion gear)
- Maximum allowance pitch variation
- Accumulated pitch error max. (over total length)



Bevel Gear

Bevel gears transmit power and motion between intersecting shafts at right angles to each other. Figure 16-28 illustrates the various terms associated with bevel gears. The required tooth-cutting data for bevel gears are similar to spur/pinion gears. These must be calculated and listed on the detail drawing. Figure 16-29 shows the order in which the data and formulas should be listed on the drawing. Bevel gears must be designed and drawn in pairs to ensure a perfect fit.

Worm and Worm Gear

The *worm* and *worm gear* is used to transmit power between nonintersecting shafts at right angles to each other. When using the worm and worm gear, a large speed ratio is possible as one revolution of a single-thread worm turns the worm gear only one tooth and one space.

Figure 16-28 Gear terminology for bevel gears

REQUIRED CUTTING DATA				
ITEM	TO FIND:	HAVING	FORMULA SPUR	FORMULA PINION
1	Number of teeth (N)	–	AS REQ'D.	
2	Diametral pitch (P)	p	$\frac{3.1416}{p}$	
3	Pressure angle (Ø)	–	20° STANDARD 14°-30' OLD STANDARD	
4	Cone distance (A)	D & d	sin d) $\frac{D}{2}$	
5	Pitch distance (D)	p	$\frac{N}{p}$	
6	Circular thickness (t)	p	$\frac{1.5708}{p}$	
7	Pitch angle (d)	N & d (of pinion)	90°-d (pinion)	tan d $\frac{N \text{ pinion}}{N \text{ gear}}$
8	Root angle (γR)	d & δ	d - δ	
9	Addendum (a)	p	$\frac{1}{p}$	
10	Whole depth (ht)	p	$\frac{2.188}{p}$ + .002	
11	Chordal thickness (C)	D & d	$\frac{1}{2}\left(\frac{D}{\cos d}\right)$	$1-\cos\left(\frac{\frac{90°}{N}}{\cos d}\right)+a$
12	Chordal addendum (aC)	d	$\sin\left(\frac{\frac{90°}{N}}{\cos d}\right)$	
13	Dedendum (bC)	P	$\frac{2.188}{P}$ - a(pinion)	$\frac{2.188}{P}$ - a (gear)
14	Outside diameter (DO)	D, a & d	D + (2 x a) x cos. d	
15	Face	A	1/3 A (max.)	
16	Circular pitch (p)	p & N	$\frac{3.1416 \times p}{N}$	
17	Ratio	N gear & N pinion	$\frac{N \text{ gear}}{N \text{ pinion}}$	
18	Back angle (γO)	–	SAME AS PITCH ANGLE	
19	Angle of shafts	–	90°	
20	Part number of mating gear	–	AS REQ'D.	
21	Dedendum angle δ	A & b	$\frac{b}{A}$ = tan δ	

Figure 16-29 Required tooth-cutting data for bevel gears

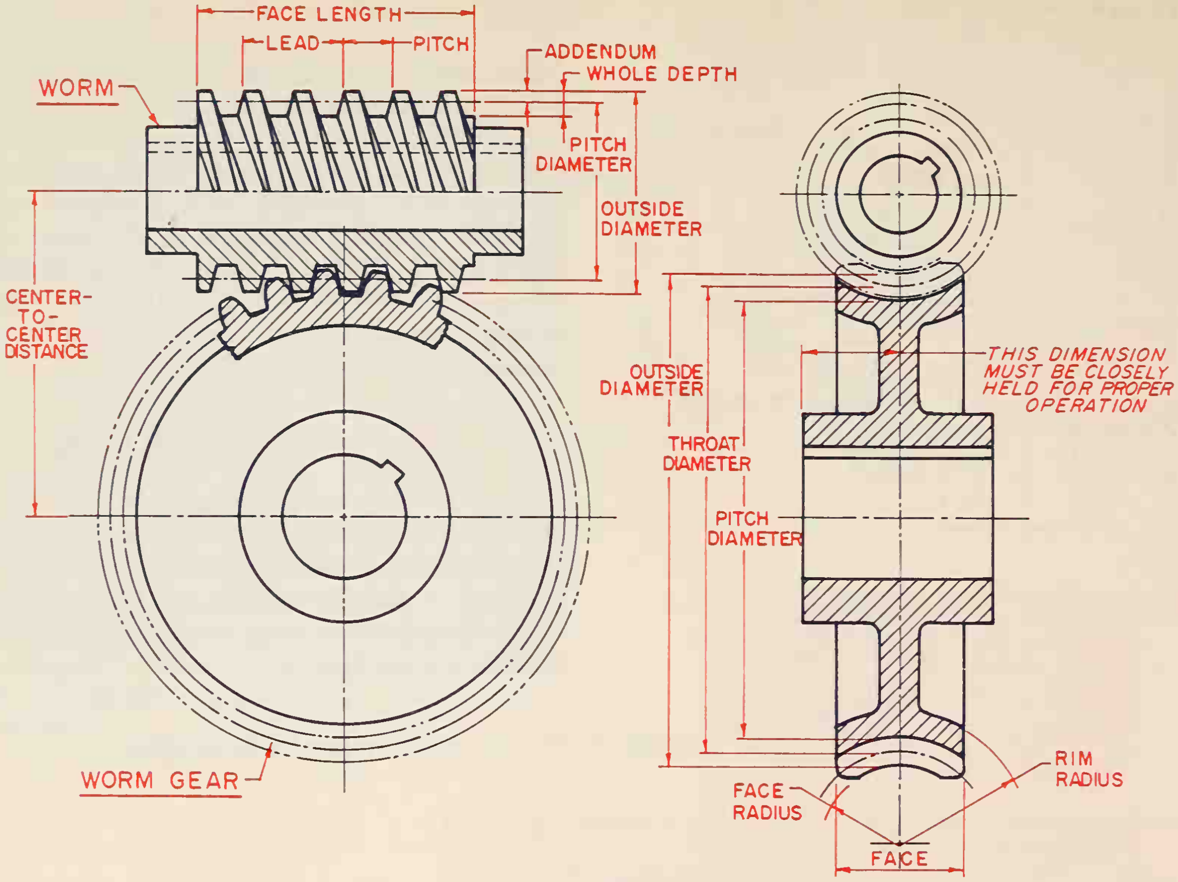


Figure 16-30 Example of worm and worm gear data

The worm's thread is similar in form to a rack tooth. The worm gear is similar in form to a spur gear, except that the teeth are twisted slightly and curved to fit the curvature of the worm.

When drawing the worm and worm gear, an approximate representation is used, Figure 16-30. Cutting data for the worm and worm gear must be listed on the drawing in the lower right side in the order illustrated in Figure 16-31 for the worm gear, and in Figure 16-32 for the worm.

Note: It is important that the mounting of a worm and gear set ensures that the central plane of the gear passes essentially through the axis of the worm. This may be accomplished by adjusting the gear axially at assembly by means of shims. When properly mounted and lubricated, worm gear sets will become more efficient after the initial breaking-in period.

Other information that must be included on a worm/worm gear detail drawing includes:

- Gear blank information
- Tooth-cutting data
- Reference to mating part

Gear Train

A *gear train* is two or more gears used to achieve a designed R.P.M. The ratio of the R.P.M. of the first gear to the R.P.M. of the final gear is called the *value* of the gear train.

Example:

$$\frac{\text{R.P.M. of shaft, first shaft}}{\text{R.P.M. of shaft, final shaft}} = \text{Value of gear train}$$

Study the example on gear trains in Figure 16-33:

- Shafts 1 and 2 are connected by gear A and pinion B
- Shafts 2 and 3 are connected by gear C and pinion D
- Shafts 3 and 4 are connected by gear E and pinion F
- Gear A has 60 teeth
- Pinion B has 15 teeth
- Gear C has 40 teeth
- Pinion D has 20 teeth
- Gear E has 45 teeth
- Pinion F has 9 teeth

Problem:

The R.P.M. of shaft 1 is 200 R.P.M. What is the R.P.M. of shaft 4? What is the gear train value?

Each shaft taken individually:

$$\text{Ratio} = \frac{\text{N spur gear (driver gear)}}{\text{N pinion gear (drive gear)}}$$

R.P.M. of driven pinion = Ratio × R.P.M. driver

REQUIRED CUTTING DATA			
ITEM	TO FIND:	HAVING	FORMULA
1	Number of teeth (N)	-	AS REQ'D.
2	Pitch diameter (D)	N & p	$\frac{N \times p}{3.1416}$
3	Addendum (a)	p	p x .3181
		P	$\frac{1}{P}$
4	Whole depth (ht)	p	p x .6866
		P	$\frac{2.157}{P}$
5	Lead (L) Right-Left	p & N	p x N
6	Worm part no.	-	AS REQ'D.
7	Pressure angle Ø	-	20° STANDARD 14°-30' OLD STANDARD
8	Outside diameter (DO)	Dt & Pa	Dt + .4775 x Pa
9	*Circular pitch (p)	P	$\frac{3.1416}{P}$
		L & N	$\frac{L}{N}$
10	Diametral pitch (P)	p	$\frac{3.1416}{p}$
11	Throat diameter (Dt)	D & Pa	D + .636 x Pa
12	Ratio of worm/worm gear	N worm & N worm gear	$\frac{N \text{ worm gear}}{N \text{ gear}}$
13	Center to center distance between worm & worm gear.	D worm & D worm gear	$\frac{D \text{ worm} + D \text{ worm gear}}{2}$

Circular pitch (p) must be same as worm Axial pitch (Pa)

Figure 16-31 Required tooth-cutting data for a worm gear

REQUIRED CUTTING DATA			
ITEM	TO FIND	HAVING:	FORMULA
1	Number of teeth (N)	P	$\frac{3.1416}{P}$
2	Pitch diameter (D)	Pa	(2.4 x Pa)+ 1.1
		DO & a	DO - (2 x a)
3	Axial pitch (Pa)	-	Distance from a point on one tooth to same point on next tooth
4	Lead (L) Right or Left	p & N	p x N
5	Lead angle (La)	L & D	$\frac{L}{3.1416 \times D}$ = tan La
6	Pressure angle (Ø)	–	20° STANDARD 14°-30' OLD STANDARD
7	Addendum (a)	p	p x .3183
		P	$\frac{1}{P}$
8	Whole depth (ht)	Pa	.686 x Pa
9	Chordal thickness	N, D & a	$\left[1 - \cos\left(\frac{90°}{N}\right)\right] \times \frac{D}{2} + a$
10	Chordal addendum	N, D & a	$\sin\left(\frac{90°}{N}\right) \times D$
11	Outside diameter (DO)	D & a	D + (2 x a)
12	Worm gear part no.	-	AS REQ'D.

Axial pitch (Pa) must be same as worm gear circular pitch (p)

Figure 16-32 Required tooth-cutting data for a worm

Step 1.

a. Shaft 1 rotates at 200 R.P.M.

b. Gear A has 60 teeth; pinion B has 15 teeth.

c. This ratio is:

$$\frac{\text{N spur gear}}{\text{N pinion gear}} = \frac{60}{15} = \frac{4}{1} \text{ or } 4:1 \text{ ratio}$$

d. R.P.M. of driven gear (shaft 2) = Ratio × .R.P.M. driver = 4 × 200 = 800 R.P.M.

Step 2.

a. Shaft 2 rotates at 800 R.P.M.

b. Gear C has 40 teeth; pinion D has 20 teeth.

c. This ratio is:

$$\frac{\text{N spur gear}}{\text{N pinion gear}} = \frac{40}{20} = \frac{2}{1} \text{ or } 2:1 \text{ ratio}$$

d. R.P.M. of driven gear (shaft 3) = Ratio × R.P.M. driver = 2 × 800 = 1600 R.P.M.

Step 3.

a. Shaft 3 rotates at 1600 R.P.M.

b. Gear E has 45 teeth; pinion F has 9 teeth.

c. This ratio is:

$$\frac{\text{N spur gear}}{\text{N pinion gear}} = \frac{45}{9} = \frac{5}{1} \text{ or } 5:1 \text{ ratio}$$

d. R.P.M. of driven gear (shaft 4) = Ratio × R.P.M. driver = 5 × 1600 = 800 R.P.M.

Step 4.

$$\text{Value of gear train} = \frac{\text{R.P.M. last shaft}}{\text{R.P.M. first shaft}} = \frac{8000}{200} = 40 \text{ value}$$

To calculate the value of a *complete* gear train use the following formula:

The product of the number of teeth on all the drivers (spur gears) divided by the product of the number of teeth on all followers (pinion gears) equals the value of a complete gear train.

Example:

$$\frac{\text{N gear A} \times \text{N gear C} \times \text{N gear E}}{\text{N pinion B} \times \text{N pinion D} \times \text{N pinion F}}$$

$$\frac{60 \times 40 \times 45}{15 \times 20 \times 9} = \frac{108{,}000}{2700} = 40$$

In Figure 16-33, the gear train has been sketched with the gears in a neat row. This is done for the purpose of showing the sketch or basic design. In the final assembly, gears are actually clustered closer together to save space, and they are almost never in a row as shown.

Materials

Gears are made of many materials, such as brass, cast iron, steel, and plastic to mention but a few. Many bevel gears are forged, some are stamped from thin material, some are cast as a blank and machined, and others are die-cast to the exact size and shape.

Each application must be carefully analyzed. Metal gears have been used for years, but, if the load is not excessive, plastic gears have many advantages. Plastic runs quieter, has a self-lubricating effect, weighs much less, and costs much less. In addition, complicated multiple gears can be molded into a single piece which further reduces cost.

Design and Layout of Gears

The initial design of gears starts with the nominal size of the pitch diameters. The required speed ratio, loading, space limitations, and center-to-center distances are also important factors to consider. Mating gears and pinions must have equal diametral pitch in order to correctly mesh; therefore, the diametral pitch should be one of the first considerations. A complete analysis and design of a gear or a complete gear chain are very complex, and far beyond the scope of this text. Most designers try to use standard gears from a company that specializes in gears, gear chains, and gear design. Most gear manufacturing companies can be of assistance in designing gears for special applications. These companies can usually manufacture gears at a lower price than if they were made in-house.

Further analysis, in-depth study, and design data can be found in the most recent edition of *Machinery's Handbook*.

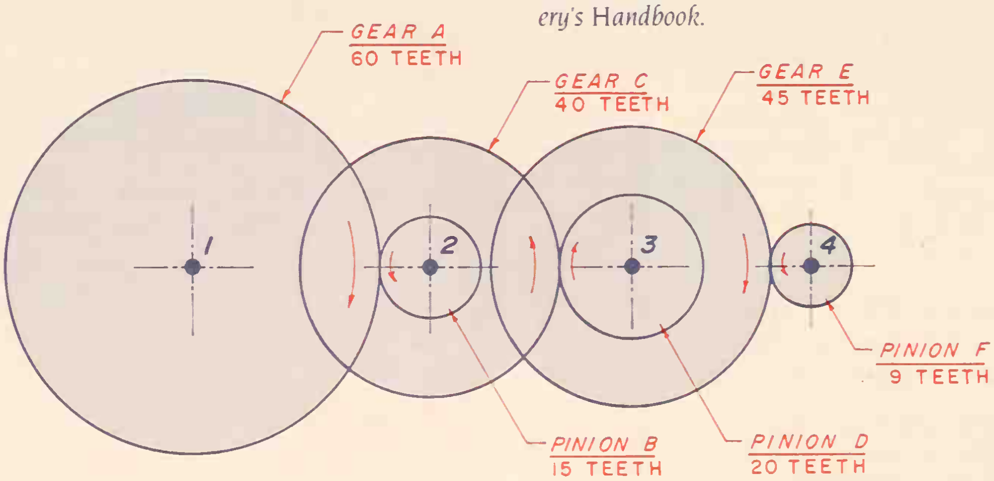


Figure 16-33 Gear train

Review

Calculate the following math problems; include all math work to illustrate how the answers were derived.

1. What is the outside diameter of a spur gear having a pitch diameter of 1.500 and 48 teeth?
2. What is the addendum and dedendum of a spur gear having a pitch diameter of 3.000 and 48 teeth?
3. With the addendum, dedendum, and pitch diameter of Problem 2, what is the root diameter and outside diameter?
4. How many teeth are on a spur gear having a pitch diameter of 1.750, diametral pitch of 20, and an outside diameter of 1.850?
5. What is the pitch diameter of a spur gear having a diametral pitch of 24, 78 teeth, and an outside diameter of 3.333?
6. What is the diametral pitch of a spur gear having 80 teeth and a 2.500 pitch diameter?
7. What is the root diameter of a spur gear having a pitch diameter of 2.000 and 32 teeth?
8. What is the pitch diameter of a spur gear having 40 teeth and a diametral pitch of 20?
9. What is the diametral pitch of a pinion gear having 75 teeth and 3.208 outside diameter? Use the formula $P = \frac{N}{D}$
10. How many teeth are required for a pinion gear with a mating spur gear having a P of 48, a 2.000 pitch diameter, and a 4:1 ratio?
11. What is the whole depth of a spur gear with the following specifications: 70 teeth, .7291 pitch diameter, .750 outside diameter, and 96 diametral pitch?
12. What is the circular pitch of a bevel pinion having a 16 diametral pitch, and 20 teeth?
13. A spur gear has a pitch diameter of 3.000 and a pinion gear has a pitch diameter of 1.500. If an R.P.M. 250 is needed at the shaft of the pinion gear, how fast should the spur gear be rotated?
14. What is the ratio between a spur gear with an R.P.M. of 175 and a pinion gear with an R.P.M. of 1050?
15. The ratio between a pair of bevel gears at a 90° angle and 28 P is:
    Gear: D = .9375, 45 teeth
    Pinion: D = .6250, 30 teeth
16. What is the outside diameter of a bevel gear with the following specifications: a 2.500 pitch diameter, a 48 diametral pitch, a 4:1 ratio, and 120 teeth?
17. What is the shaft center distance between a worm and a worm gear with the following specifications:

Worm:	Pitch diameter .500
	Diametral pitch 24
	Single thread
Worm Gear:	Pitch diameter 4.000
	Diametral pitch 24
	(N) Teeth 100

18. What is the gear ratio of a spur gear and pinion gear with the following specifications? (Calculate the answer using three different methods.)

Spur gear:	Pinion gear:
75 teeth	15 teeth
3.208 DO	.6250 D
3.125 D	.708 DO
725 R.P.M.	24 P
24 P	3/16 face
3/16 face	3625 R.P.M.

Chapter Sixteen Problems

The following problems are intended to give the beginning drafter practice in using the many formulas associated with gears, and practice in designing and laying out finished professional detail drawings of many major kinds of gears.

The steps to follow in laying out gears are:

Step 1. Study the problem carefully.

Step 2. Make a sketch if necessary.

Step 3. Do all math required for each problem. Keep all math work for rechecking.

Step 4. Center the required views within the work area.

Step 5. Include all dimensioning according to the most recent drafting standards.

Step 6. Add all required gear cutting specifications in the lower, right side of the paper.

Step 7. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problem 16-1

Use the following specifications to lay out a single-view drawing of a 2:1 ratio spur gear and pinion gear *in mesh*.

Spur gear:	Pinion gear:
88 teeth	hub diameter 1.625
pressure angle 20°	bore of 1.000 diameter
pitch diameter 5.500	pressure angle 20°
hub diameter 2.625	
bore of 2.000 diameter	

Use all standard drafting methods to illustrate the outside diameter, pitch diameter, and root diameter. Calculate and add the center-to-center distance between the shafts.

Problem 16-2

Draw a spur gear having the following specifications: 56 teeth, pressure angle 20°, pitch diameter 3.500, hub diameter 1.00 gear blank with overall size (width) 1.00, face size .50, bore .5625; use a ⅛'' set screw.

Complete two views using the half-section method of representing gears. Do not show the gear teeth; use the conventional method of illustrating teeth. Dimension per all standard practices. Calculate and add all standard required cutting data to the lower right side of the work area. Material S.A.E. #3120 cast steel. Heat treatment: carburize .015-.020 deep.

Problem 16-3

Complete a two-view detail drawing of a pinion gear having the following specifications: calculate and add all standard cutting data: 30 teeth, pressure angle 20°, pitch diameter 6.000, hub diameter 2.000, heat treatment: carburize .050 deep, gear blank with overall size (width) 3.500, face size 1.250, bore 1.000, material S.A.E. #4620 steel.

Problem 16-4

Make a detail drawing, completely dimensioned, of a spur gear with the following specifications: diametral pitch 16, pressure angle 20°, pitch diameter 5.500, whole depth .1348, outside diameter 5.625, addendum .0625, working depth .125, circular thickness .098, chordal thickness .0633, chordal addendum .0985, whole depth .1348, and dedendum .0723, material cast brass.

Design a simple gear blank with a set screw to fasten gear to a .75 dia. shaft.

Problem 16-5

Design and draw a detail drawing, completely dimensioned, of a pair of bevel gears having teeth of a 4.0 diametral pitch; the gear with 25 teeth, the pinion gear with 13 teeth, face width of 1.00, gear shaft 1.25 diameter, and pinion shaft .875 diameter. (Calculate for FN-2 fits with the shaft.)

Design the hub diameter to be approximately twice the diameter of the shaft diameter. Backing for the gear 1.375 and for the pinion .75. Design and dimension the remaining portion to suit, using standard drafting practices. Add all cutting data to the lower right side of the work area. *Material*: S.A.E. #3120 cast steel, heat treatment: carburize .015/.020 deep.

Problem 16-6

Make a design layout of a worm and worm gear with the following specifications: shaft diameter 1.25, single-thread worm, lead .75, worm gear with 28 teeth. Add all dimensions and cutting data as required.

Problem 16-7

Sketch a clock gear chain with the following specifications:

First gear (main wheel): 84 teeth
Second gear: pinion gear 8 teeth
spur gear 60 teeth
Third gear (center shaft): pinion gear 12 teeth
spur gear 68 teeth
Fourth gear: pinion gear 7 teeth
spur gear 66 teeth
Fifth gear (escapement gear): pinion gear 7 teeth
spur gear 33 teeth

Note: In actual practice, a clock's first gear (main wheel) is usually driven by a spring. The minute hand is connected to the shaft of the third gear (center shaft) and the fifth gear is the escapement gear.

Problem 16-8

Using the sketch of a clock gear chain in Problem 16-7, answer the following questions:

1. How many times will the second gear rotate for one full revolution of the first gear?
2. How many turns will the third gear rotate for one full revolution of the second gear?
3. How many teeth of the main wheel are required to turn the third gear shaft one complete revolution? (On a clock, one revolution of the third gear equals one hour. This wheel turns 24 times for one day.)
4. What is the required revolution fo the first gear (main wheel) for one day's running time (24 turns of the center wheel).
5. What is the value of the complete gear train?
6. As this is a clock gear chain in revolutions, how many will the fifth gear (escapement) make in twelve hours? (The third gear will turn 12 times.)

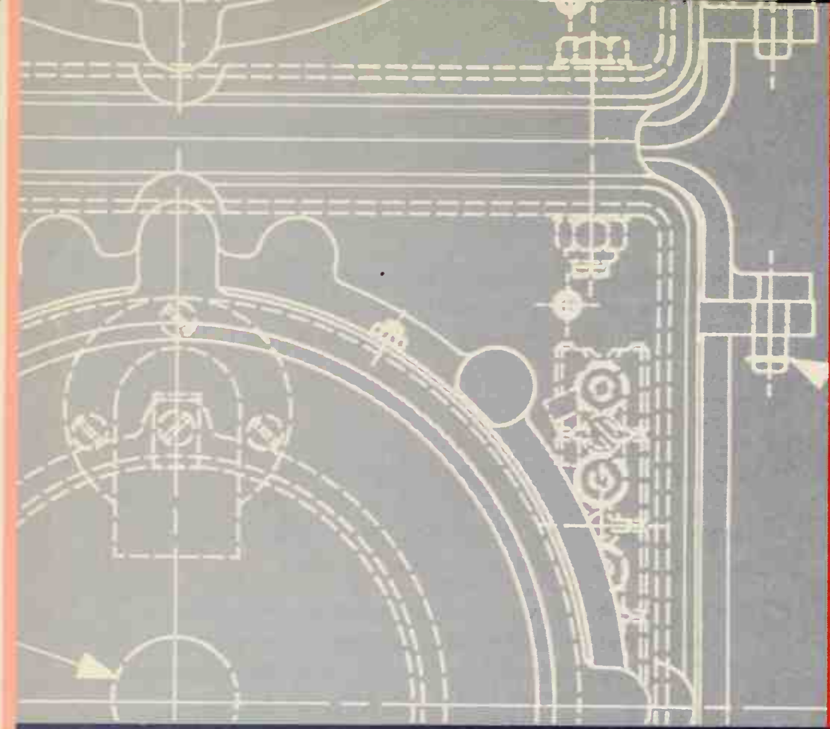
Problem 16-9

Design and develop a design layout two-view drawing of a gear train with the following specifications. Design a compact clustered arrangement of the gears within an 8.0 x 10.0 supporting plates area.

First shaft: 42 teeth/4.0 outside diameter-gear
Second shaft: 6 teeth/1.0 outside diameter-pinion
Third shaft: 6 teeth/.75 outside diameter-pinion
30 teeth/2.5 outside diameter-gear
Fourth shaft: 6 teeth/.75 outside diameter-pinion
30 teeth/2.0 outside diameter-gear
Shaft sizes = .375 dia/supporting plates 1.5 apart

Problem 16-10

Locate a windup clock or some other such small gear chain device and make a design layout similar to that in Problem 16-9.



CHAPTER 17

A hypothetical engineering department and the chain of command for this department are given in this chapter. Related information, such as engineering change order procedures, master lists, and the kinds of drawings used in industry, is also covered. The beginning drafter is given the opportunity to do basic designing and develop various tolerances for mating parts. The most recent dimensioning standards and the correct tolerances for mating parts should be stressed in all drawing problems at the end of this chapter.

ASSEMBLY AND DETAIL DRAWINGS

The Engineering Department

Engineering departments vary from company to company, but most of them have various things in common. An example of a relatively small engineering department is illustrated in Figure 17-1.

An engineering department consists of various departments, usually headed by a chief engineer. An example of the various departments associated with a small engineering division would include the design section, the application section, and the quotation department. The *design section* is responsible for new design products and design improvement of existing products. The *application section* handles special order variations of existing products. For example, a scale company customizes a scale platform size to meet a particular customer need. The *quotation department* gives estimated costs or quotations to customers needing special modifications of standard products manufactured by the company. In some companies or engineering departments, these various departments may be broken down into actual fields of engineering, such as the mechanical section, the electronic section, the illustration section, and so forth.

Directly under the Chief Engineer are the various department heads, usually engineers, designers or supervisors. Regardless of their expertise, these department heads have drafters of many levels under them. Most engineering departments have a clear-cut departmental structure. Others move drafters back and forth among the various departments as needed.

New personnel should fully understand the engineering department structure of the organization. An engineering department must work as efficiently as possible in order to provide an orderly flow of drawings, parts lists, and drawing changes.

Drawing Revisions

Anyone having a suggestion to improve a part or assembly within the product, or a need to correct an error on a drawing, must bring it up at an *engineering change request* meeting. This is sometimes referred to as an ECR meeting, Figure 17-2. After a drawing has been released to the factory *no* change can be made to it without an *engineering change order* (ECO), even by the drafter who originally drew it. The change cannot be made unless all departments concerned agree to it, (refer back to Figure 17-2). The ECR and ECO explain *what* change is to be made, what it *was* before, *why* the change is to be made, whether it *affects other*

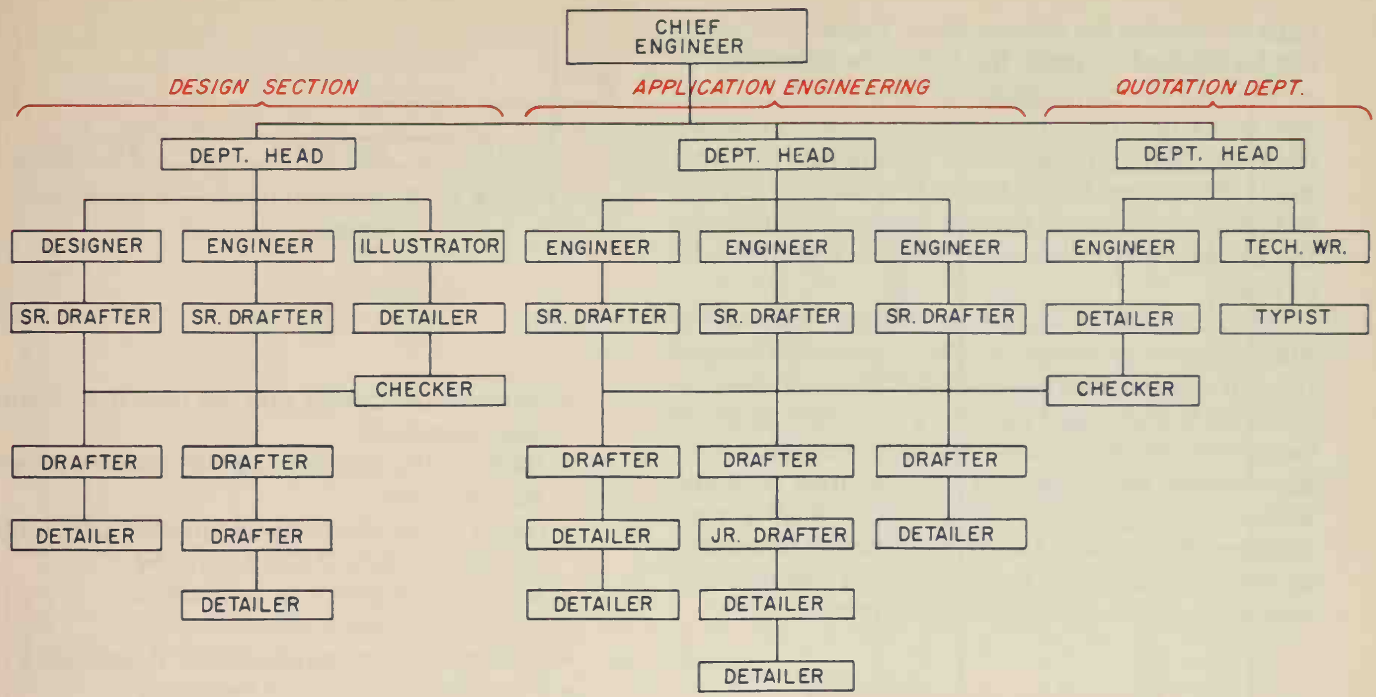


Figure 17-1 Chain of command in an engineering department

parts, and *who* suggested the change. The ECR and ECO sometimes list the departments throughout the company that will be directly affected by the change. When the engineering change request has been approved, the committee issues an engineering change order. The ECO is usually given to a beginning drafter or detailer to make the actual change.

Changes are made by erasures directly on the original drawing. Additions are simply drawn in on the original drawing. If a dimension is not noticeably affected by the change, the dimension is simply corrected and underlined with a heavy black line. This indicates that the dimension is correct, but slightly out-of-scale, Figure 17-3.

If the change is extensive, the drawing must be redrawn. The original drawing is *not* destroyed: it is stamped OBSOLETE and includes the note, "SUPERSEDED BY (the number of the corrected drawing)." The new drawing must have a note referring back to the superseded drawing. The change must be indicated, both as to *where* it has been made, and basically as to *what* was changed. Each company has its own standard method to indicate this information. The most common method is to place a letter or number in a small balloon near the dimension or dimensions where the change was made. Note in Figure 17-3 that the A within the balloon indicates which dimension was changed. The same letter or number

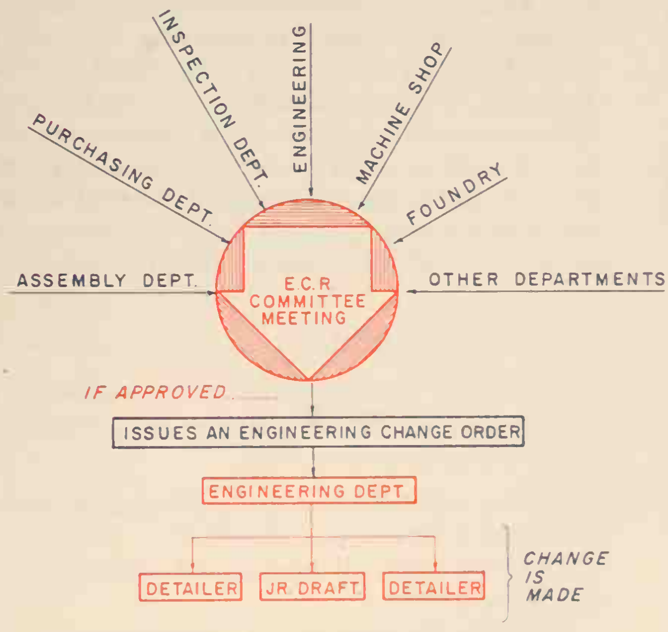


Figure 17-2 Engineering change request order procedure

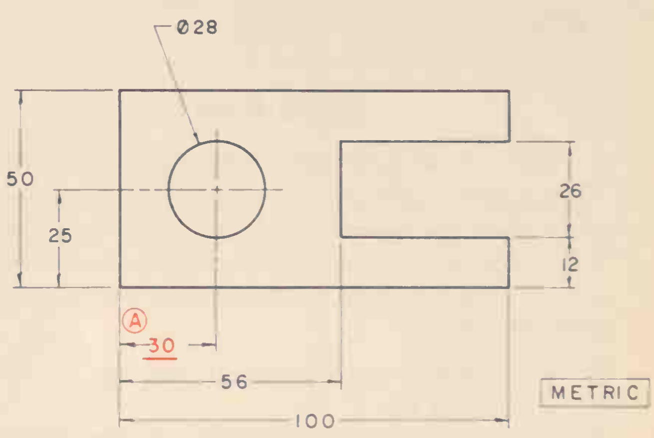


Figure 17-3 Balloon change call-off

must be listed in the revision block. Figure 17-4, which can be located either to the left of the title block or on the top right corner of the drawing sheet. The revision block lists the letter or number of the change, what was changed, the date of the change, and who made the change. If the change is extensive, only the ECO number is listed. Anyone needing to know why the change was made can refer back to the ECR or ECO.

Some companies add the *last* changed letter to the drawing number which, in effect, actually changed the part number. Part number C-65498 would become C-65498-A. If changed again at a later date, it would become C-65498-B, and so on. In certain cases, appropriate administrative changes may be made without an engineering change order. Such simple changes as misspelled words or incorrect references to improve clarity are nonengineering changes that would not affect any other department.

A	WAS 25 - SEE E.C.O. 8635	PRS	9APR86
LET	REVISION	BY	DATE

Figure 17-4 Revision block (*Courtesy Bishop Graphics Accupress*)

Invention Agreement

Anyone who works in a job that is creative, such as a drafter, a designer or an engineer, must sign an agreement form giving the company the right to any new invention designed while working for the company. The form puts in writing that the employee will not reveal any of the company's discoveries or projects. The invention agreement is in effect from six months to two years after an employee leaves the company, depending upon the company. This is so employees will not invent something, quit, and patent it themselves.

A company is not obligated to, and does not usually, give extra pay for an invention an employee develops. This is what the employee is paid to do. However, a company usually recognizes talent, and will reward an employee with a promotion, stocks, bonds, or, possibly, a raise. Signing an employer/employee invention agreement is a normal request in any company. A prospective employee should read the contract carefully and understand it fully before signing it. An applicant who does not sign the agreement will probably not be offered the job.

Title Block

Title blocks vary from company to company. The latest ANSI standard title block is illustrated in Figure 17-5. The function of a title block is to indicate information that is not given directly on the drawing itself. The following information is usually found in the title block:

- Name and address of the company
- Drawing title
- Drawing or part number
- Scale of the drawing
- Name of the drafter and the date the drawing was completed
- Name of the checker and the date the drawing was checked
- Name of the chief official approving the drawing and the date it was approved
- Material the part is to be made of
- Tolerance/limits of dimensions
- Heat treatment requirements, if necessary
- Finish requirements, if necessary

Size of Lettering within Title Block

- General information, .125 (3) freehand letters/ .120 mechanical letters
- Drawing title, .250 (6) freehand letters/.240 mechanical letters
- Drawing number, .312 (8) freehand letters/.350 mechanical letters

Checking Procedure

The importance of absolute accuracy in engineering drawings cannot be stressed enough. The slightest error could cause tremendous and unnecessary expenses. In some fields of engineering, such as in aircraft or space products, an error could cost lives. Therefore, it is important to take every precaution against errors. In most engineering departments, checkers are used to verify all dimensions and all stress analysis, and to see that standard material and tools are used wherever possible. It is a checker's responsibility to check the drawing before it is released.

Drafter's Checklist

The drafter should check the drawing before giving it to the checker to further ensure accuracy. Some of the things to look for are:

- What is the drawing's general appearance (legibility, neatness, and so forth)?
- Does it follow all drawing and company standards?
- Are the dimensions and instructions clear and understandable?
- Is the drawing easy to understand?

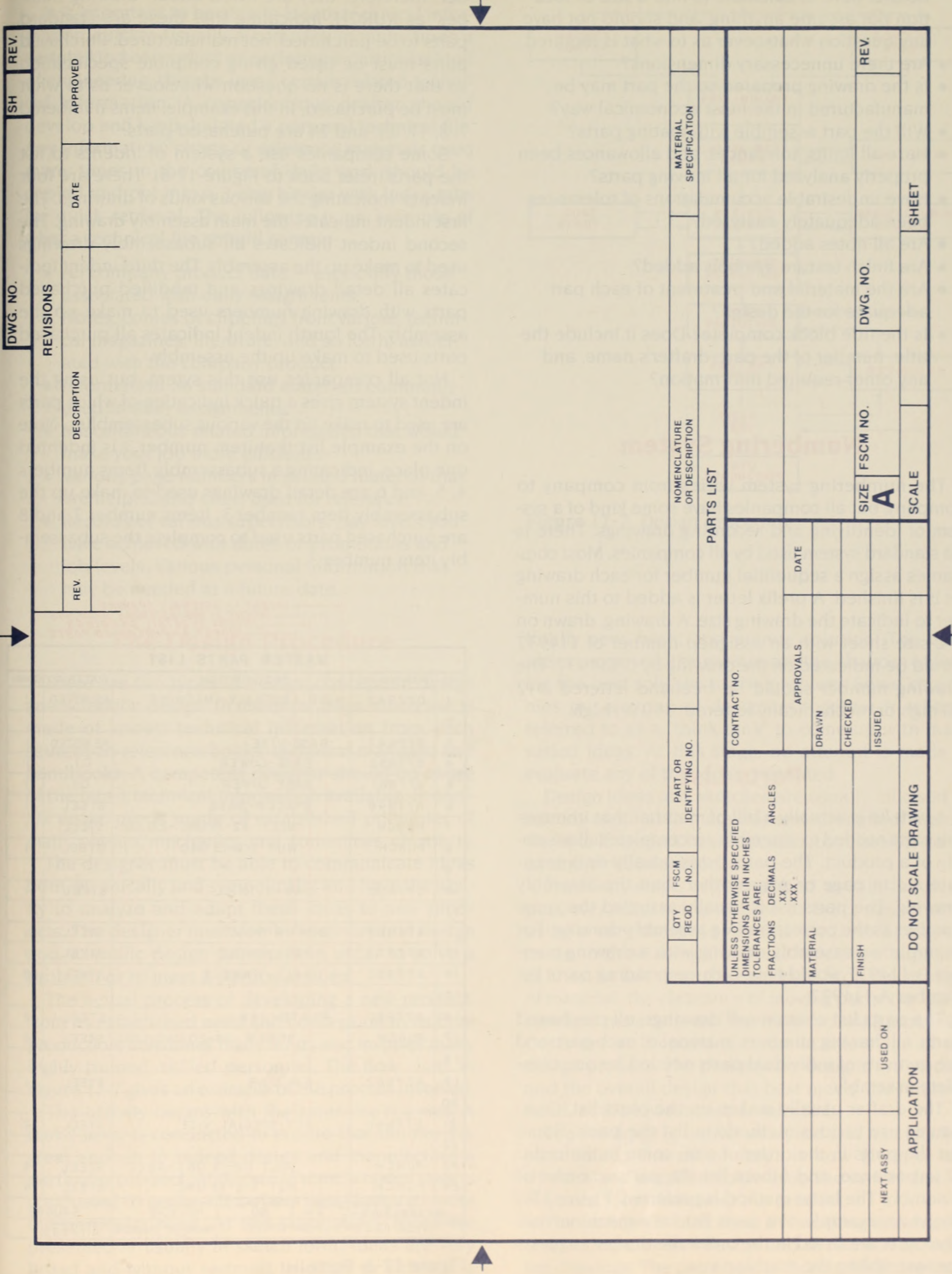


Figure 17-5 Title block

- Are all dimensions included? A machinist must neither have to calculate to find a size or location nor assume anything, and should not have any question whatsoever as to what is required.
- Are there unnecessary dimensions?
- Is the drawing prepared so the part may be manufactured in the most economical way?
- Will the part assemble with mating parts?
- Have all limits, tolerances, and allowances been properly analyzed for all moving parts?
- Have undesirable accumulations of tolerances been adequately analyzed?
- Are all notes added?
- Are finish texture symbols added?
- Are the material and treatment of each part adequate for the design?
- Is the title block complete? Does it include the title, number of the part, drafter's name, and any other required information?

Numbering System

The numbering system varies from company to company, but all companies have some kind of a system of identifying and recording drawings. There is no standard system used by all companies. Most companies assign a sequential number for each drawing as it is finished. A prefix letter is added to this number to indicate the drawing size. A drawing, drawn on a C-size sheet with an assigned number of 114937 would be indicated on the drawing by C-114937. The drawing number should be freehand lettered .312 (8) high or mechanically lettered .350 (9) high.

Parts List

A *parts list* is actually a bill of material that itemizes the parts needed to assemble *one* complete full assembly of a product. The parts list is usually on a separate A-size page or pages other than the assembly drawing. The parts list is usually assigned the same number as the corresponding assembly drawing. For example, an assembly drawing with a drawing number D-114937 would have a corresponding parts list number A-114937.

The parts list contains all drawings, all purchased parts, all drawing numbers, material of each part, and the quantity of individual parts needed for one complete assembly.

The drafter usually makes up the parts list. Companies use various methods to list the parts. Some list the parts in the order of size, some in the order of importance, and others list the parts in order of assembly. The latter method is preferred. Figure 17-6 shows an example of a parts list for a machine vise. The parts are listed in the order the drafter suggests for assembling the machine vise.

Note that purchased parts do not have a plan number; therefore, they are listed under "drawing number" as PURCH, indicating that these are standard parts to be purchased, not manufactured. Purchased parts must be listed giving complete specification so that there is no question whatsoever as to what must be purchased. In this example, items numbered 7, 8, 17, 23, and 24 are purchased parts.

Some companies use a system of indents to list the parts (refer back to Figure 17-6). There are four indents, indicating the various kinds of drawings. The first indent indicates the main assembly drawing. The second indent indicates all subassembly drawings used to make up the assembly. The third indent indicates all detail drawings and modified purchased parts with drawing numbers used to make up the assembly. The fourth indent indicates all purchased parts used to make up the assembly.

Not all companies use this sytem, but using the indent system gives a quick indication of which parts are used to make up the various subassemblies. Note on the example list that item number 3 is indented one place, indicating a subassembly. Items numbers 4, 5, and 6 are detail drawings used to make up the subassembly item number 3. Items number 7 and 8 are purchased parts used to complete the subassembly item number 3.

INDENT 1 = ASSEMBLY DRAWING
INDENT 2 = SUB-ASSEMBLY DRAWINGS
INDENT 3 = DETAIL DRAWINGS
INDENT 4 = PURCHASED PARTS

MASTER PARTS LIST

NO	DRAWING NO.	DESCRIPTION	MATERIAL	QUAN
1	D77942	VISE ASSEMBLY - MACHINE	AS NOTED	1
2				
3	C77947	BASE-VISE	AS NOTED	1
4	B77952	BASE-LOWER	C.I.	1
5	A77951	BASE-UPPER	C.I.	1
6	A77946	SPACER-BASE	STEEL	1
7	PURCH.	BOLT 1/2-13 UNC -2.0 LG	STEEL	1
8	PURCH.	NUT 1/2-13 UNC	STEEL	1
9				
10	C77955	JAW-SLIDING	STEEL	1
11				
12	A77954	SCREW-VISE	STEEL	1
13	A77953	ROD-HANDLE	STEEL	1
14	A77956	BALL-HANDLE	STEEL	2
15				
16	A77961	PLATE-JAW	STEEL	2
17	PURCH.	SCREW 1/4-20 UNC-1.0LG.	STEEL	4
18				
19	A77962	COLLAR	STEEL	1
20				
21	A77841	KEY-SPECIAL VISE	STEEL	2
22				
23	PURCH	BOLT 1/2-13 UNC-4.0LG.	STEEL	4
24	PURCH	NUT 1/2-13 UNC	STEEL	4
JAN ENGINEERING PETERBOROUGH, N.H.	Model No. 160	Parts Lister NELSON	Date 6 AUG 86	
Title VISE ASSEMBLY-MACHINE		PAGE 1 OF 1 PAGES	Drawing No. A119889	

Figure 17-6 Parts list

Personal Technical File

It is important to be able to locate technical information quickly. Usually, a company manufactures a certain kind of product or performs a particular kind of engineering, thereby using certain related technical information. A conscientious drafter should develop and keep updated a personal technical file. Any information, charts or reference materials used many times in the course of daily work should be copied and put into a 3-ring binder with index tabs for quick retrieval. The following is an example of what a technical file should contain:

- All company product data — especially those associated with daily assignments.
- Notes, copies or clippings from various technical magazines, literature, and so forth, associated with the company product.
- Information on standard materials commonly used in daily assignments.
- Miscellaneous related information that would make your job more efficient.
- Various page numbers in printed material that are helpful and often used for reference.
- Records of various supervisors, pay levels you have achieved with dates or promotions and job levels. Various personal information that may be needed at a future date.

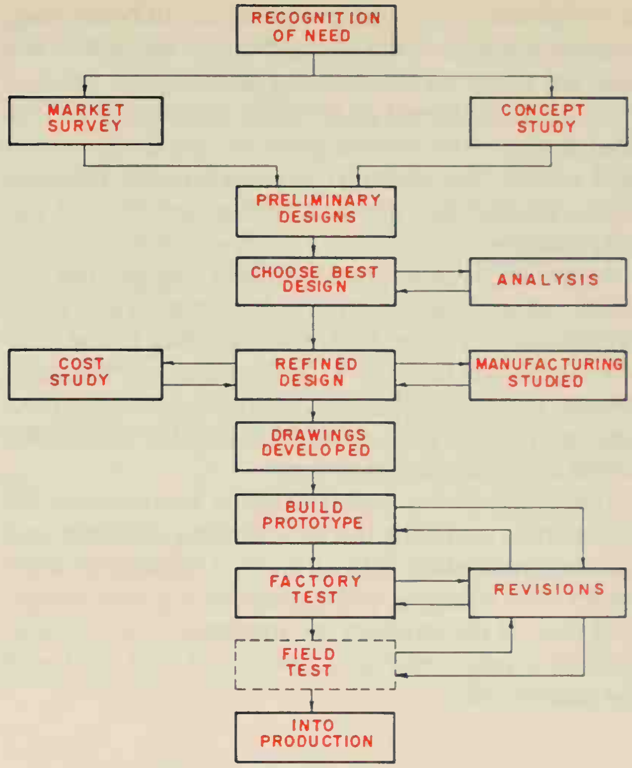


Figure 17-7 Design procedure

The Design Procedure

There are two types of design: conceptual design and scientific design. In *conceptual design*, much use is made of known technical information from such sources as reference books, technical manuals, and handbooks. A competent designer should be aware of the latest technical information available. In *scientific design*, use is made of established principles of math, physics, mechanics, and, sometimes, chemistry.

The designer must be able to communicate ideas both graphically and symbolically, and have the ability to analyze and adapt these ideas to new products. The designer must combine conceptual design and scientific design principles in order to solve a problem or to meet a particular need.

The actual process of developing a new product, from its established need and conception to its final production, consumes many hours and involves many highly trained, skilled personnel. The flow chart in Figure 17-7 gives an example of the process involved.

The activity begins with the *recognition of a need*. A *market survey* is conducted to ensure that the need is great enough to indeed design and manufacture a particular product. At the same time, a *concept study* is conducted to get an idea of the best design to meet the particular need. At this stage, many ideas are presented — usually in sketch form. Ideas are very broad and without restraint in order to arrive at a totally new, fresh, and unique solution. The more ideas proposed, the greater are the chances of finding the best solution to the problem. Some companies put a group of designers together in what is referred to as a "think tank" to come up with many varied ideas. At this stage, no attempt is made to evaluate any of the ideas presented.

Design ideas and sketches are usually followed by a study of suitable materials and strength of materials, and, if needed, basic calculations related to velocity and/or acceleration.

Preliminary designs are developed, usually full size if possible. All drawing is done to exact size or scale using a very sharp 4-H or 6-H lead. No attempt is made to draw using the usual "thick-thin" alphabet of lines. At this time, the emphasis is on the strength of material, the clearance of moving parts, the use of standard materials, and the manufacturing processes. Costs are an important factor in this stage of the design process. The preliminary designs are studied and the overall design that best meets the required need, at the lowest cost, is selected.

The *best design* is further analyzed and a *cost study* is conducted. The *refined design* is now given to the drafters and detailers to develop the *working drawings* required for *manufacturing* the product.

The *prototype* is built from the working drawings to test both the overall design and to recheck all working drawings. The prototype is thoroughly *factory tested*.

Any improvements in the overall design or better manufacturing methods are studied and, if necessary, *revisions* are made to the working drawings. A product must be as foolproof as possible before it goes into final production. If time permits, the prototype is field tested. The working drawings are now released to the production division of the factory and put *into production*.

A product, such as an automobile, requires the previously described design process for each and every subassembly, Figure 17-8. Components in the console system in Figure 17-9, such as the laser key entry system, the automatic level attitude, spoiler control system, and the map navigation display system followed a similar design process.

The engineering department is responsible for maintaining and filing the final working drawings, and keeping up-to-date with all ECOs and records associated with changes. If the product is a new design, or if part of the product incorporates a new design feature, a *patent drawing* is developed and filed with the patent office.

Figure 17-8 Innovative automobile evolved from design process (*Courtesy Buick Public Relations*)

Figure 17-9 Touch control electronic console system was created using the design process steps (*Courtesy Buick Public Relations*)

Working Drawings

Many different kinds of drawings are associated with the development and production of a product. The drafter must be familiar with each kind and able to recognize each, know the company standards used for each kind, and be able to draw each kind of drawing.

The major kinds of working drawings are:

- Design layout
- Assembly drawing
- Subassembly drawing
- Detail drawing
- Purchased parts
- Modified purchased parts drawing

Design Layout

The design layout is usually done by the designer or engineer using a sharp 4-H or 6-H lead. This is either an exact size or scaled as large as space permits. The *design layout* is drawn from various sketches made in the first steps of the design process. The designer tries to use standard materials, standard manufacturing processes and, if needed, standard size fasteners. A design layout is not usually dimensioned, except for general overall dimensions. Many designers pencil in nominal sizes, special notes or requirements and important required tolerances or limits.

After the preliminary design layout has been approved, the detailer or drafter uses it to draw the necessary subassemblies and detail parts. As there are very few or no dimensions on the design layout, the detailer or drafter must carefully transfer each size dimension from the design layout to the working drawing. In transferring these size dimensions, the detailer or drafter must also try to use standard materials and standard manufacturing processes, as well as calculate all dimensions. Before starting a project, regardless of its complexity, the detailer or drafter must fully understand the function of the design. All tolerances should be kept as large as possible, except in the clearance of moving or mating parts. Tight or close tolerances add extra cost to the product.

Assembly Drawing

Any product that has more than one part must have an assembly drawing. The *assembly drawing* illustrates how a product is assembled when completed. The assembly drawing can have one, two, three or more views that are placed in the usual positions. Because the assembly drawing is used to show how the parts are assembled, a full section view is usually used. There is only one assembly drawing for any given product.

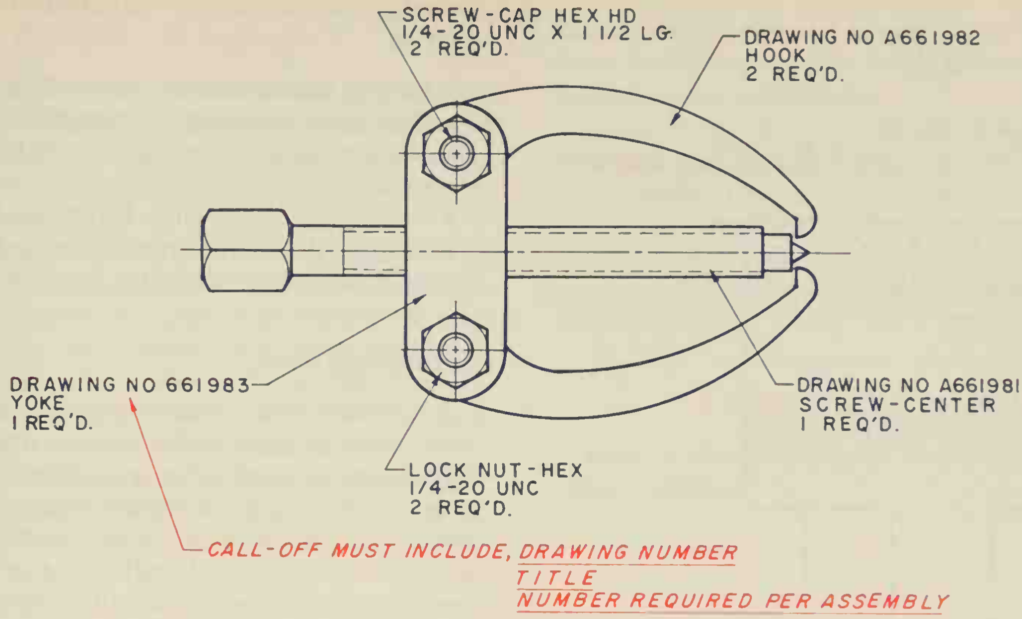


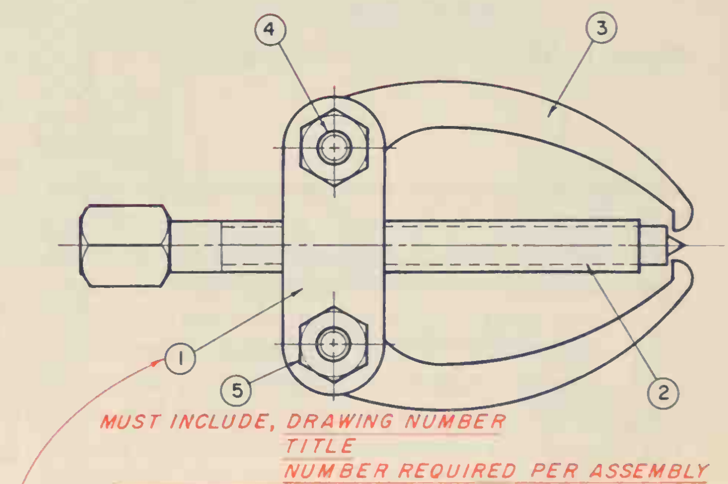
Figure 17-10 Assembly call-off (Method 1)

Assembly drawings are usually not dimensioned, except for general overall dimensions or to indicate the capabilities of the assembly. For example, a clamp assembly might add a dimension to illustrate how wide it opens. Assembly drawings, as a rule, do not contain hidden lines, unless they are absolutely necessary to illustrate some important feature that otherwise may be missed.

An assembly drawing must call-off each part that is used to make up the assembly. Each part must be called off by its part number, and title, and the total number required to make up one complete assembly. Companies usually use one of two methods to call-off the parts.

Method one: Each part has a leader line with the part number, title, and number required, Figure 17-10.

Method two: Each part has a leader line with a balloon call-off letter inside, Figure 17-11. This method uses a parts tabulation chart to also list the part number, title, and number required. Because the assembly drawing is made up of many different parts, each of which could be manufactured of a different material, the title block material box indicates "AS NOTED."



-	-	1/4-20 UNC	-
5	PURCH	LOCK NUT-HEX	2
-	-	1/4-20 UNC X 1 1/2 LG.	-
4	PURCH	SCREW-CAP HEX HD	2
3	A661982	HOOK	2
2	A661981	SCREW-CENTER	1
1	A661983	YOKE	1
NO.	DRAWING NO.	ITEM	REQ'D.

Figure 17-11 Assembly call-off (Method 2)

Subassembly Drawing

A subassembly is composed of two or more parts permanently fastened together. A *subassembly drawing* is very similar to an assembly drawing. All standard practices associated with an assembly drawing apply to the subassembly drawing. That is, no or few overall dimensions, no hidden lines unless absolutely necessary, material listing "AS NOTED," and call-offs using either method one or two.

Subassemblies sometimes require machining operations *after* assembly, Figure 17-12. For instance, a hole is drilled through the parts *after* assembly. This would have been much more difficult and costly if it had been done to each individual part. Thus, all the

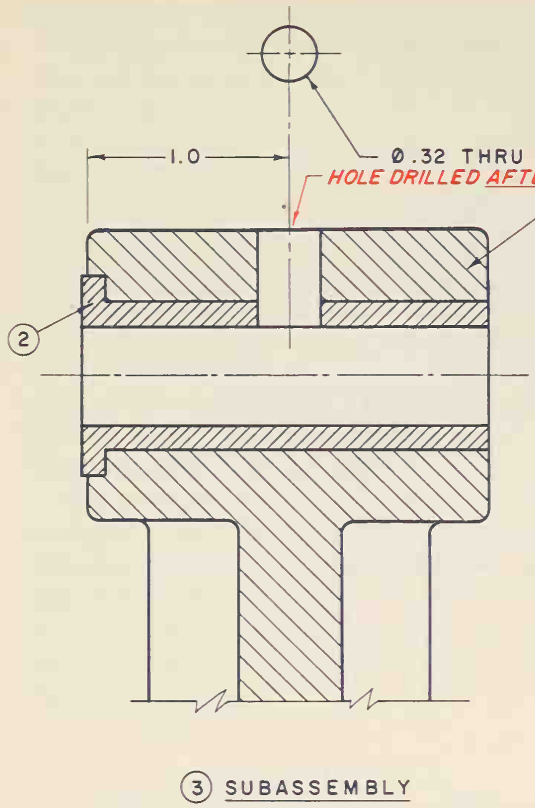


Figure 17-12 Subassembly drawing

required dimensions to drill the hole must be added to the subassembly drawing.

The subassembly is used whenever two or more small assemblies are permanently made up; and, alone with other parts, makes up the final assembly. There can be any number of subassemblies in the final assembly. Think of a subassembly as the major components needed to put together an automobile. The engine is a subassembly, the water pump is a subassembly, and the transmission is a subassembly, and so forth. These subassemblies, together with various single parts, make up the final assembly of the automobile.

Note that subassemblies are usually stocked and purchased as a unit by themselves.

Detail Drawings

Every part must have its own fully dimensioned detail drawing, with its own drawing number and title block. All information needed to manufacture the part is contained in the *detailed drawing*, including as many views as are needed to fully illustrate and dimension the parts.

The general practice in mechanical drafting is to draw only one part to one sheet of paper, regardless of how small the part is.

Most companies use general detail drawings as just described. However, some companies break the detail drawings into the various manufacturing processes, such as:

- Pattern detail drawings for castings
- Cast detail drawings for cast parts
- Machine detail drawings for machining processes
- Forging detail drawings for forged parts
- Welding detail drawings for welded parts
- Stamping detail drawings for stamped parts

Purchased Parts

A manufacturing company cannot make such standard items as nuts, bolts, screws, and washers as cheaply as companies that specialize in making these fasteners. All design, therefore, should specify standard parts whenever possible. Purchased parts are not drawn but are simply called-out on the assembly drawing. It is important that all specific information be given for the particular purchased part. A full description must be given as to diameter, length, material, and so forth. Odd purchased parts, such as a 12-volt D.C. motor would list its size and a note such as: "12-VOLT, D.C. MOTOR, G.E. NO. 776113 OR EQUAL."

Modified Purchased Parts

A purchased part that needs to be modified, however slightly, must be fully detailed and dimensioned as with any detail part, except that under "material" the purchased part size and description is given, Figure 17-13. In this example, a standard 1/4-20 UNC x 1.5 long hex-head machine screw has a special tip and a .125 dia. hole in it. The standard fastener is drawn with the modifications added and dimensioned. The standard fastener is called-out in the title block under "material." This indicates that this particular part must be manufactured from a standard fastener.

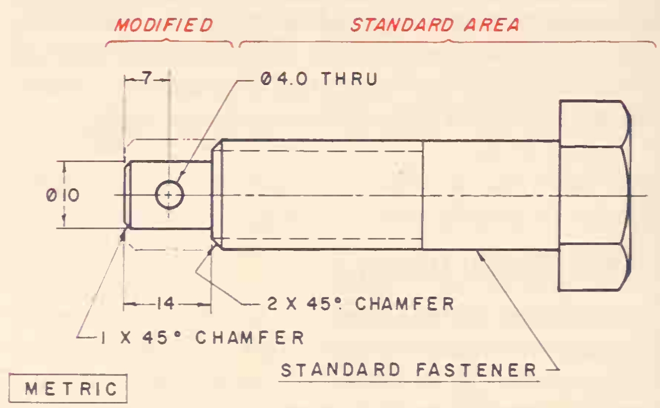


Figure 17-13 Drawing of modified purchased part

Patent Drawings

All patent applications for a new idea or invention must include a patent drawing to illustrate and explain its use. Patent drawings must be mechanically correct, and must adhere to strict patent drawing regulations, Figure 17-14.

Patent drawings are more pictorial and explanatory in nature than regular detail or assembly drawings. Center lines, dimensions, and notes are omitted from patent drawings. All features and parts are identified by numbers which refer to the written explanation of description of the new idea or invention. Line shading is used to improve readability.

All patent drawings must be done in ink on heavy white paper, exactly 10.0 x 15.0 in size, with a 1.0 border on all sides. A space of not less than 1.25 from the shorter border is left blank for data to be added by the patent office.

Because of the many patent drawing rules and requirements, special drafters are employed to make only patent drawings. A complete list of these standards can be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Write for the publication, *A guide for patent drawings.*

Computer Drawings

Refer to Chapters 10 and 11 for information about *computer drawings.*

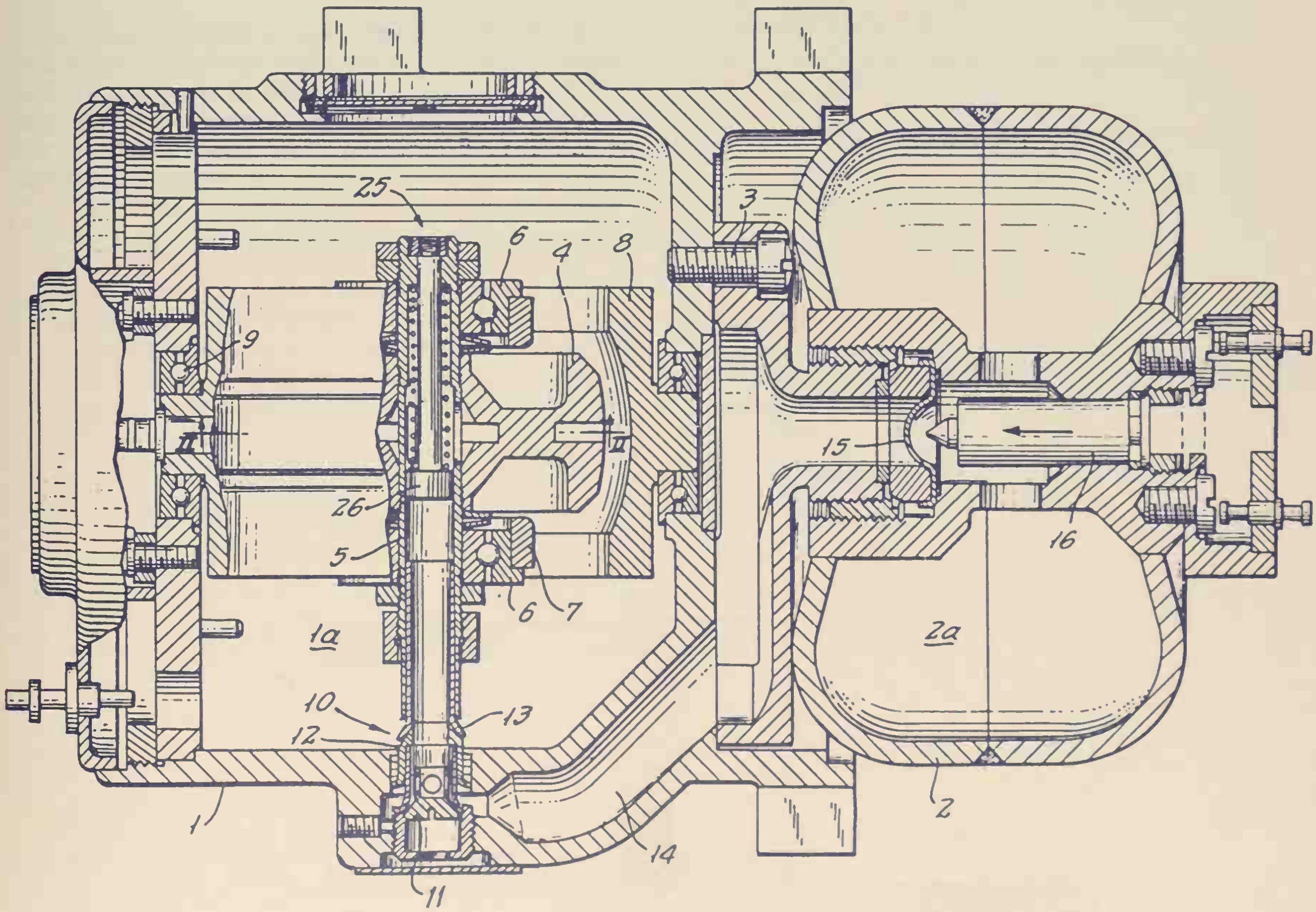


Figure 17-14 Patent drawing (*Courtesy Timex Corporation*)

Review

1. List the information that must be included in a title block according to the most recent ANSI standard.
2. What three general methods are used in listing parts of an assembly on a parts list?
3. Explain the design process.
4. What is a modified purchased part, and does it need a drawing? Explain.
5. Explain the drawing revision process.
6. What is the difference between an assembly drawing and a subassembly drawing?
7. What is the invention agreement, and who must sign it?
8. What is a design layout drawing and who usually draws it?
9. List the important parts of the drawing that should be checked by the drafter before submitting the final drawing to the checker.
10. What should be included in a personal technical file?
11. Explain in full what an assembly drawing is.
12. Explain what must be done if a drawing revision is extensive and the drawing must be completely redrawn.

Chapter Seventeen Problems

The following problems are intended to give the beginning drafter knowledge of the many drafting procedures, and practice in developing detail drawings, subassembly drawings, and assembly drawings. Students should practice calculating tolerances for various fits of mating parts, and filling out parts lists.

The steps to follow in developing these problems are:

Step 1. Using a sharp 4-H lead, lay out a full scale design layout drawing of the problem, using the basic overall dimensions provided. Lay out and design any missing dimensions, using standard sizes and materials. (Use as many views as necessary to fully illustrate the assembly.)

Step 2. Calculate all required fits and tolerances as necessary on a separate sheet of paper.

Step 3. Center a fully dimensioned detail drawing of each part using the latest drafting standards. Apply tolerances and limits to mating parts. Assign the drawing number per the numbering provided on the design layout drawing, and include the material to be used.

Step 4. Develop *subassembly drawings* wherever two or more parts are assembled, *before* the final assembly, as needed. List each part and part number, using standard drafting practice. (Material is to be listed "AS NOTED.")

Step 5. Develop a final assembly drawing and list each part and part number, using standard drafting practice. (Material is to be listed "AS NOTED.") Use standard fasteners wherever possible.

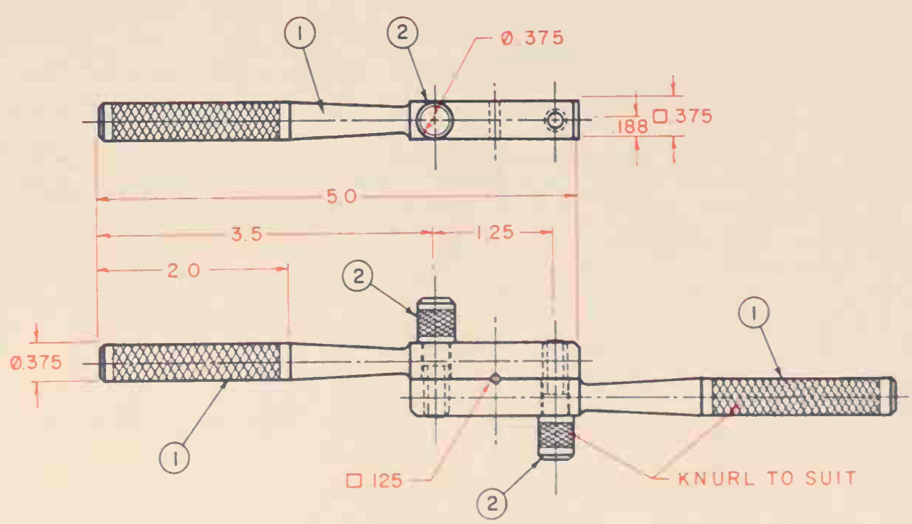
Step 6. Develop a parts list of the assembly. List parts per standard drafting practices, in the recommended order of assembly.

Step 7. Recheck all drawings and related calculations for accuracy.

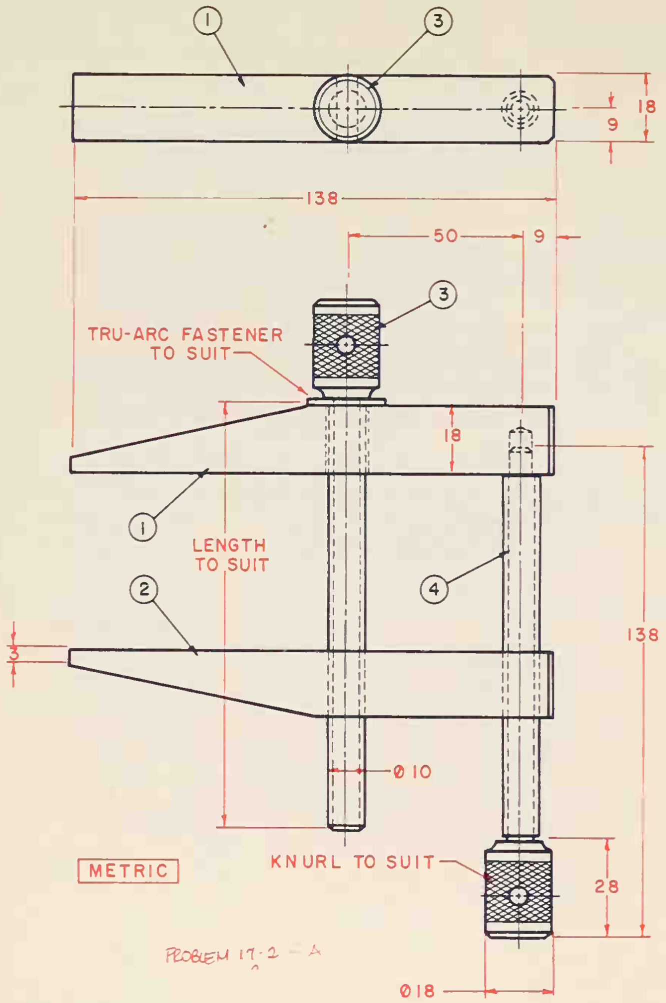
Step 8. Make a list of recommendations as to how the design could be improved.

Problems 17-1 through 17-8

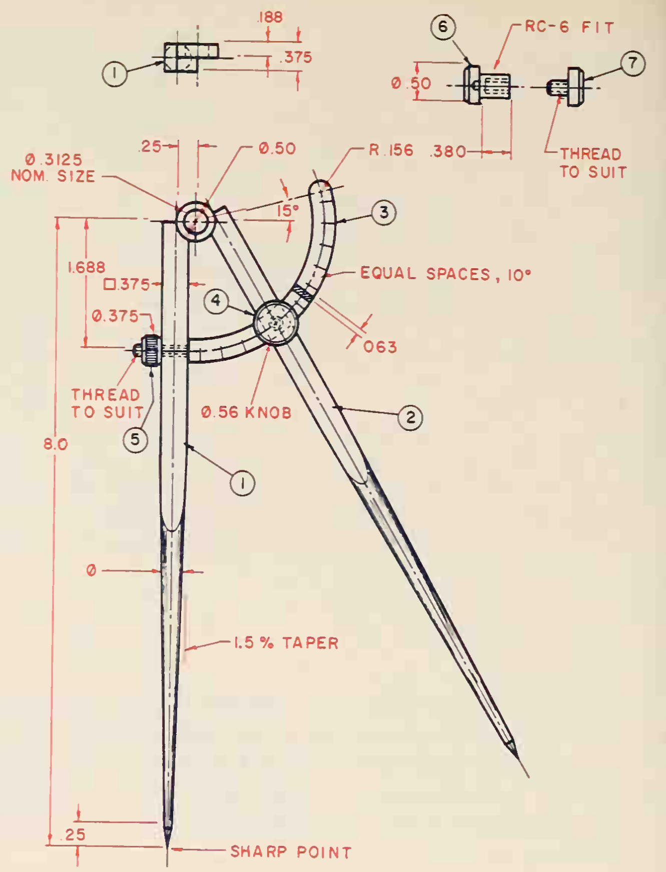
Follow the eight listed steps to develop Problems 17-1 through 17-8.



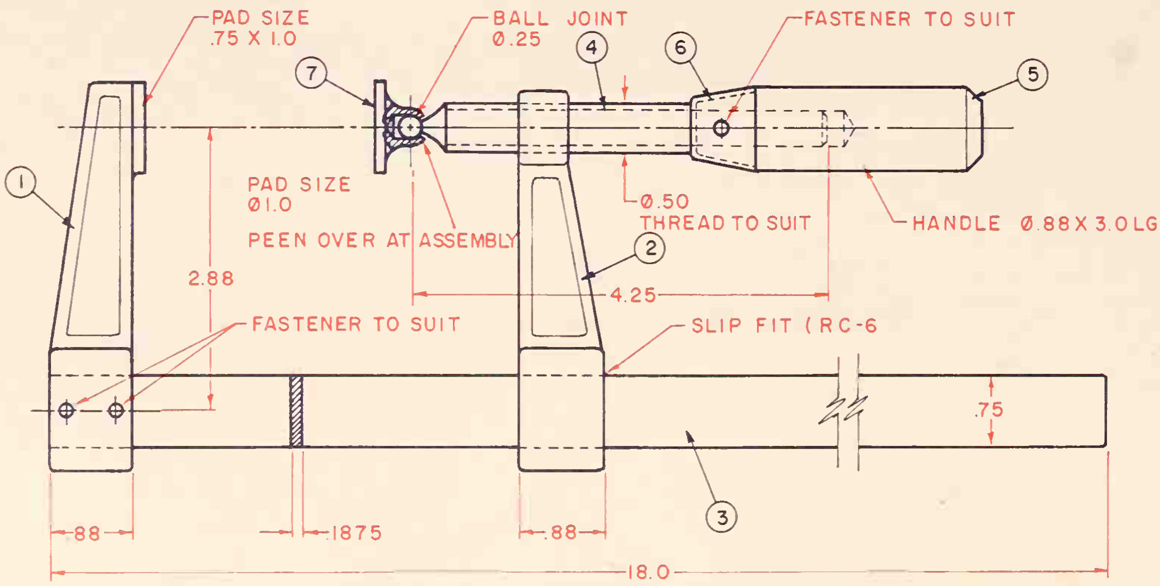
Problem 17-1



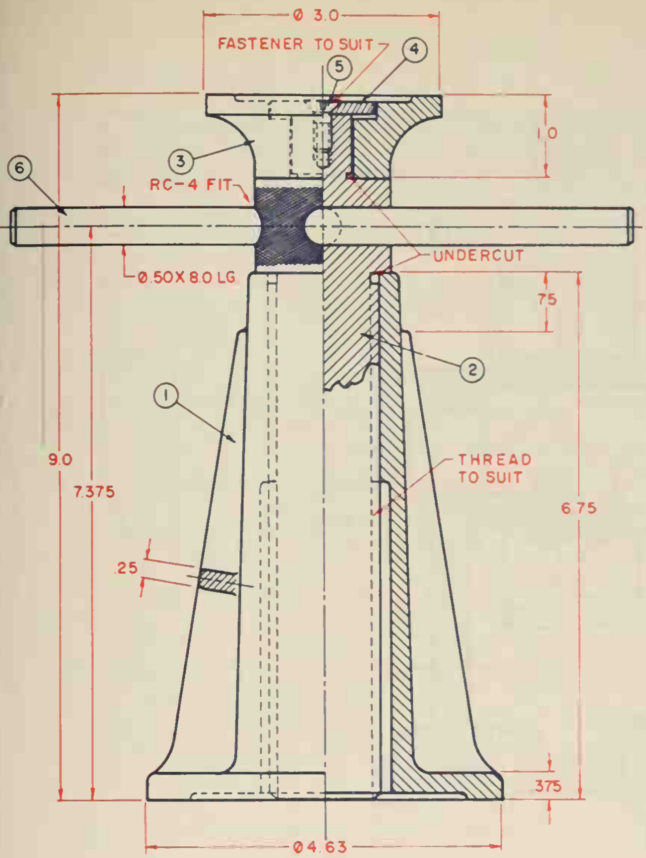
Problem 17-2



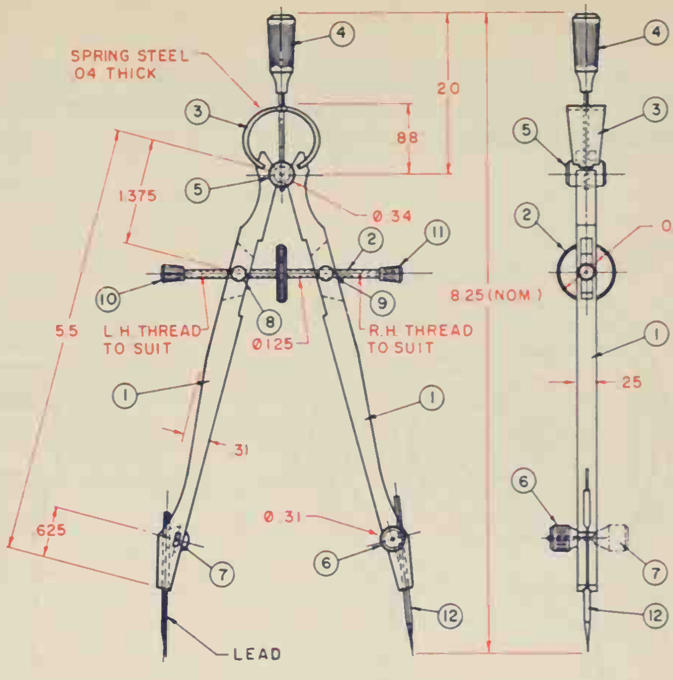
Problem 17-3



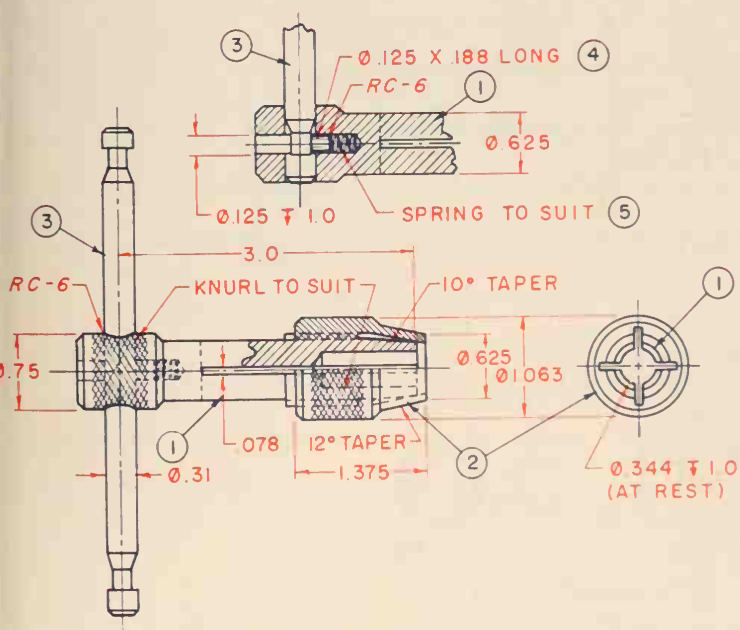
Problem 17-4



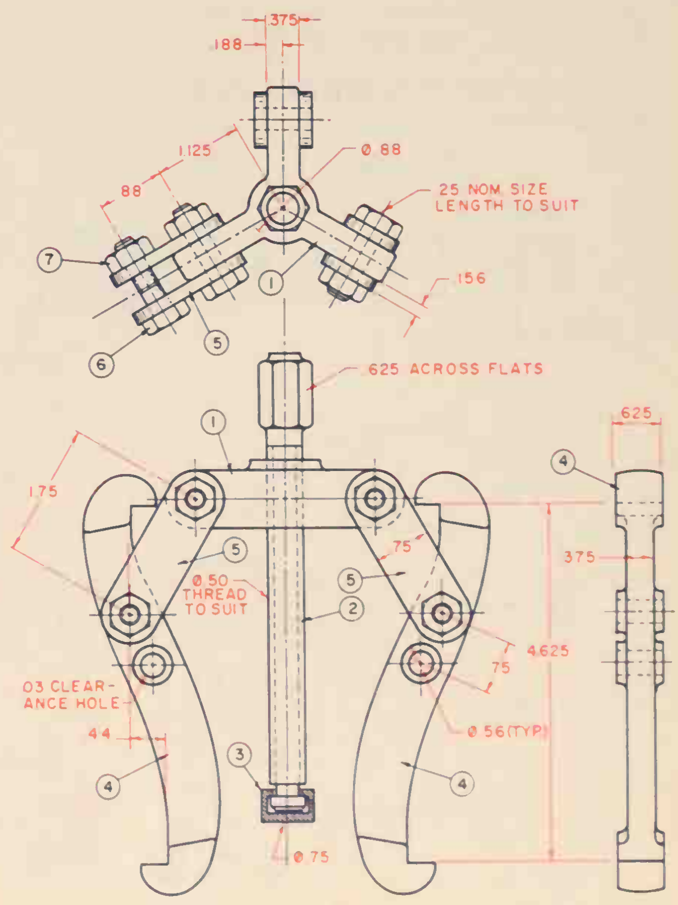
Problem 17-5



Problem 17-7



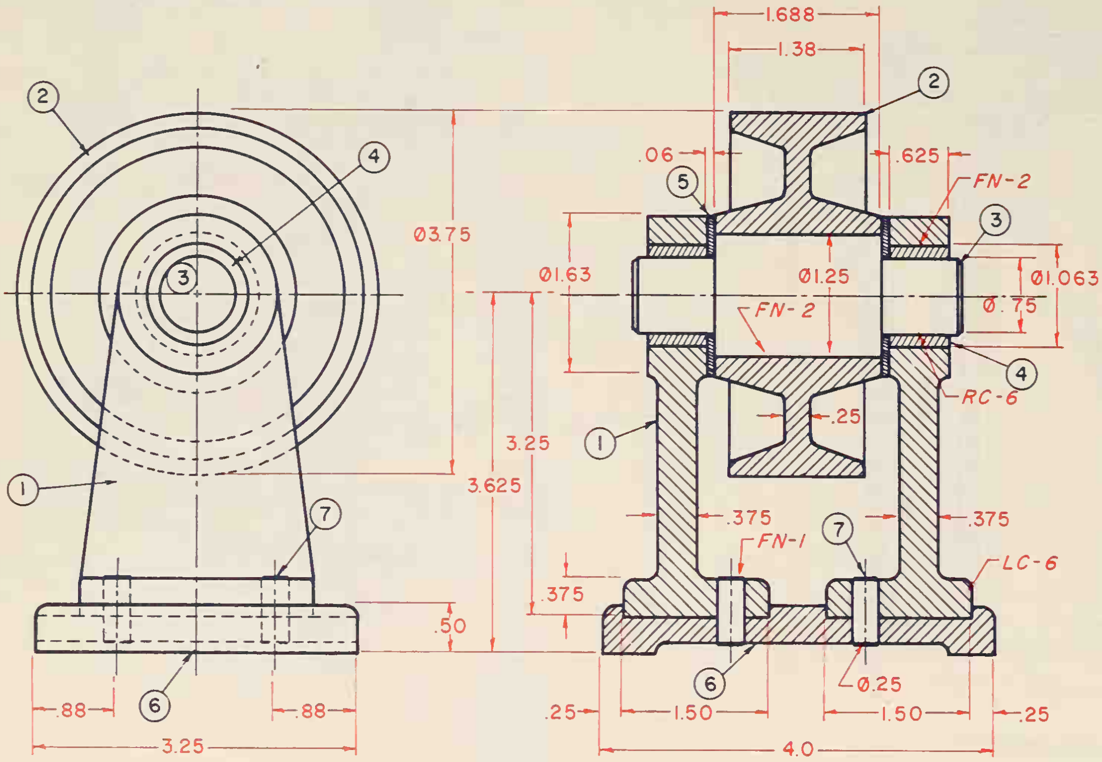
Problem 17-6



Problem 17-8

Problem 17-9

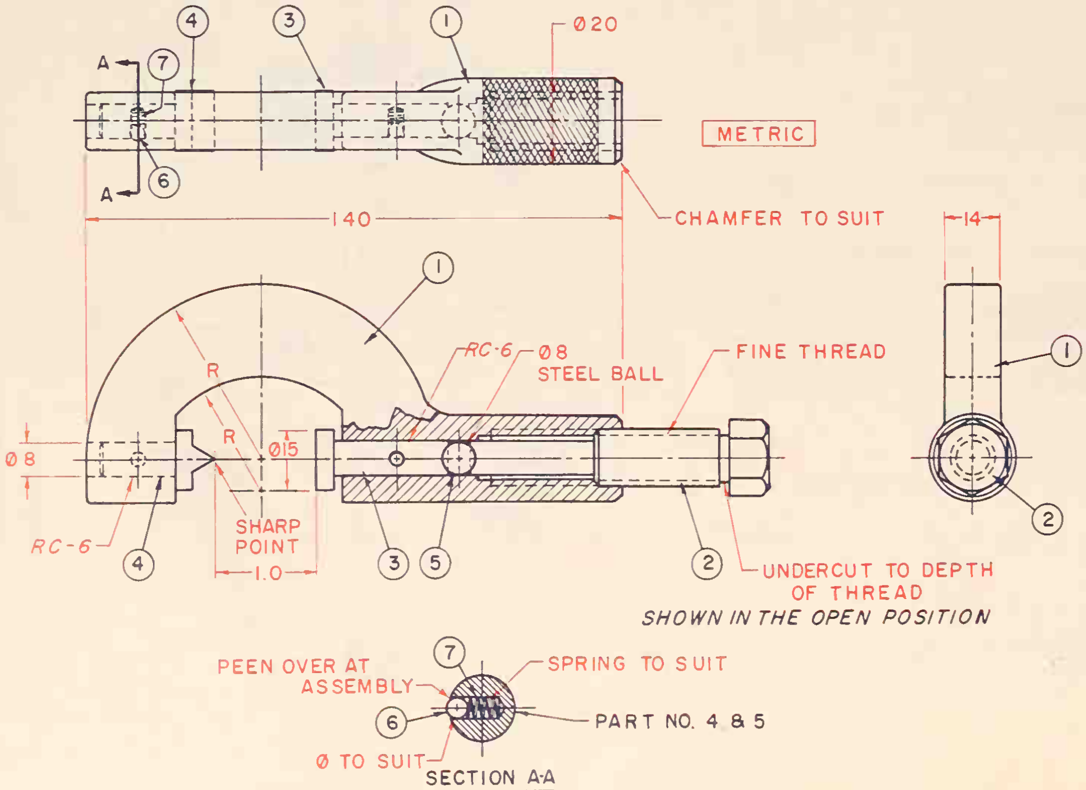
Follow the eight listed steps to develop Problem 17-9. Redesign the layout to include standard ball bearings in place of the bushings, part No. 4.



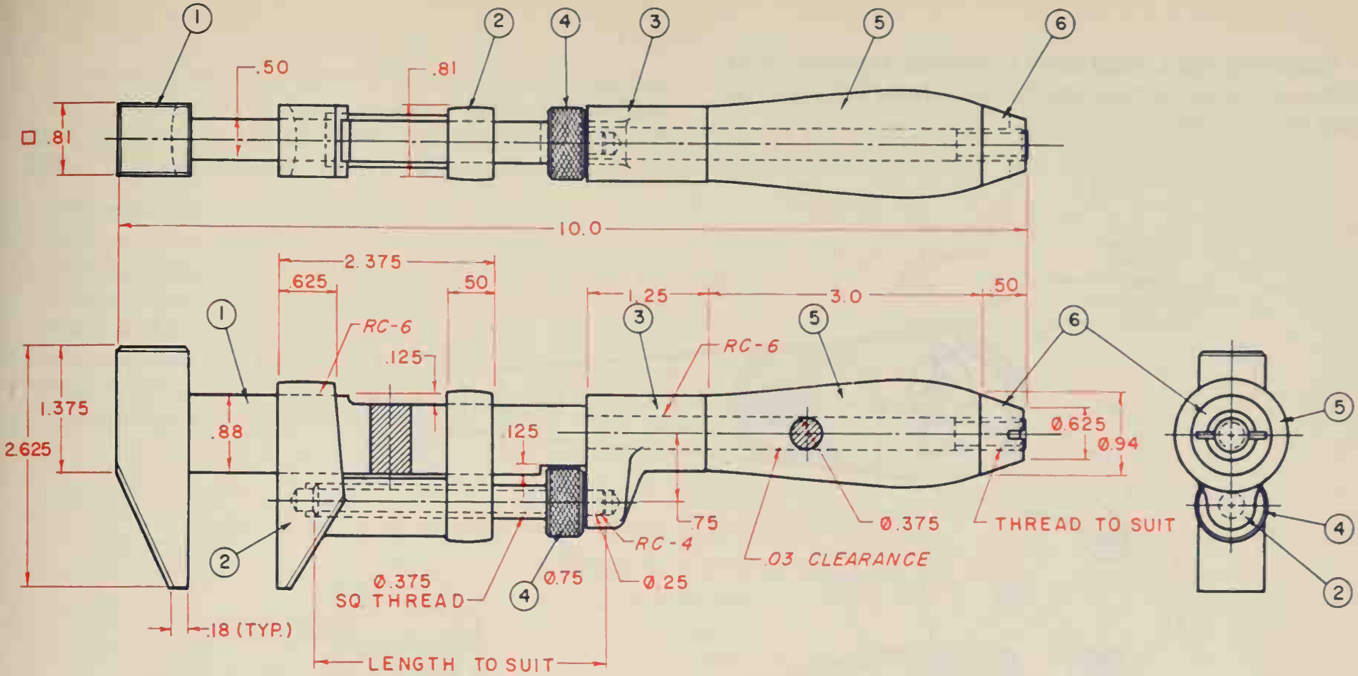
Problem 17-9

Problems 17-10 through 17-12

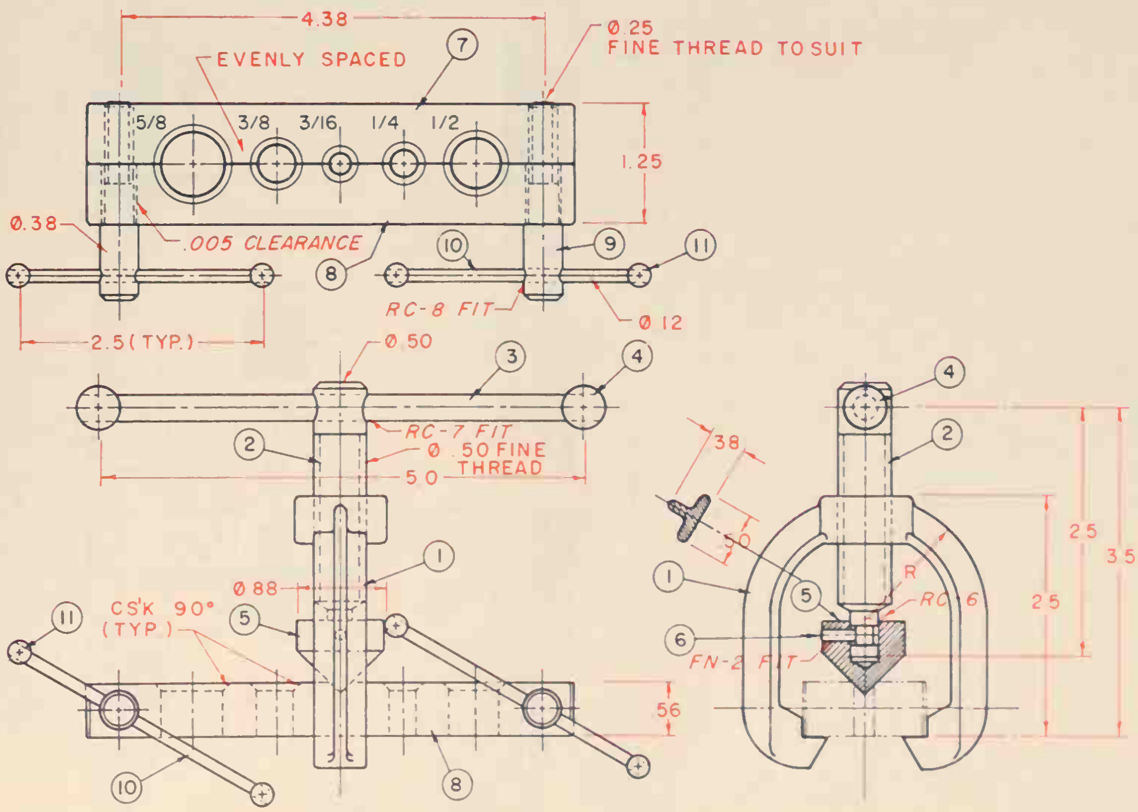
Follow the eight listed steps to develop Problems 17-10 through 17-12.



Problem 17-10



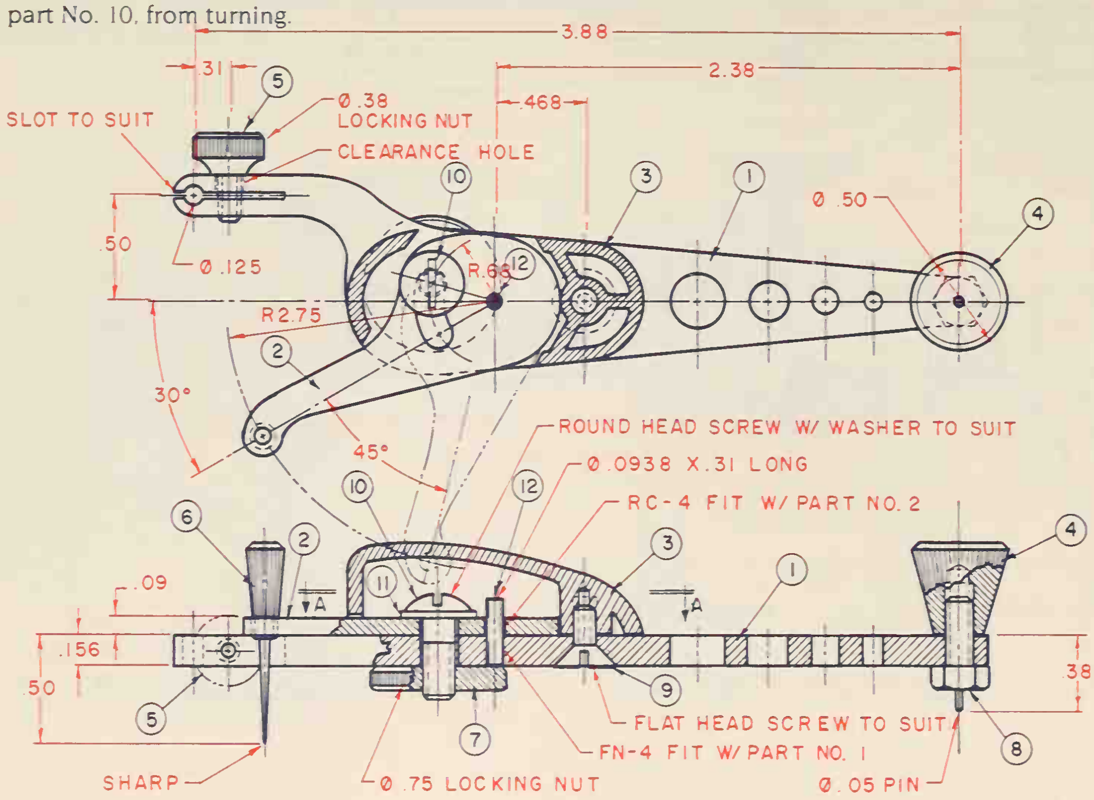
Problem 17-11



Problem 17-12

Problem 17-13

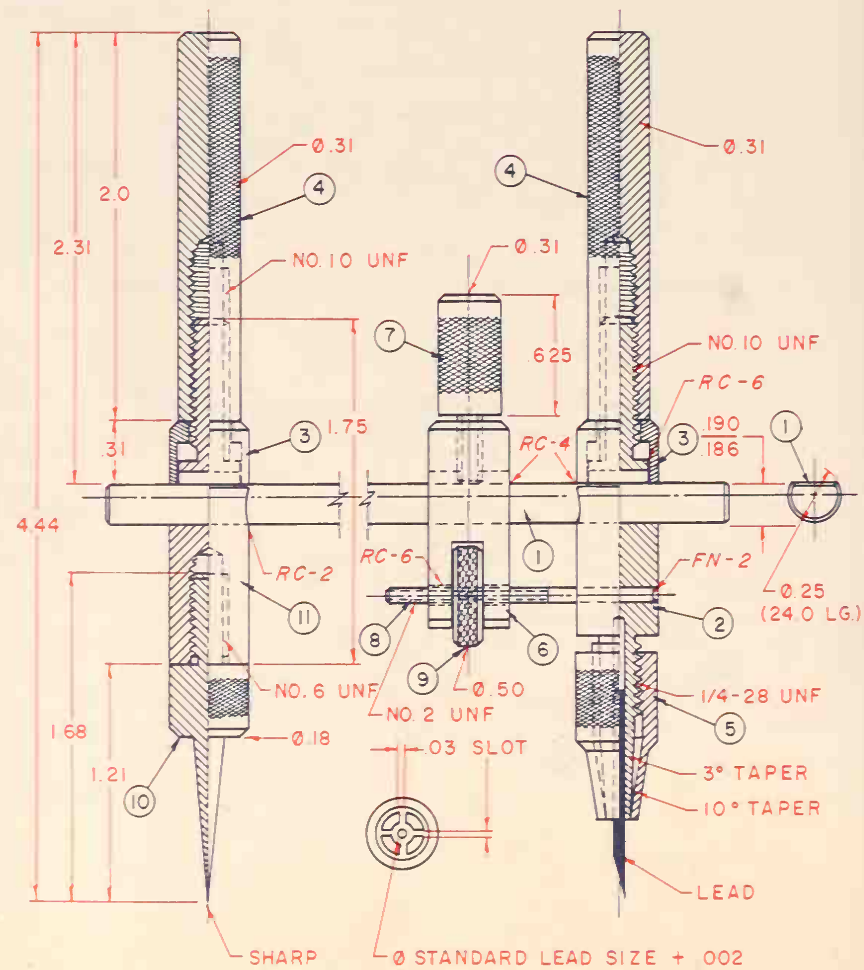
Follow the eight listed steps to develop Problem 17-13. Redesign the layout to secure the round head locking screw, part No. 10, from turning.



Problem 17-13

Problem 17-14

Follow the eight listed steps to develop Problem 17-14.

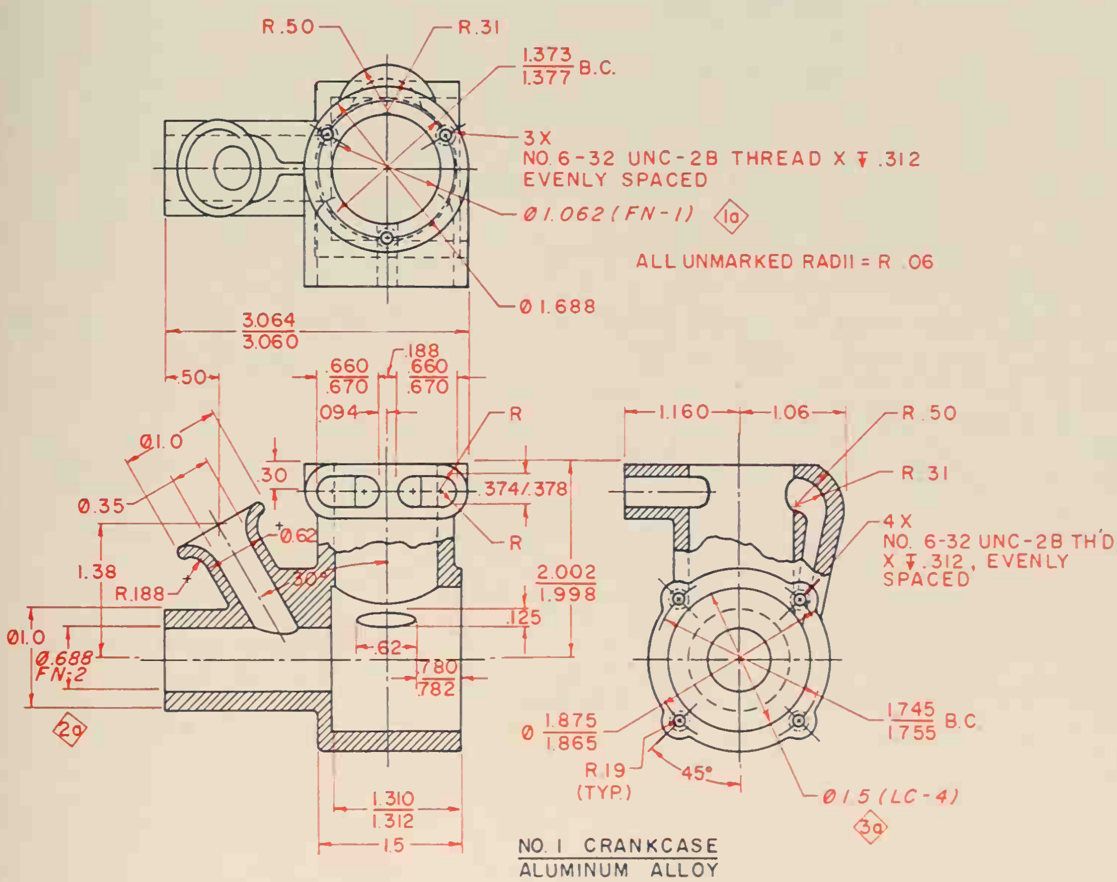


Problem 17-14

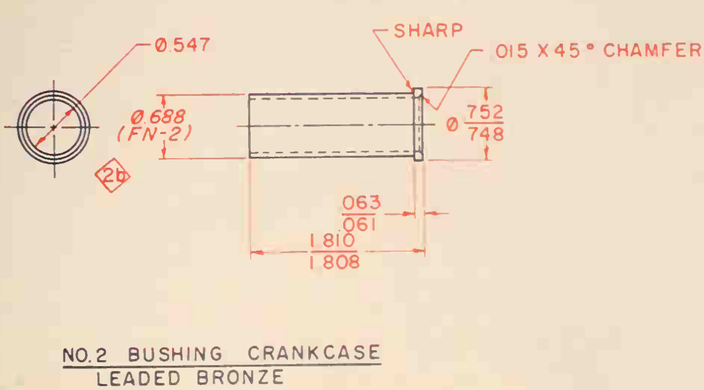
Problem 17-15

Using detail drawings 17-15-1 through 17-15-15, lay out a three-view assembly drawing. Call off parts per standard drafting practices. Calculate the following fits using each of the 15 detail drawings. Show all calculations.

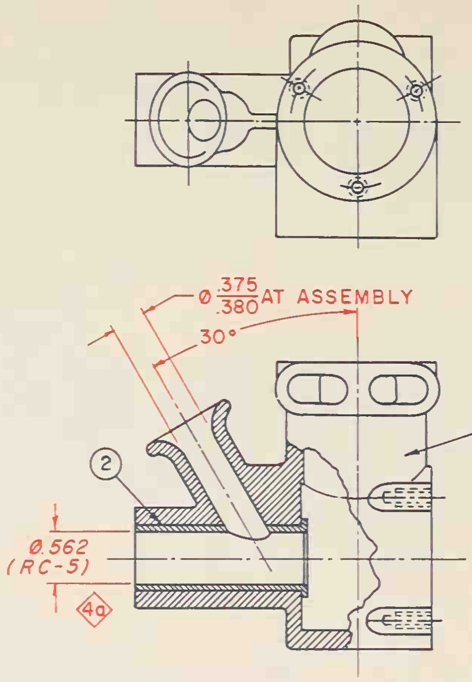
Part numbers 1-12, FN-1/1.062
Part numbers 1-2, FN-2/.688
Part numbers 1-11, LC-4/1.50
Part numbers 3-4, RC-5/.562
Part numbers 4-5, RC-5/.375
Part numbers 4-8, LC-2/.125
Part numbers 9-14, FN-2/.250
Part numbers 13-14-15, RC-6/.938



Problem 17-15-1

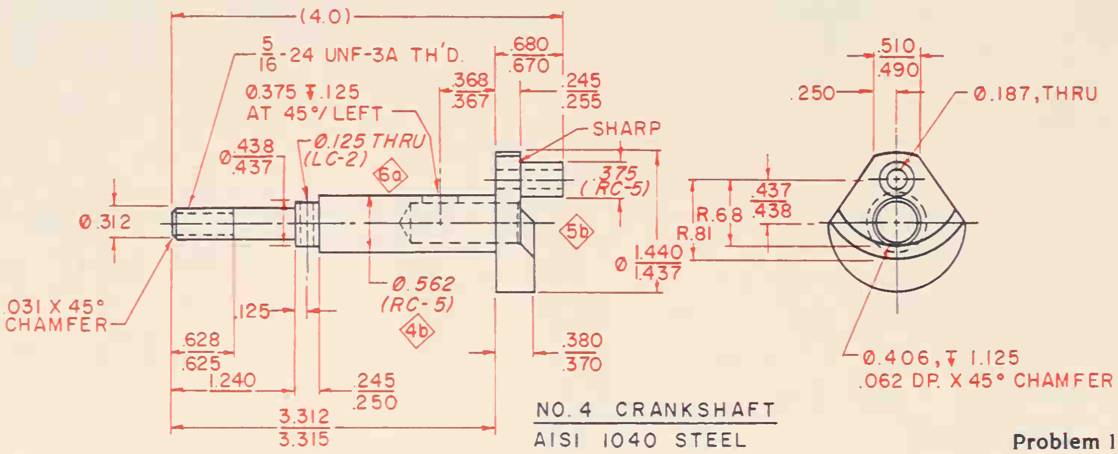


Problem 17-15-2



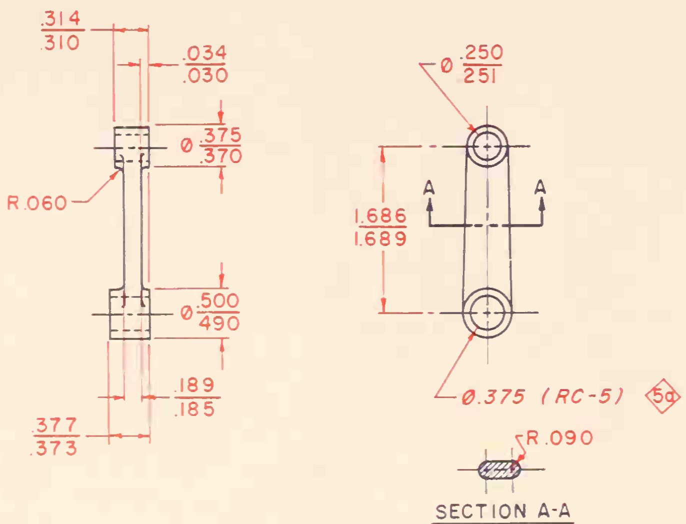
NO. 3 CRANKCASE SUBASSEMBLY
MAT'L. AS NOTED

Problem 17-15-3



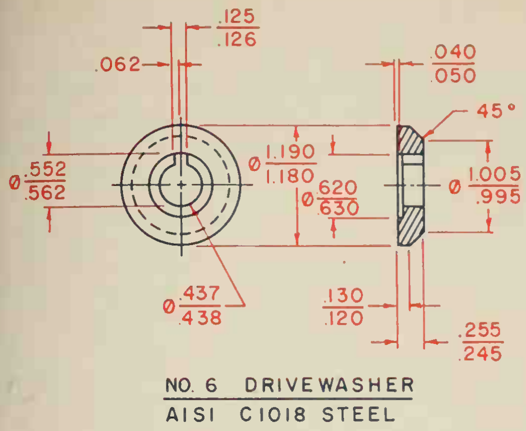
NO. 4 CRANKSHAFT
AISI 1040 STEEL

Problem 17-15-4

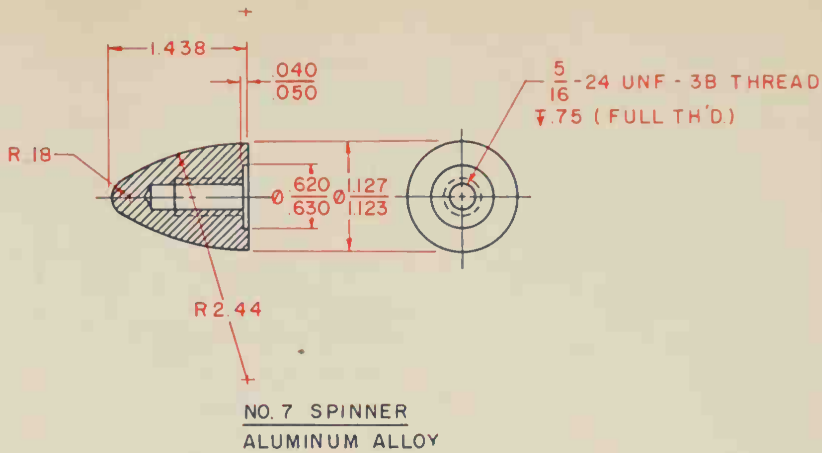


NO. 5 ROD-CONNECTING
ALUMINUM ALLOY 7075-T6

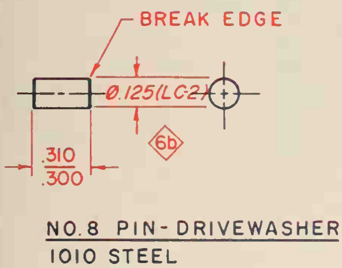
Problem 17-15-5



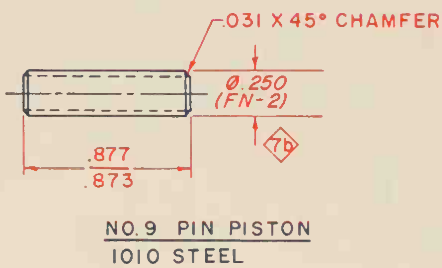
Problem 17-15-6



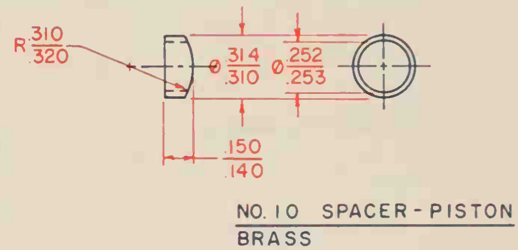
Problem 17-15-7



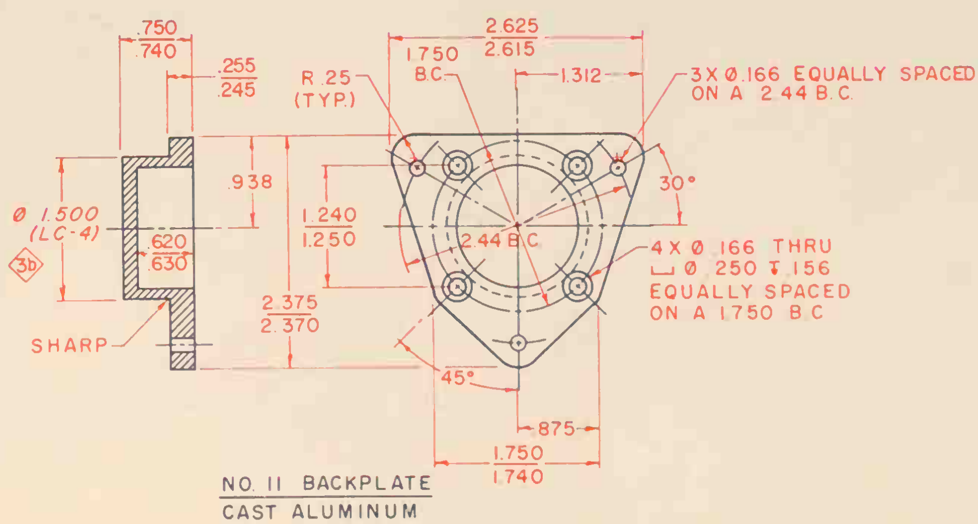
Problem 17-15-8



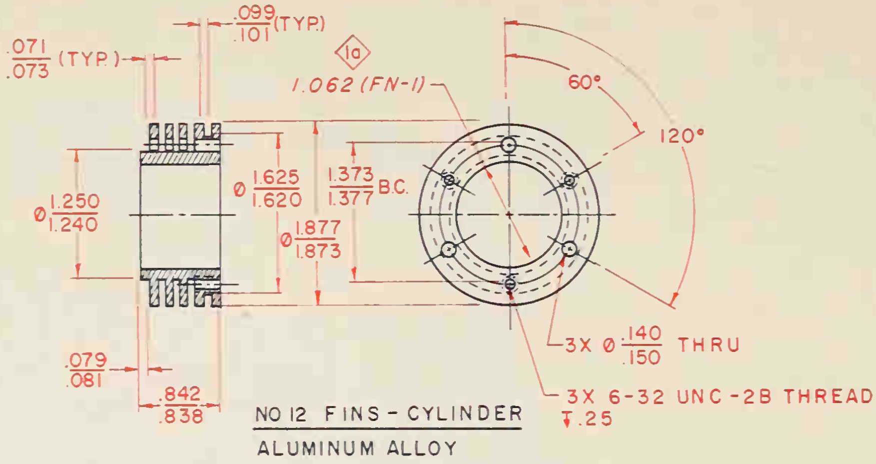
Problem 17-15-9



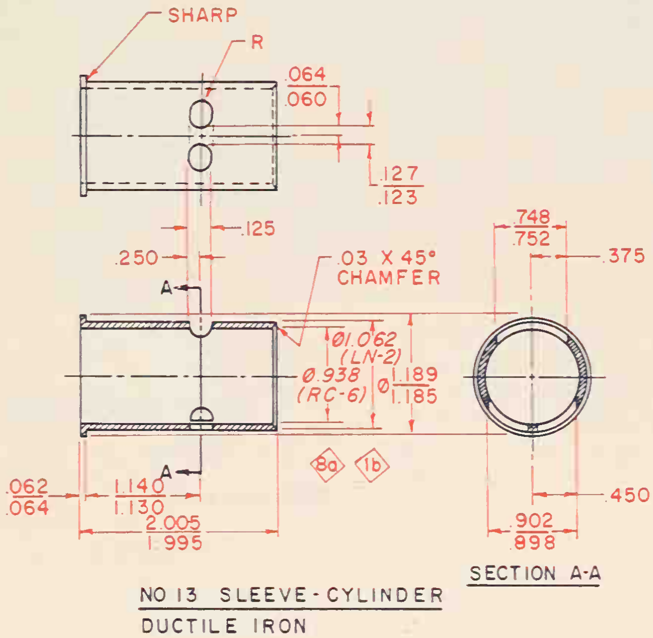
Problem 17-15-10



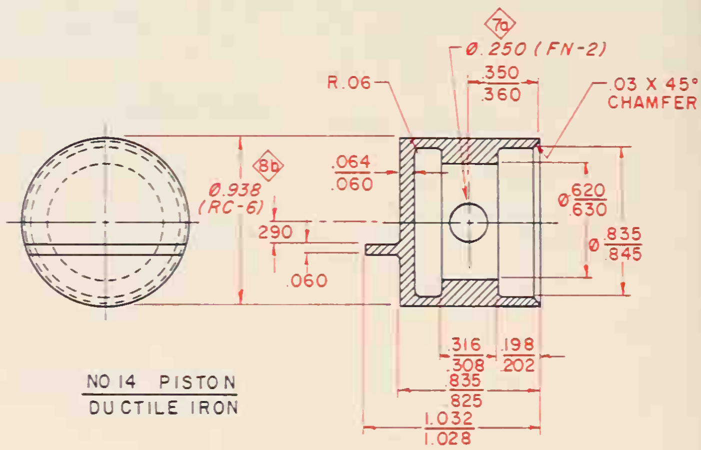
Problem 17-15-11



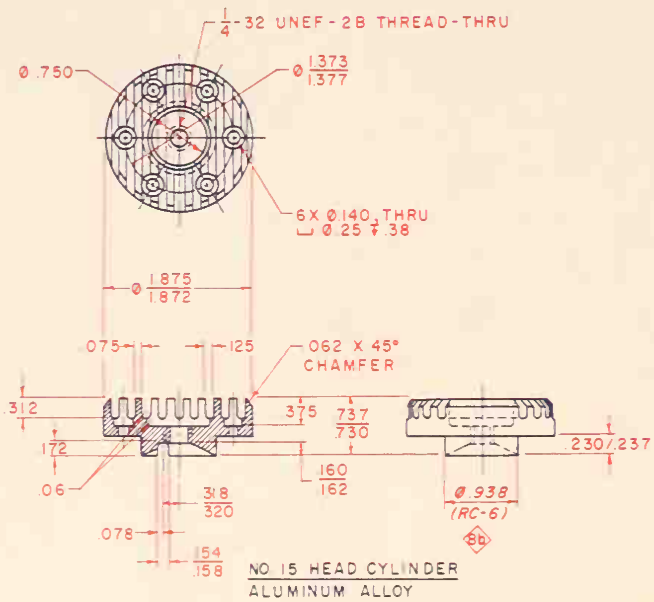
Problem 17-15-12



Problem 17-15-13



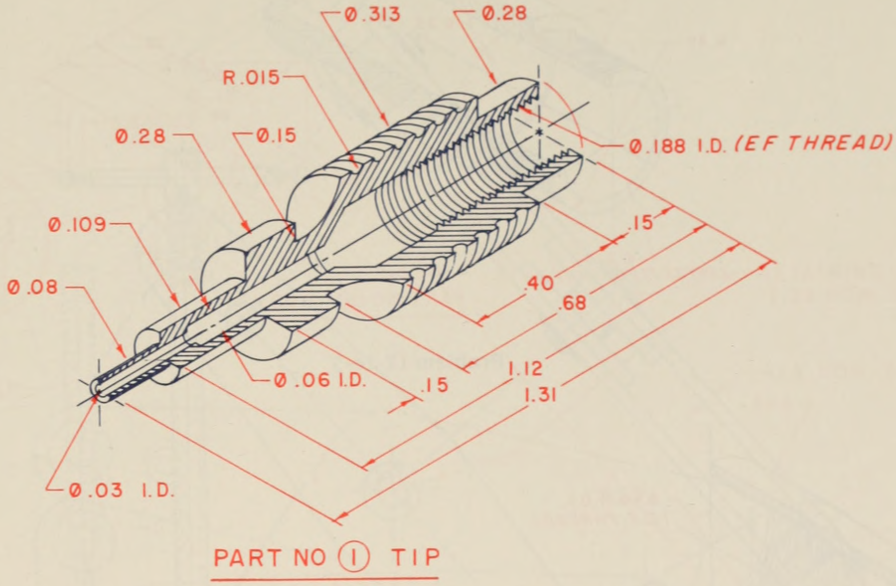
Problem 17-15-14



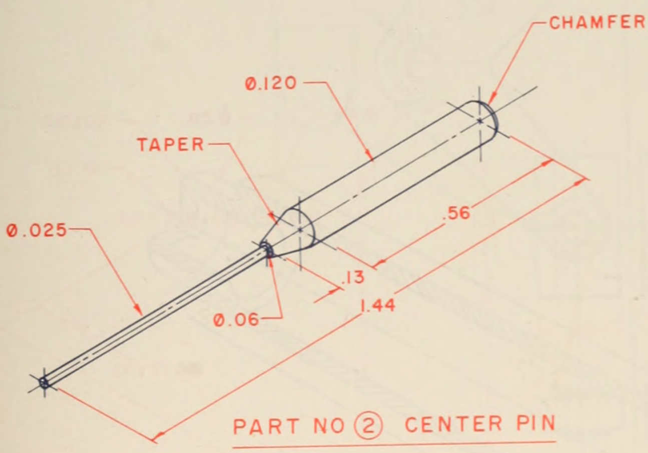
Problem 17-15-15

Problem 17-16

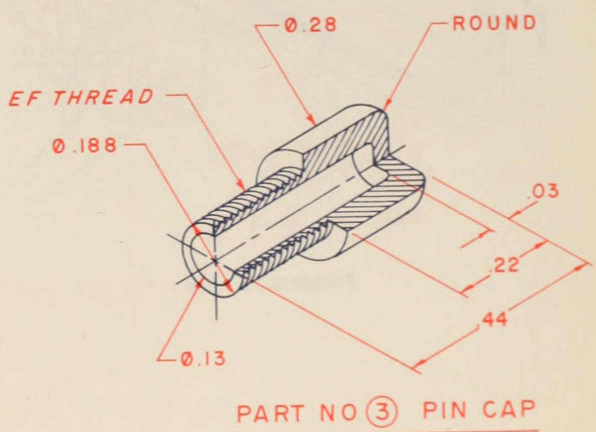
Using detail drawings 17-16-1 through 17-16-7, lay out a one-view assembly drawing. Call off parts per standard drafting practices. Design special extra-fine threads where required.



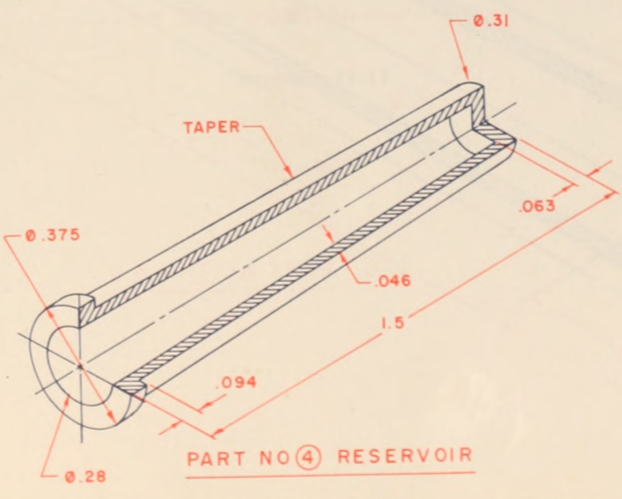
Problem 17-16-1



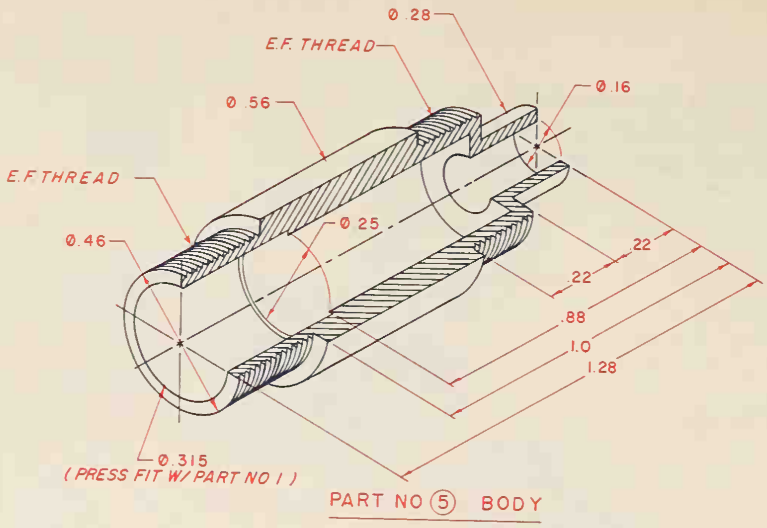
Problem 17-16-2



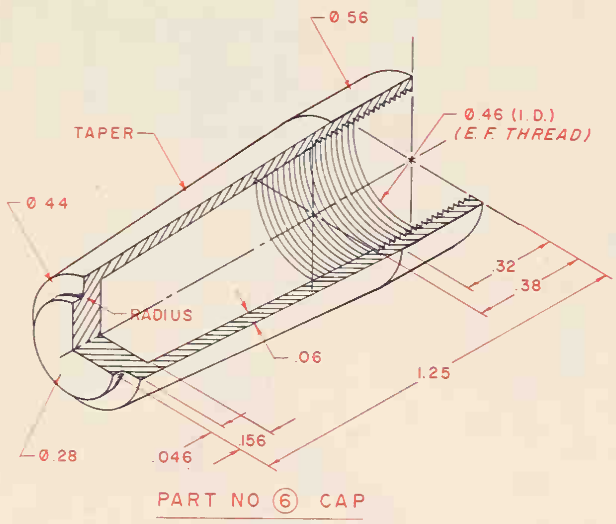
Problem 17-16-3



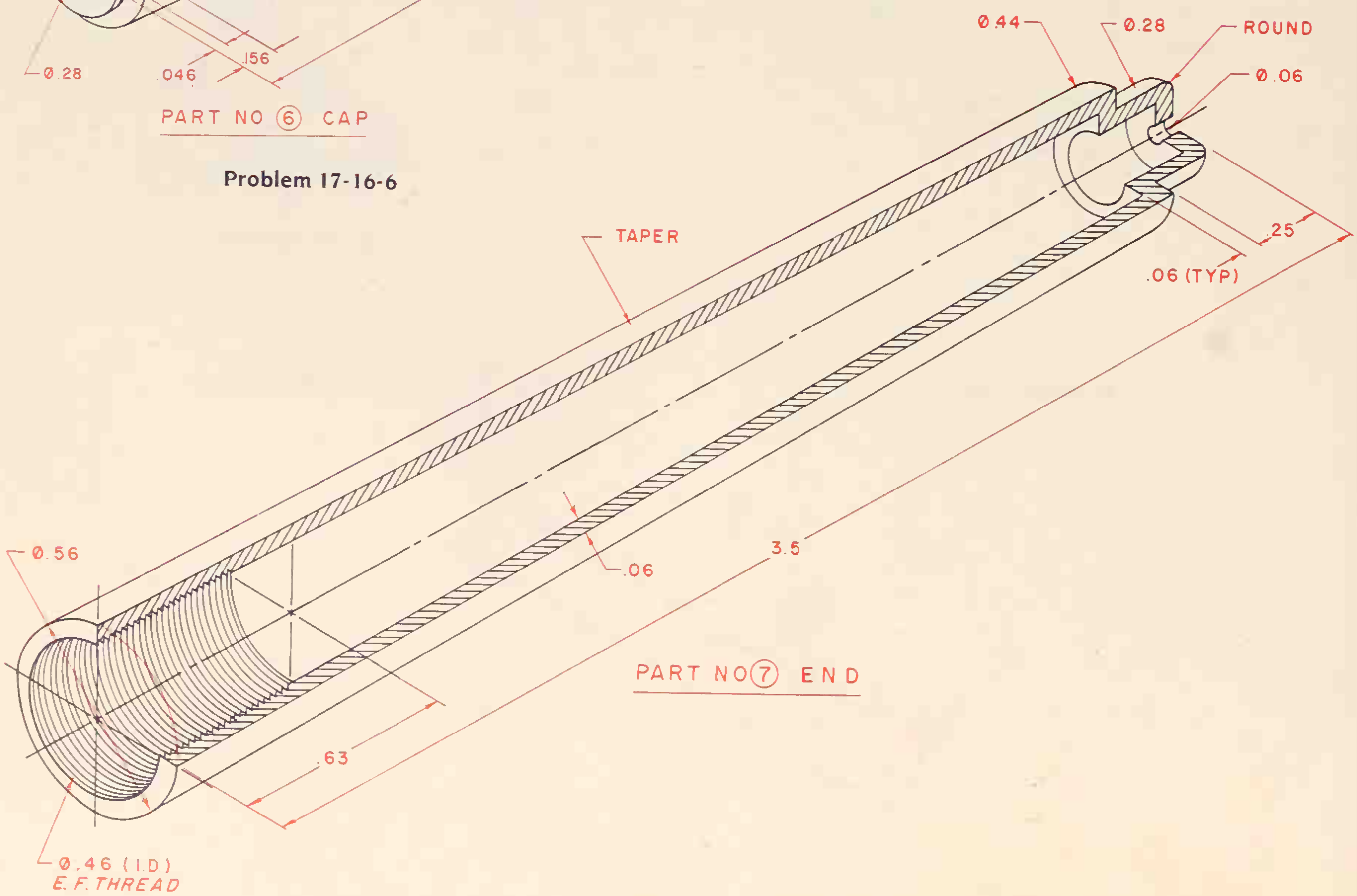
Problem 17-16-4



Problem 17-16-5



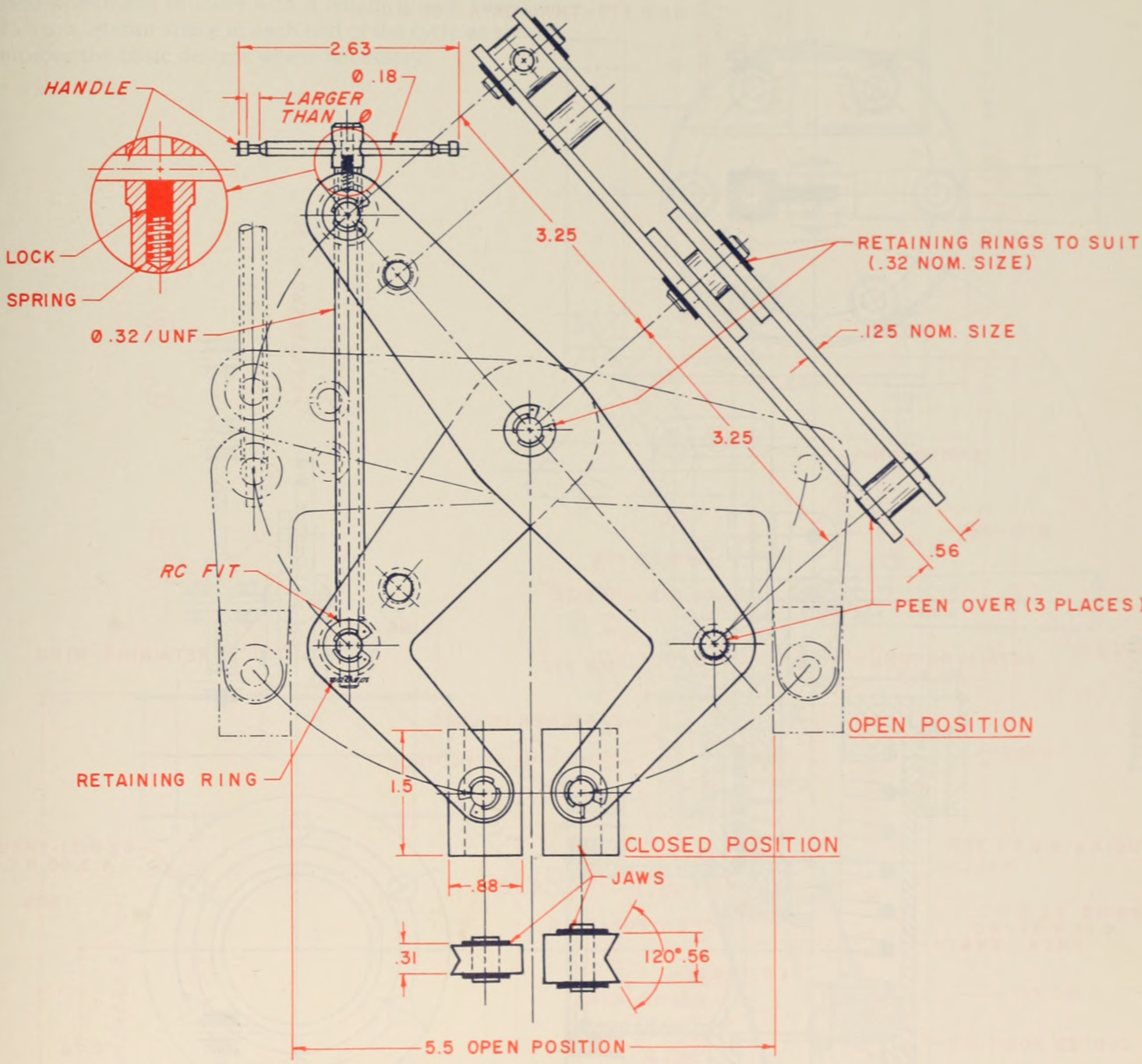
Problem 17-16-6



Problem 17-16-7

Problem 17-17

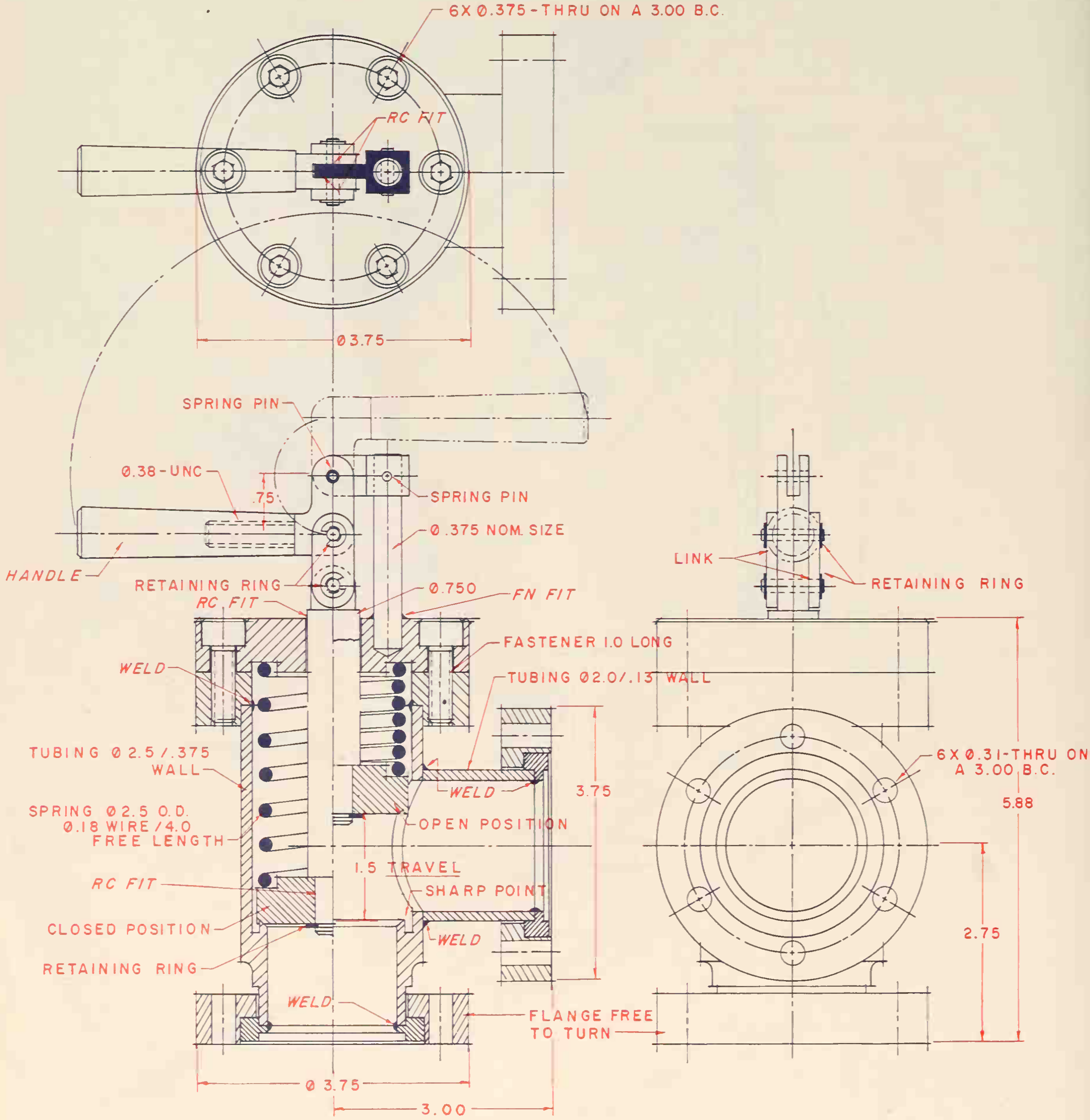
Follow the eight listed steps to develop Problem 17-17.



Problem 17-17

Problem 17-18

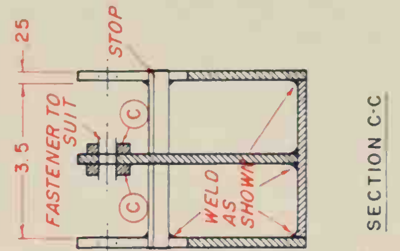
Follow the eight listed steps to develop Problem 17-18.

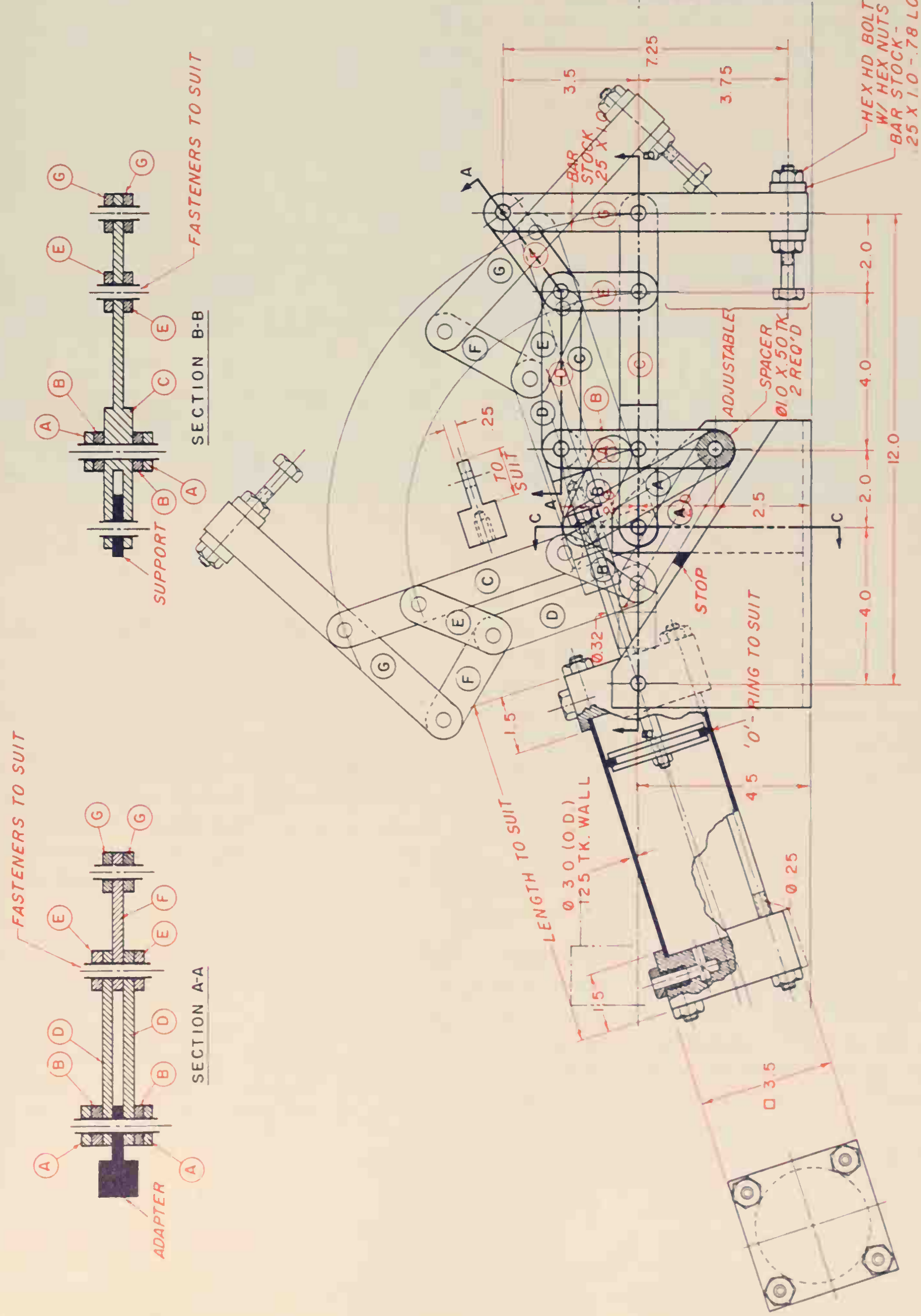


Problem 17-18

Problem 17-19

Follow the eight listed steps to develop Problem 17-19. Draw the clamping device in the position shown, and draw arm A at 30° and 60° to the left as shown. Design a complete pneumatic cylinder with a length to suit based on .75 extra interior space at each end of the cycle as shown. Improve the basic designs where necessary.

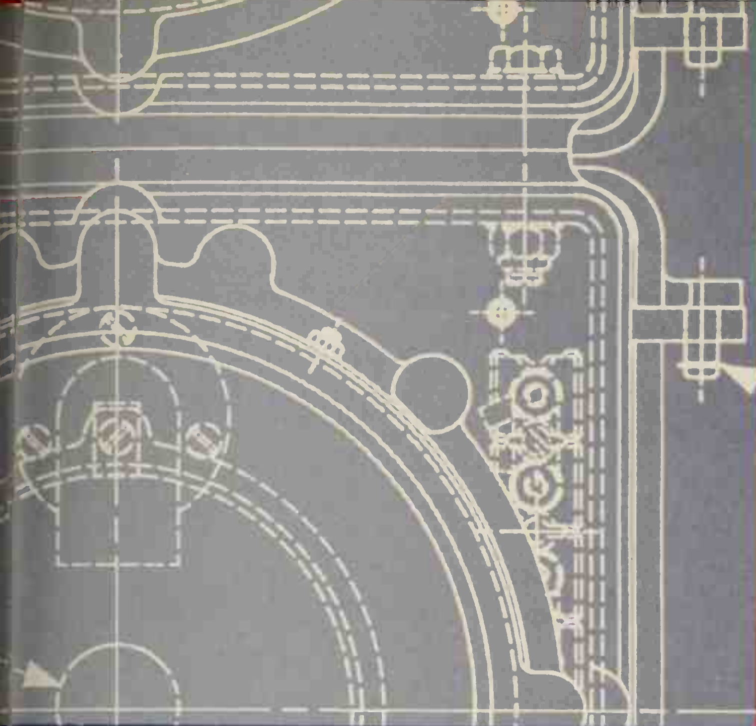




Problem 17-19

Problem 17-20

Choose an existing mechanical device of your choice and develop a design layout drawing of it. Improve the overall design for its function, or for better use of standard materials in place of special materials. Follow the eight listed steps.



CHAPTER 18

Although pictorial drawings are not used extensively in drafting and designing, the drafter should have the ability to create a pictorial drawing if necessary. A pictorial drawing is often needed in industry to convey an idea, present a new product, or to aid in the assembly of a completed object. This chapter describes and illustrates how to develop the major kinds of pictorial drawings, and discusses the techniques used to draw such features as threads, chamfers, and knurls. How to add dimensions is fully illustrated.

PICTORIAL DRAWINGS

Pictorial drawings are, as their name implies, pictorial views of an object. They are used in industry for sales presentations, to aid workers on complicated assemblies, to record new design ideas, for owner's manuals and parts catalogs, and for technical printed articles. In industry, a technical illustrator usually does most of this type of drawing, but all drafters should have a basic working knowledge in this area of drawing. This chapter touches on the various kinds of illustrations used, and basically how they are developed.

Types of Pictorial Drawings

Three types of pictorial drawings are used in industry today: axonometric, oblique, and perspective. Each type is illustrated using a simple cube in order that they may be compared and studied. Each is explained in full.

Axonometric Drawings

In *axonometric drawing*, an object is represented by its perpendicular projection on a surface so that it appears as inclined and shows three faces. Axonometric projection includes isometric, dimetric and trimetric projections, Figure 18-1. It is customary to consider the three edges of the basic shape that meet at the corner *nearest* the viewer as the *axonometric axes*, Figure 18-2.

Isometric Projection

Isometric means "equal measure"; all three principal edges or axes are projected with equal 120° angles, Figure 18-3. Any line on any surface that is either parallel to or perpendicular to one of the principal edges is called an *isometric line*. Any line on any surface that is *not* either parallel to or perpendicular to one of the principal edges is called a *nonisometric line*. In drawing an isometric projection, use the 30°-60° triangle to construct all isometric lines.

Technically, an isometric projection should be drawn approximately 80% of its true size, but, in actual practice, it is drawn full size. Isometric templates and grid paper are available to aid and speed up the drawing process.

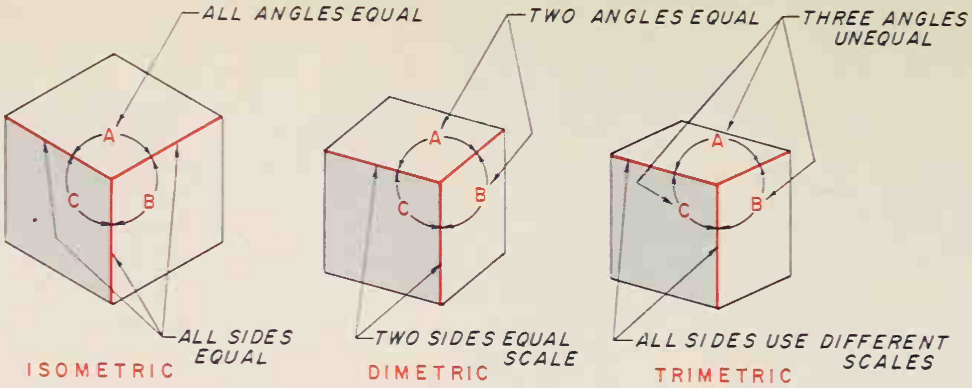


Figure 18-1 Axonometric projections

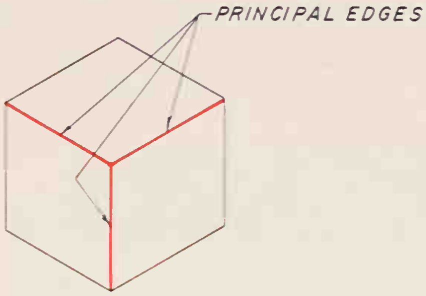


Figure 18-2 Axonometric axes

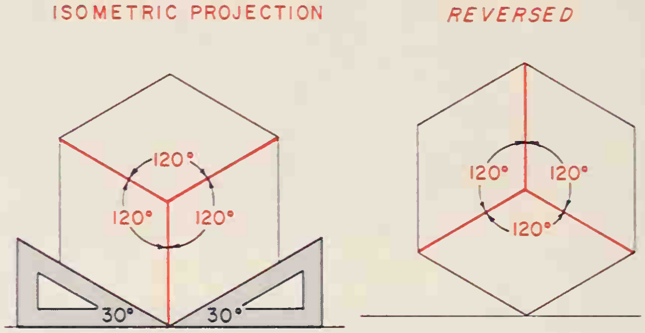


Figure 18-3 Isometric projection

Dimetric Projection

Dimetric projection differs from isometric projection in that only *two* angles are equal. Figure 18-4 illustrates some of the many combinations used to draw a dimetric projection.

In drawing a dimetric drawing, the object is turned so that two of the axes make the *same* angle with the plane of projection while the third is at a different angle. Edges that are parallel to the first two axes are drawn full size. The edge parallel to the third axis is drawn to a different scale. Because two different scales are used, less distortion is apparent and the object looks more natural.

A dimetric drawing is laid out in exactly the same way as an isometric drawing. All layout procedures to locate and draw nondimetric lines, circles, and arcs are exactly the same as those used in isometric projections.

Isometric and dimetric grid paper are available to aid and speed up the drawing process, Figure 18-5. Dimetric templates are also available.

Trimetric Projection

In *trimetric projection* the axes are rotated so that each of the three axes are drawn at different angles to the plane of projection. Each axis uses a different scale

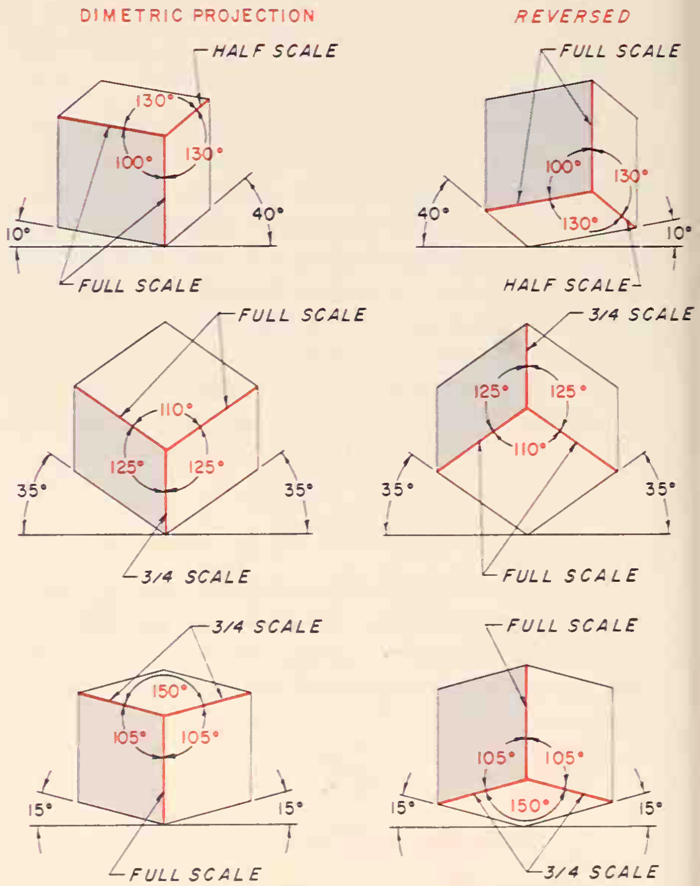


Figure 18-4 Dimetric projection

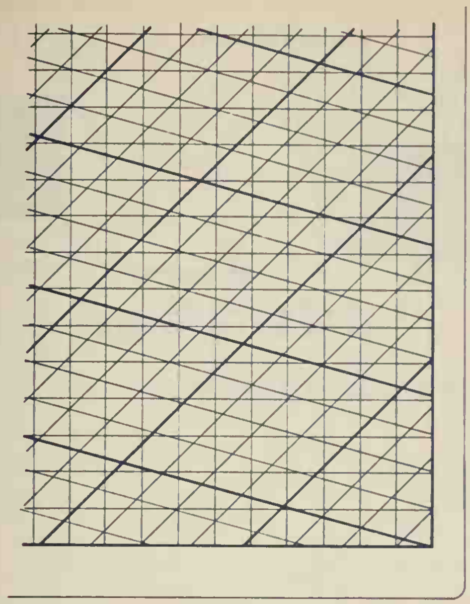


Figure 18-5 Isometric and dimetric grid

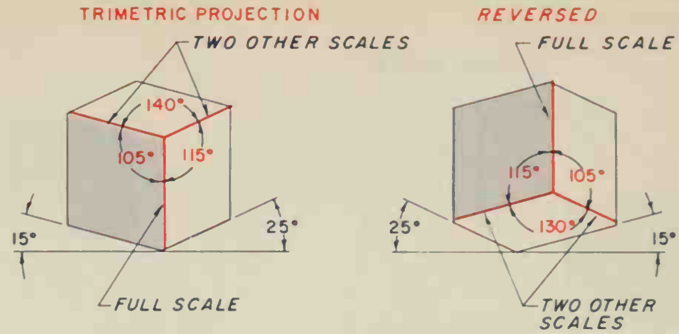


Figure 18-6 Trimetric projection

of reduction, Figure 18-6. Of the three kinds of axonometric projection, trimetric is the most complicated to draw, but it has by far the least amount of distortion, and truly appears as a picture of the object. Trimetric projections are rarely used in industry as they take too much drafting time.

All basic procedures used in laying out an isometric or dimetric projection are incorporated into drawing the trimetric projection.

As this text is primarily for drafters and not particularly for technical illustrators, concentration is given only to isometric projections. Once mastered, these same methods and basic procedures can be applied to dimetric and trimetric projections.

Oblique Drawings

The easiest type of pictorial drawing to develop is the oblique projection. In *oblique drawing*, one surface of the object, usually the most important view, is drawn exactly as it would be drawn in a multiview projection. It is drawn true size and shape.

Oblique drawings use three axes. Two at right angles to each other, as in multiview drawings; the other, the receding axis, is drawn at any convenient angle to the horizon.

There are three kinds of oblique drawings: cavalier, cabinet, and general oblique, Figure 18-7. In each of the three kinds of oblique drawings, its most important surface is drawn parallel to the plane of projection.

Cavalier Drawing

In the *cavalier drawing*, the receding axis is drawn from 30° to 60° to the horizon. As with the isometric projection, the receding distances are drawn full size,

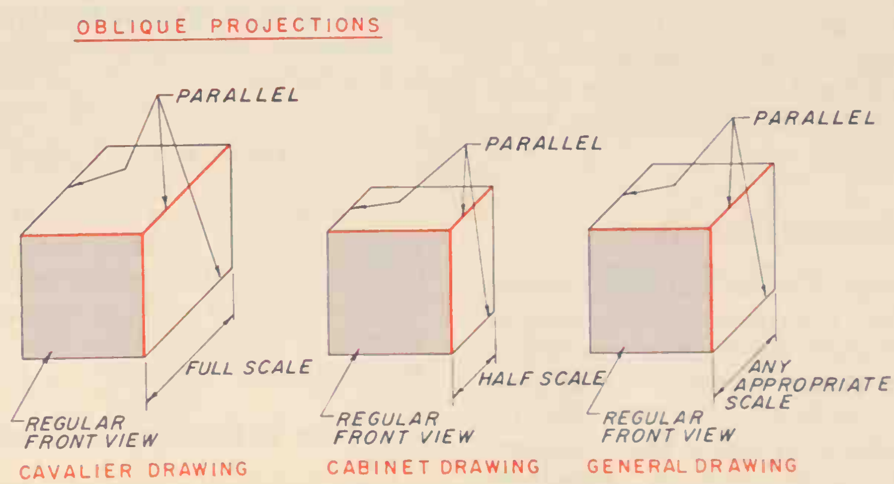


Figure 18-7 Oblique drawings

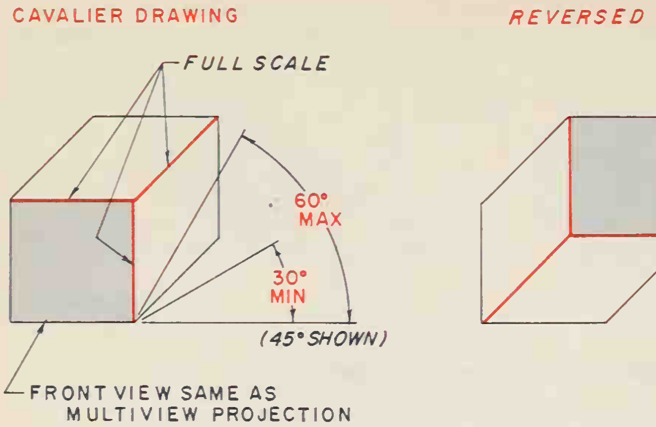


Figure 18-8 Cavalier drawing

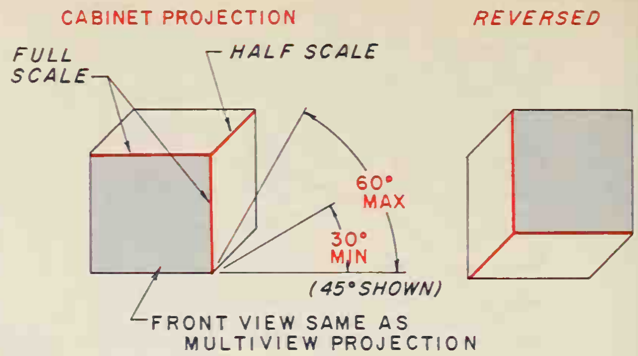


Figure 18-9 Cabinet drawing

Figure 18-8. Notice how this creates much distortion; therefore, this type of drawing is seldom used.

The term *cavalier* originated from the drawing of medieval fortifications. The center area of these fortifications was much higher than the rest of the fortification, and was referred to as the *cavalier* because of its command position.

Cabinet Drawing

In the *cabinet drawing*, the receding axis is drawn from 30° to 60° to the horizon. The receding distances are drawn half size, Figure 18-9. This helps somewhat to eliminate the distortion associated with the oblique projection system. In past years, cabinet drawings were used to illustrate furniture and cabinets.

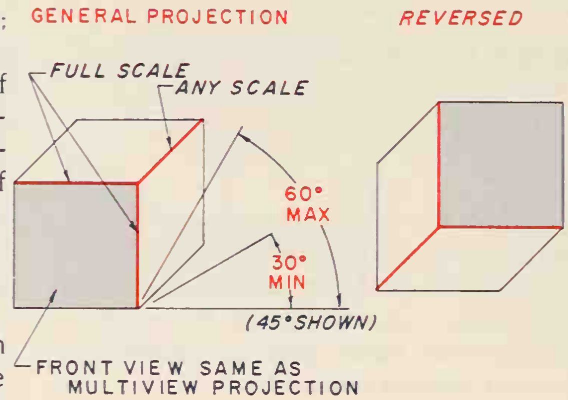


Figure 18-10 General oblique

General Oblique

The *general oblique* drawing is very similar to the cabinet drawing, except that the receding distances are drawn to *any* scale that seems the most natural for that particular object. This could be from one-third full size to three-quarters full size, Figure 18-10.

The receding angle can vary from 30° to 60°, as with all oblique projections. In oblique drawings, it is best to choose the most complete shape as the front surface, and project all receding lines from that surface.

Perspective Drawing

Perspective drawings illustrate the object better than any other method. In a *perspective drawing*, there is little or no distortion, and it approximates the object as it would be seen by the human eye or as projected upon the film inside a camera, Figure 18-11.

A perspective drawing is used by architects, designers, and technical illustrators in order to convey their ideas. Architects often use perspectives to illustrate how a proposed building will look when completed. As a general rule, however, perspective drawings are *not* used in the mechanical drafting field. Although they illustrate the object exactly as it will appear, they are too time-consuming and costly for drafters to construct. Therefore, drafters need only a working knowledge of perspective layout procedure.

Perspective drawings are discussed more fully later in this chapter.

Isometric Principles

An isometric drawing is drawn around three equally spaced principal edges or axes, Figure 18-12. The top illustration is the most commonly used. The object should be placed either in the position it is usually seen or in the position that best illustrates all the most important features.

How To Draw an Isometric Drawing

Given: A multiview drawing of an object, Figure 18-13A.

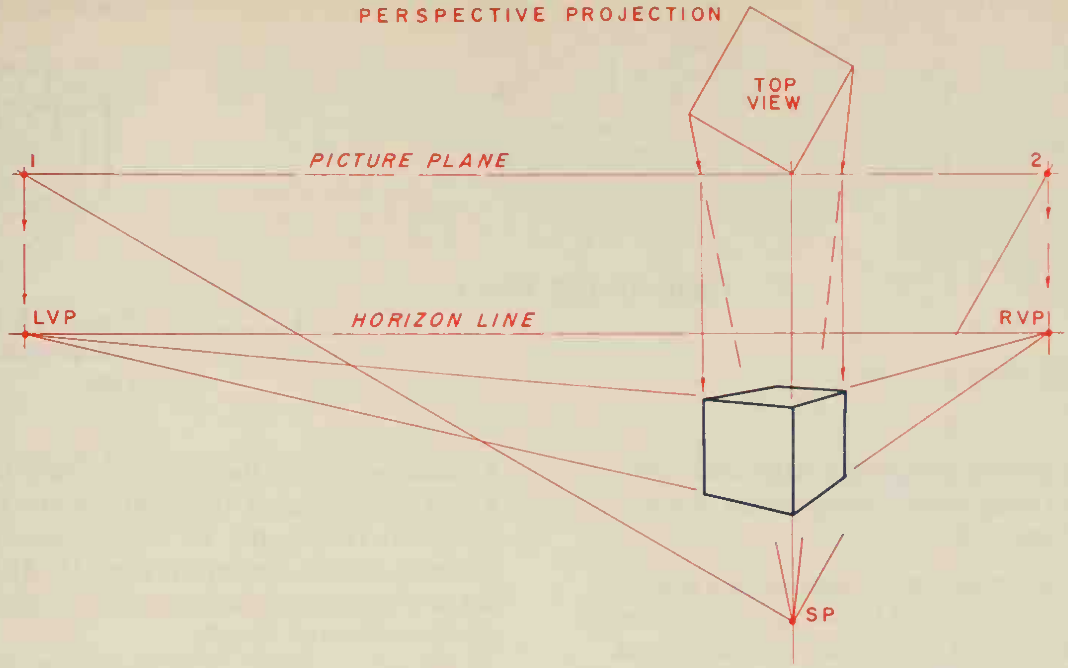


Figure 18-11 Perspective drawing

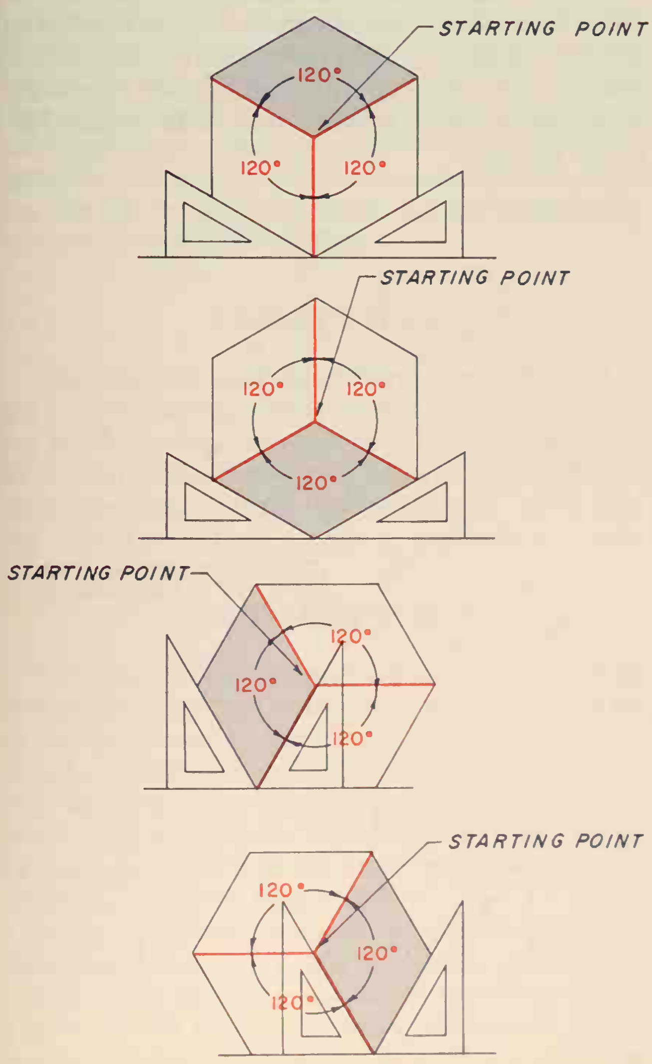


Figure 18-12 Isometric principles

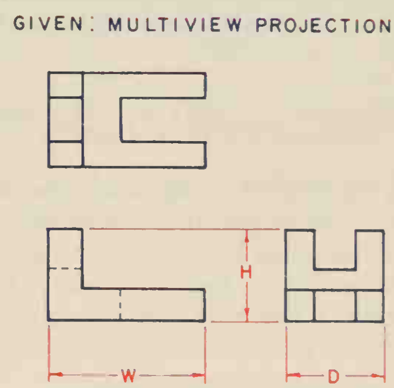


Figure 18-13A How to draw an isometric drawing

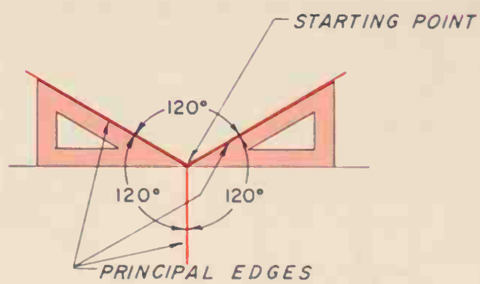


Figure 18-13B Step 1

Step 1. Locate the starting point and lightly draw the three principal edges 120°, as illustrated in Figure 18-13B. Use the 30°-60° triangle.

Step 2. Transfer the depth, height, and width directly from the multiview drawing, Figure 18-13A, to the three principal edges. Measure

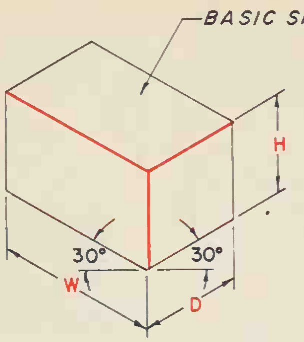


Figure 18-13C Step 2

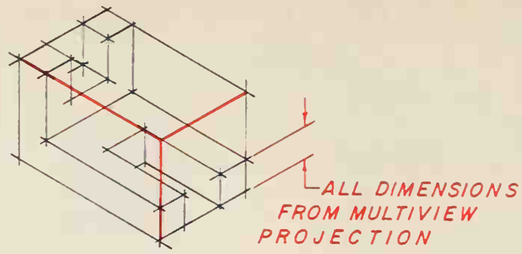


Figure 18-13D Step 3

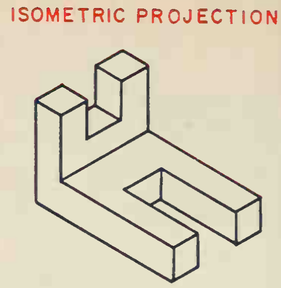


Figure 18-13E Completed isometric view

full size directly along each edge, and lightly construct an isometric, basic shape of the object, Figure 18-13C.

Step 3. Transferring the full size lengths from the multiview drawing, fill in the various features of the object. Again, all full size measurements must be constructed along or parallel with one of the principal edges, Figure 18-13D.

Step 4. Check all work, and, if correct, darken in the object using correct line thickness, Figure 18-13E.

Nonisometric Lines

If a line is *not* parallel or perpendicular to any of the three principal edges, it is a *nonisometric* line. A nonisometric line must be reduced to two points: a point at each end of the line, as shown in the given multiview drawing, Figure 18-14A. Line a-b is *not* parallel or perpendicular to any of the three principal edges, thus it is a nonisometric line.

Referring to Figure 18-14B, the isometric drawing is developed exactly as described, except that points a and b must be located before the nonisometric line a-b can be drawn. Point a is located along one axis distance X from the back end; point b is located Y distance up from the bottom surface. When points a and b are located, the nonisometric line a-b can be drawn. Notice, the 30° angular dimension given on the multiview drawing in Figure 18-14B has *no* bearing on the isometric layout and is *not* used. Also, line a-b is *not* the true length.

Hidden Lines

Hidden lines in pictorial drawings, regardless of which kind is used, are *not* drawn, unless needed to illustrate some important hidden feature that otherwise would not be seen. The object should be rotated or placed in such a position that no important feature is omitted.

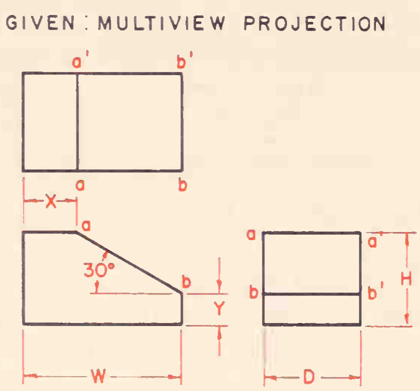


Figure 18-14A Nonisometric lines

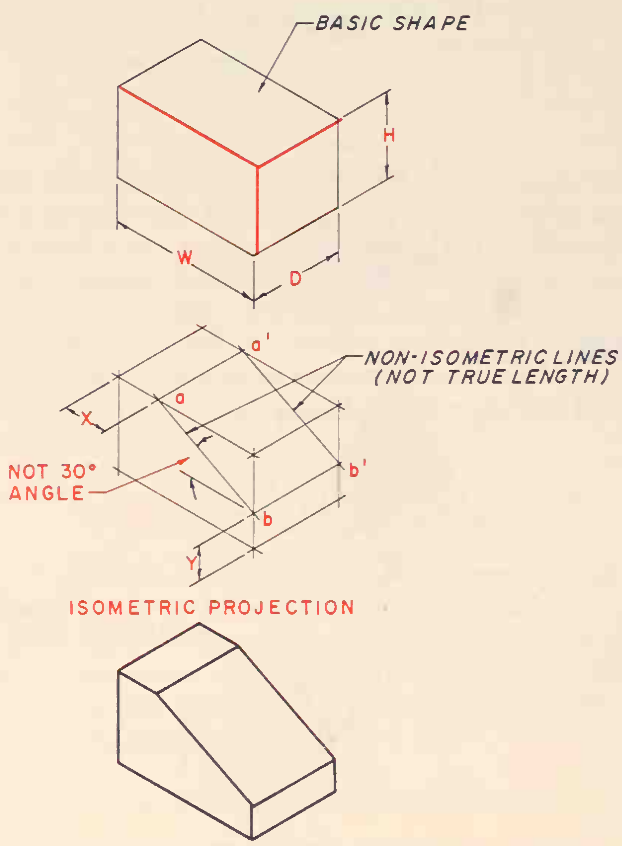


Figure 18-14B Locating points

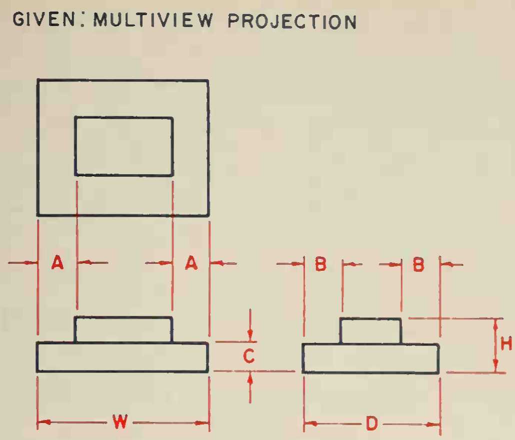


Figure 18-15A Multiview projection

Offset Measurements

Offset measurements are used to locate one feature in relationship to another. All offset measurements must be made either parallel to or perpendicular to any of the three principal surfaces.

A multiview drawing is given in Figure 18-15A. The isometric drawing is developed as outlined before, except that the offset measurements A, B, and C are measured parallel to and perpendicular to the three principal edges, Figure 18-15B. If a line or surface is *parallel* to another line or surface in the multiview drawing, the line or surface must be parallel, respectively, in the isometric drawing also.

Center Lines

Center lines are used to indicate symmetry and to aid in dimensioning. Center lines in an isometric drawing are drawn following the same drafting standards as in a multiview drawing. All holes must include the coordinates to indicate the exact center point, Figure 18-16. Center lines must extend outside the circle.

Box Construction

Some objects do not conform to any of the three principal edges. If an object does not conform, a *box* or rectangle must be constructed around the object parallel to and perpendicular to the principal edges. This then becomes the basic shape of the object. Refer to the multiview in Figure 18-17A. A basic shape is constructed around the object so various points of the object touch, Figure 18-17B.

An isometric basic shape of the object is drawn as shown in Figure 18-17C, and the various points, A, B, C and 0, are located on or within the basic shape, Figure 18-17D. Points A, B, and C are located on the base of the basic shape, and point 0 is located, by offset measurements, on the top surface.

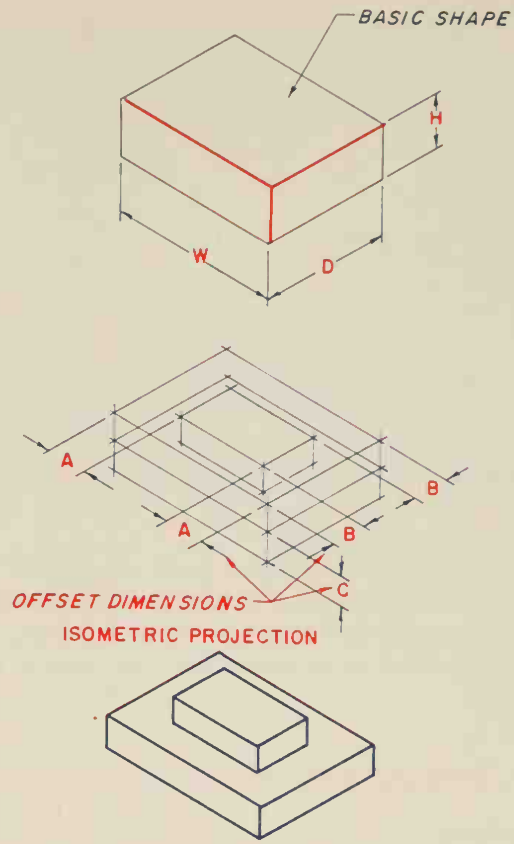


Figure 18-15B Offset measurements

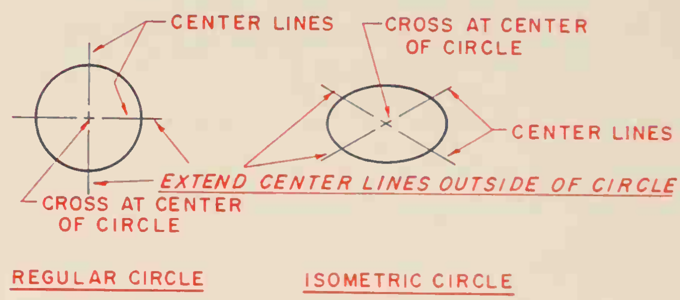


Figure 18-16 Center lines

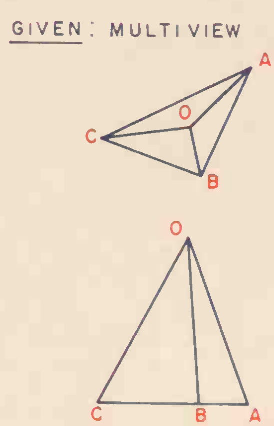


Figure 18-17A
Box construction

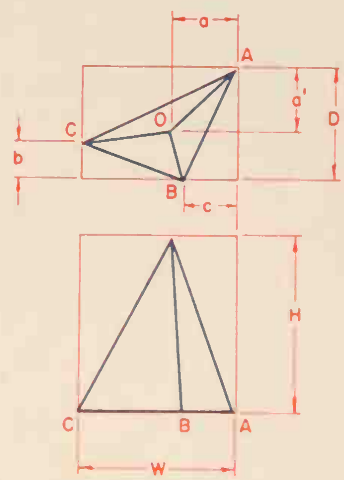


Figure 18-17B
Basic shape

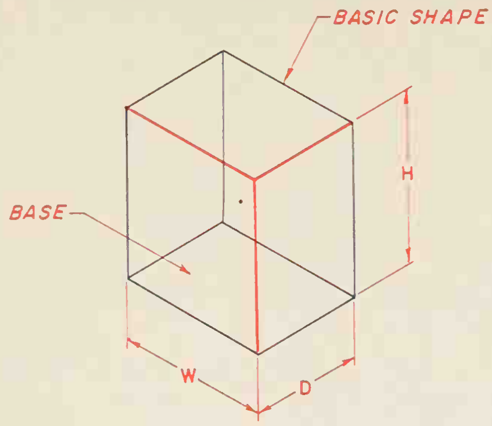


Figure 18-17C Isometric basic shape

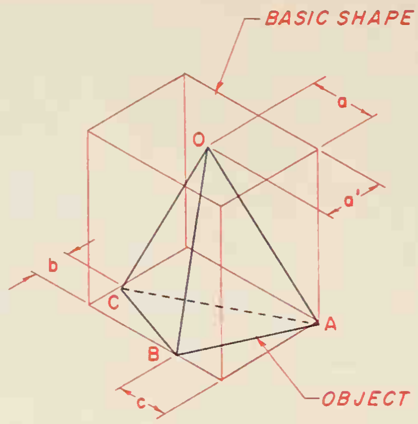


Figure 18-17D Locating points of object

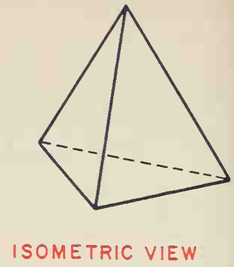


Figure 18-17E isometric view Completed

After all points are found, lines are drawn from A to B, B to C, and C to A to form the triangular base. Lines from 0 to A, 0 to B and 0 to C are constructed and darkened in to complete the object, Figure 18-17E.

Irregularly Shaped Objects

An irregularly shaped object is drawn by breaking it into a series of sections. Carefully locate each section in relationship to the others, and draw each individual section as an isometric, Figure 18-18A. Illustrated is a multiview drawing of a simple boat. Divide the object into a series of sections, A through H. Starting from a baseline, in this example the center line, locate and draw each section A through H, Figure 18-18B. Connect all sections together and the object is completed, Figure 18-18C.

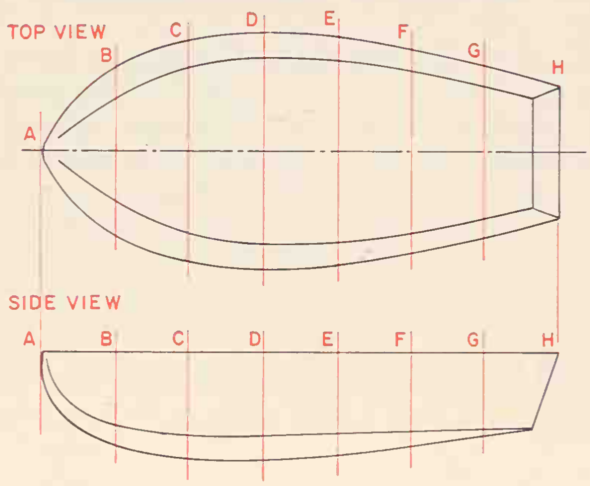


Figure 18-18A Irregularly shaped object

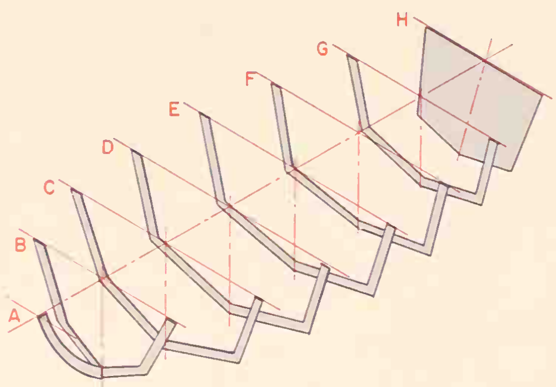


Figure 18-18B Drawing each section

Isometric Curves

Curves are drawn either by a series of offset distances or by the use of a grid. In using the series of offset distances, use any desired number of evenly spaced lines parallel to one of the principal edges, Figure 18-19A. In this view, the curved surface is shown as a profile. In this example, the lines are drawn in the front view. These lines are all parallel to one another and parallel to the bottom surface. Transfer these lines to the isometric layout and transfer each distance, respectively, to find each offset distance, Figure 18-19B. To give depth, project a line 30° from

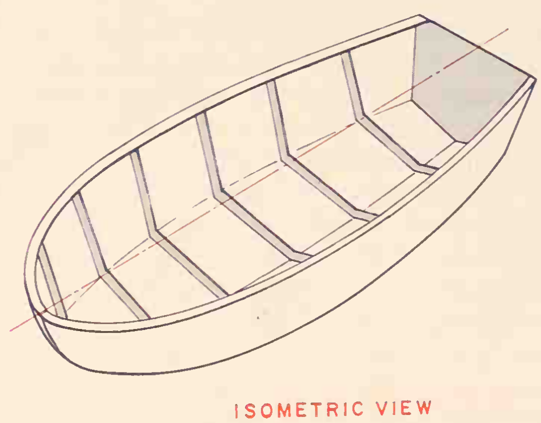


Figure 18-18C Completed object

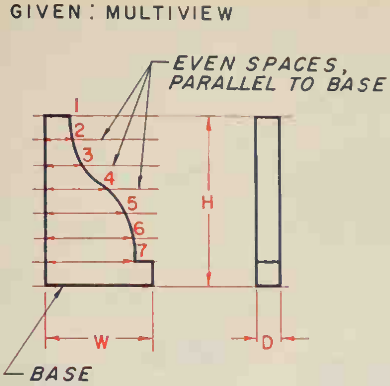


Figure 18-19A Drawing an isometric curve (offset method) distance

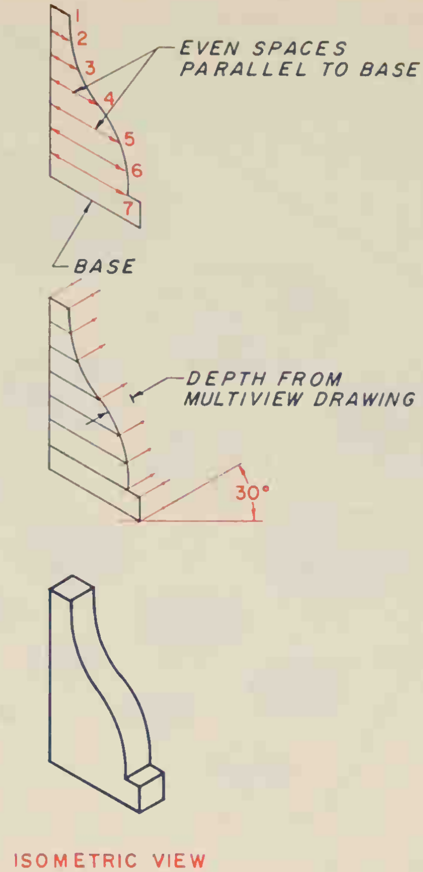


Figure 18-19B Drawing an isometric curve (finding the offset distance)

each point and transfer the distance of the depth of the object along each of the 30° projection lines. Check all work and, if correct, darken in the object using correct line thickness.

In using a grid, choose a grid of a size that will give the maximum number of points along the irregular curve in order to pick up as much detail as possible. See the given multiview in Figure 18-20A. A grid is drawn in the view where the irregular line appears; in this example the front view.

Draw the basic shape of the object as an isometric projection, and add the grid to the basic shape as constructed in the multiview. Transfer the irregular curve, square-by-square, from the multiview drawing to the isometric grid, Figure 18-20B. Check all work, and, if correct, darken in using correct line thickness.

Isometric Circles or Arcs

The drawing of circles or arcs in isometric drawing takes a lot of valuable drafting time. For small circles or arcs, use an isometric (circle) elliptical template, Figure 18-21. The actual angle of an isometric elliptical template is 35°16', which is slightly different from the standard 30° ellipse template. An isometric elliptical template has eight short hash marks

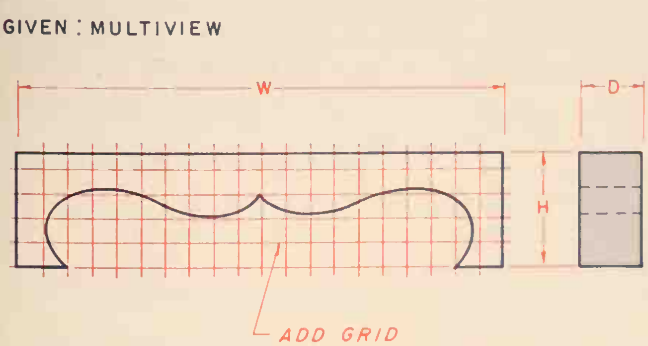


Figure 18-20A Drawing an isometric curve (grid method)

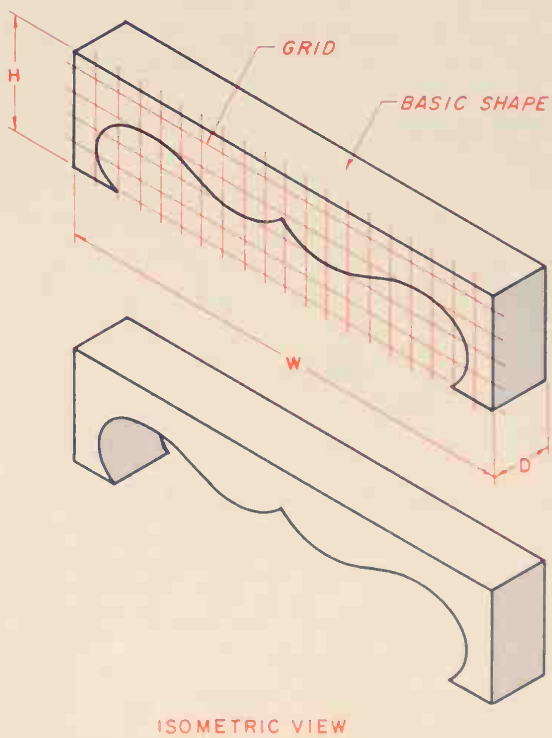


Figure 18-20B Isometric grid layout

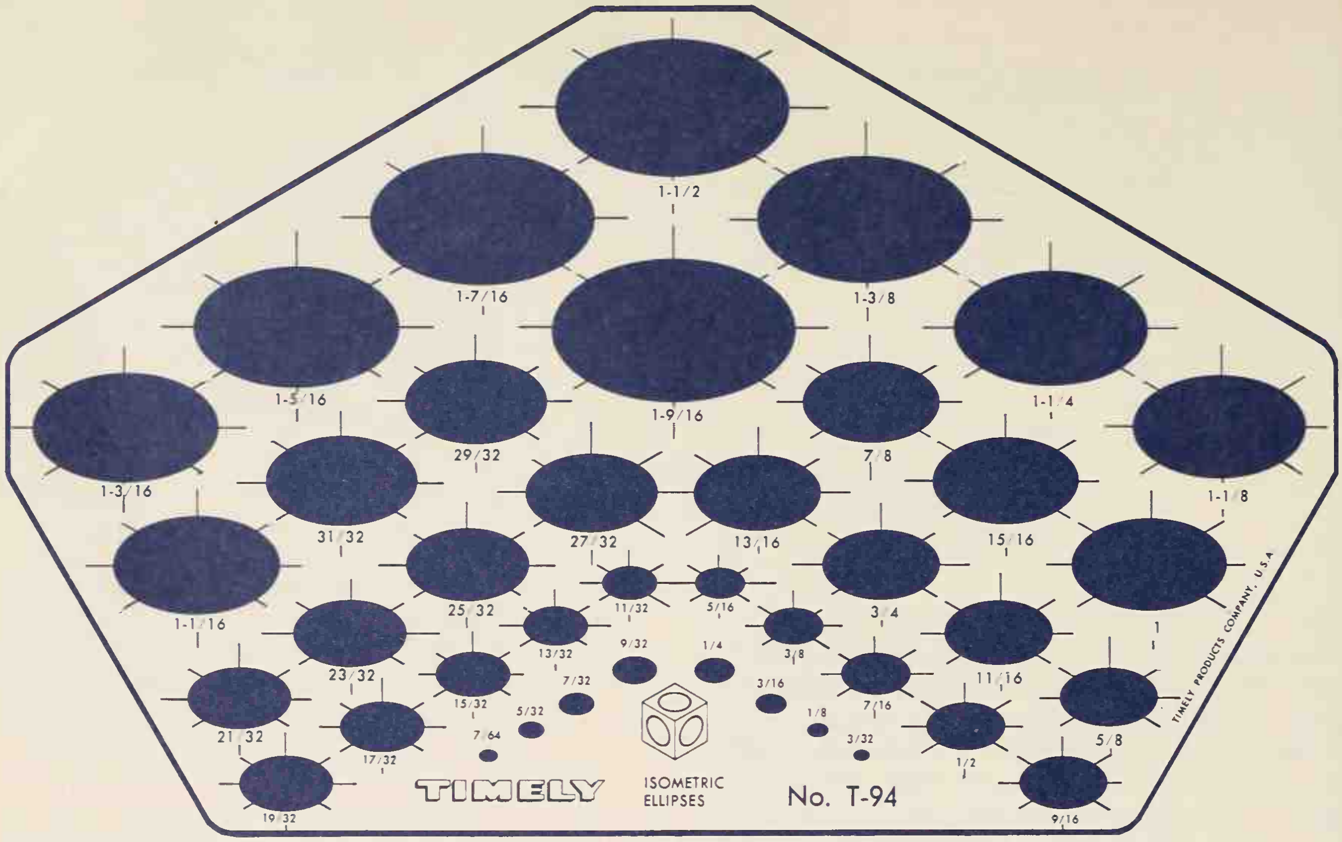


Figure 18-21 Isometric ellipse template (*Courtesy Timely Products Company*)

printed around the perimeter of each circle. The four longer hash marks indicate the *isometric* center lines of the circle or arc, and also indicate the four tangent points of the isometric circle with the isometric basic shape of the circle. The four short hash marks line up with the axis of the circle and are perpendicular to the axis of the circle, Figure 18-22A.

How To Use an Isometric Circle Arc Template

Step 1. Locate and draw the actual center lines of the circle or arc.

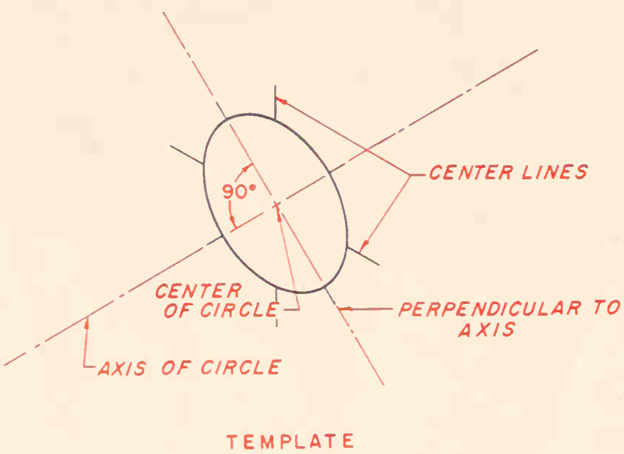


Figure 18-22A How to use an isometric ellipse template

Step 2. Draw the basic shape of the circle or arc, Figure 18-22B. The basic shape of the circle must be drawn parallel to and perpendicular to the principal edges where the circle or arc is located. *This is important.*

Step 3. Lightly extend the axis of the circle out as far as space will permit (refer again to Figure 18-22B).

Step 4. Choose the correct template size, and place it *within* the basic shape of the circle or arc. Align the longer center line hash marks on the template on the center lines of the circle or arc. These four hash marks should also be *tangent* to the basic shape of the circle, Figure

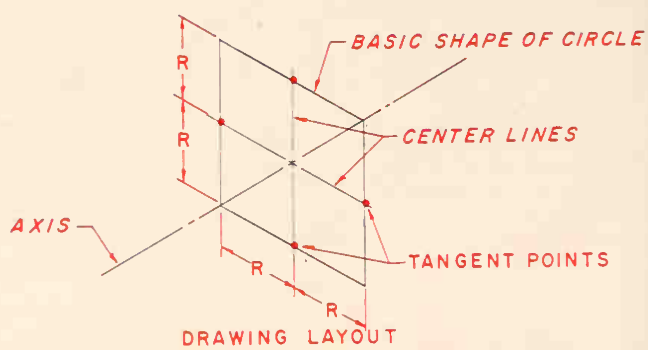


Figure 18-22B Draw the basic shape of the circle

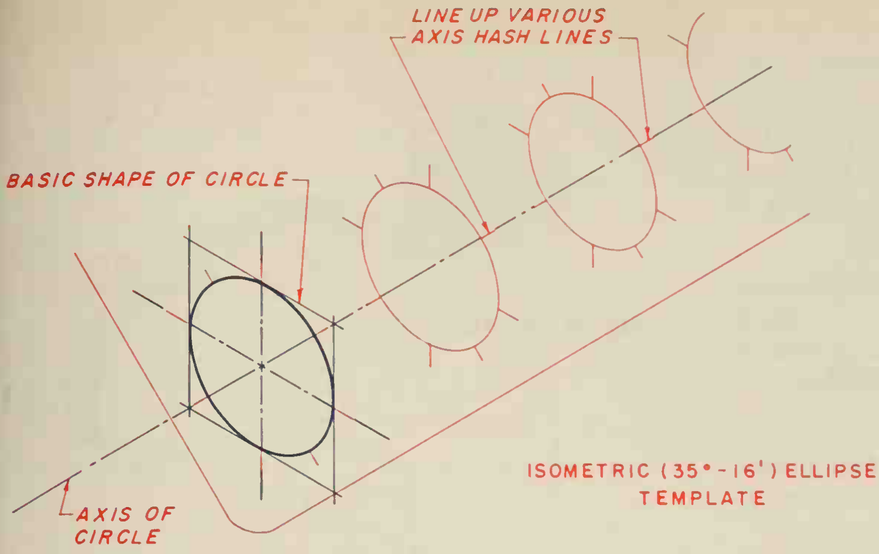


Figure 18-22C Drawing the ellipse from the basic shape

18-22C. To double check position for accuracy, line up *all* hash marks from other circles along the light axis line of the circle.

Step 5. If everything is in line and fits correctly, darken in the circle or arc using correct line thickness.

Regardless of the view in which the circle or arc is located, the foregoing steps apply. The basic shape of the circle or arc helps to eliminate any layout errors, Figure 18-23.

How To Draw a True Isometric Circle or Arc

Where accuracy is very important or where various points around a circle or arc must be established, the following method is used to draw an isometric circle or arc.

A true isometric circle or arc is drawn very much like any isometric circle using various offset measurements. Because the circle or arc is symmetrical, it is best to use evenly spaced offset measurements. In this example, 12 evenly spaced increments are used.

Before beginning, notice how a regular circle compares to an isometric circle, Figure 18-24A. Both have a basic shape with equal sides – each side being equal to the circle's diameter. Both are tangent to or touch the basic shape at four places, indicated by 3, 6, 9 and 12. Both are divided into four parts or quadrants.

Given: Regular circle in Figure 18-24A.

Step 1. In the view of the regular circle, divide it into 12 equal, even spaces, using the 30°-60° triangle, Figure 18-24B. Lightly label each point clockwise 1 through 12.

Step 2. Divide the circle into:

1. A square, the basic shape, tangent to points 3, 6, 9 and 12.

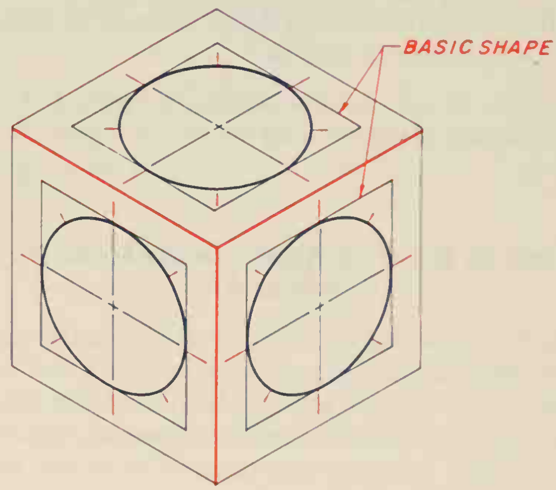


Figure 18-23 Isometric circles in various planes

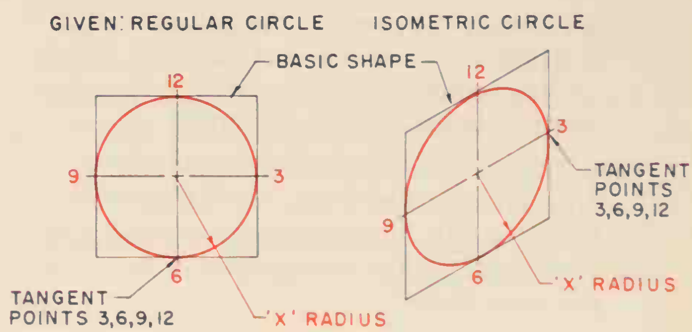


Figure 18-24A Regular circle and isometric circle

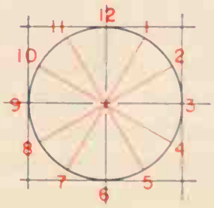


Figure 18-24B How to draw an isometric circle – Step 1

2. A rectangle tangent to points 1, 5, 7 and 11.
3. Another rectangle tangent to points 2, 4, 8 and 10. See Figure 18-24C.

Step 3. Locate the center of the isometric circle and draw the basic shape of the circle, Figure 18-24D. This automatically locates points 3, 6, 9 and 12. Lightly label these points.

Step 4. Using the offset measurement technique, lightly draw the rectangle 1, 5, 7 and 11. Transfer distances X and Y from the regular view of the circle, Figure 18-24E. Lightly label each point.

Step 5. Again, using the offset measurement technique, lightly draw the rectangle 2, 4, 8 and 10. Transfer distances X and Y from the regular view of the circle, Figure 18-24F.

Step 6. Check all work, and, if correct, darken in the isometric circle using an irregular or French curve, Figure 18-24G.

To draw an arc, use the foregoing steps, but use only that part of the circle as necessary, Figure 18-25.

How To Draw an Approximate Isometric Circle or Arc

For most drafting, an approximate isometric circle or arc is sufficient. This method takes much less time to draw, and is close enough for illustration where various points around the perimeter are not required. This method is sometimes referred to as the four-center isometric circle or arc.

Given: Regular circle with X radius (refer back to Figure 18-24A).

Step 1. Locate the center of the isometric circle and draw the basic shape of the circle, Figure 18-26A. Locate and label each of the four tangent points clockwise, 1, 2, 3 and 4.

Step 2. From each of the four tangent points, draw a line perpendicular (90°) as shown in Figure 18-26B. Where these lines *intersect* is the location of the four swing points, A, B, C, and D, Figure 18-26C.

Step 3. Set compass at swing point A and adjust lead to tangent point 1, Figure 18-26D. From swing point A, swing an arc to tangent point 2. From swing point B, swing this same arc from tangent point 3 to tangent point 4.

Step 4. Set compass at swing point C and adjust lead to tangent point 2, Figure 18-26E. From swing point C, swing an arc to tangent point 3. From swing point D, swing this same arc from tangent point 4 to tangent point 1.

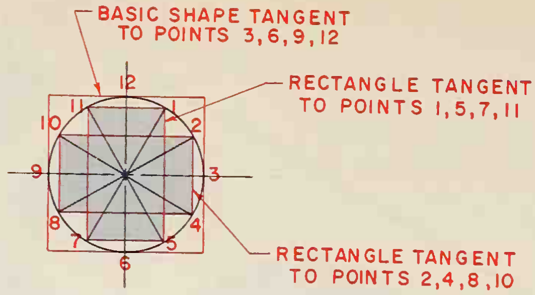


Figure 18-24C Step 2

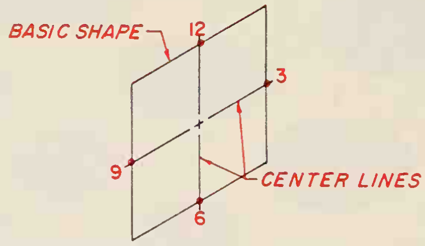


Figure 18-24D Step 3

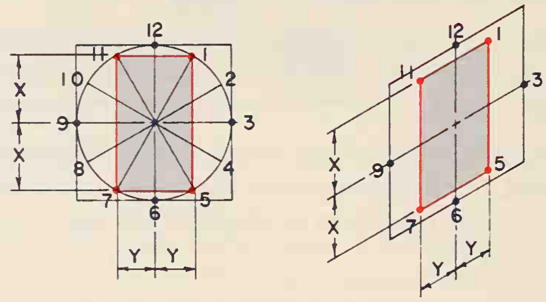


Figure 18-24E Step 4

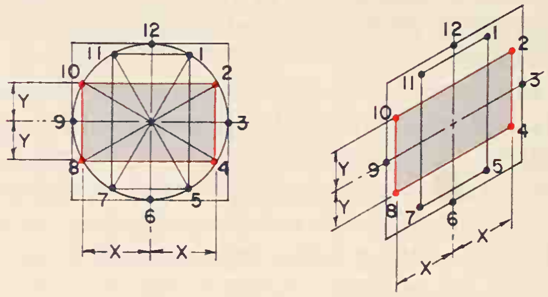


Figure 18-24F Step 5

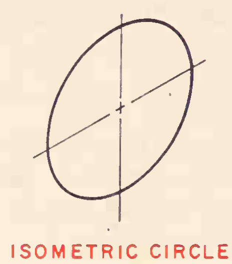


Figure 18-24G Completed isometric circle

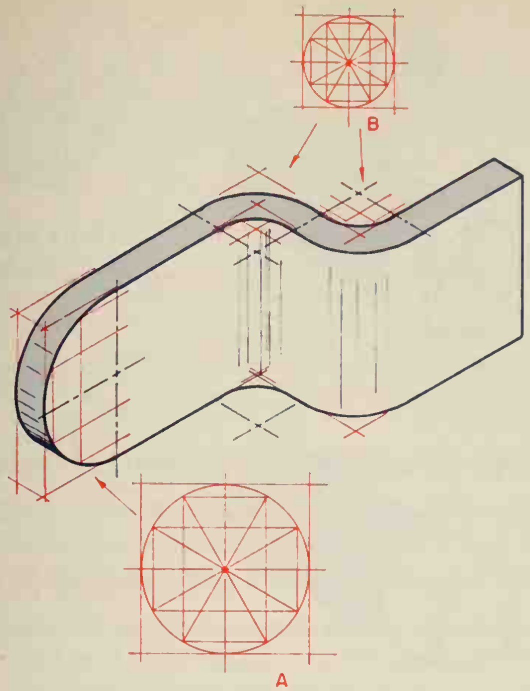


Figure 18-25 How to draw an isometric arc

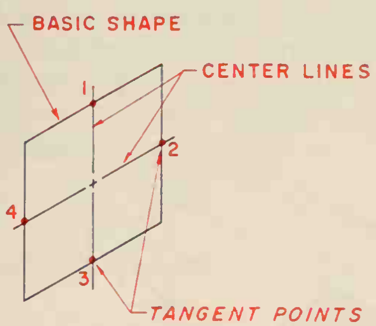


Figure 18-26A How to draw an approximate isometric circle — Step 1

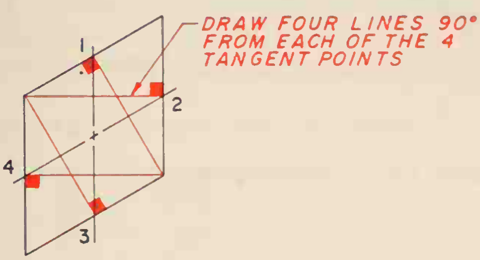


Figure 18-26B Step 2

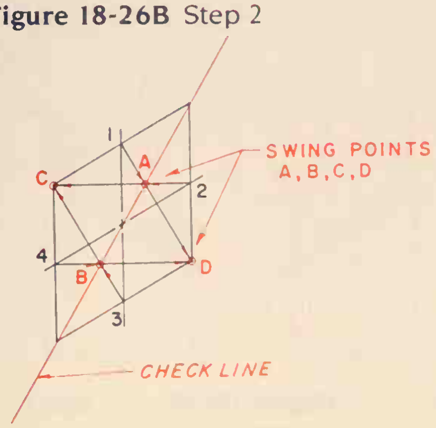


Figure 18-26C Step 2

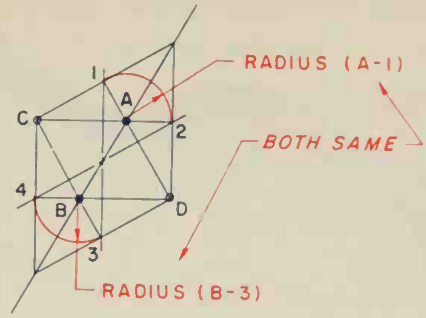


Figure 18-26D Step 3

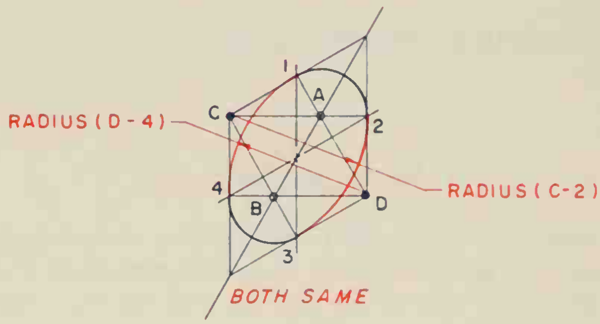


Figure 18-26E Step 4

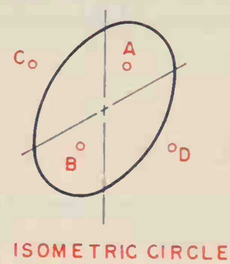


Figure 18-26F Completed isometric circle

Step 5. Check all work, and, if correct, darken in the completed isometric circle using correct line thickness; then, darken in the center lines, Figure 18-26F.

Regardless of the position in which the isometric circle is placed, the exact same steps are used (refer back to Figure 18-23).

Isometric Arcs

Usually, the four-center isometric circle method is used for drawing isometric arcs. In this example, radius X is measured off from the projected corners to locate the tangent points, Figure 18-27. From the tangent points, construct perpendicular lines to locate the swing points.

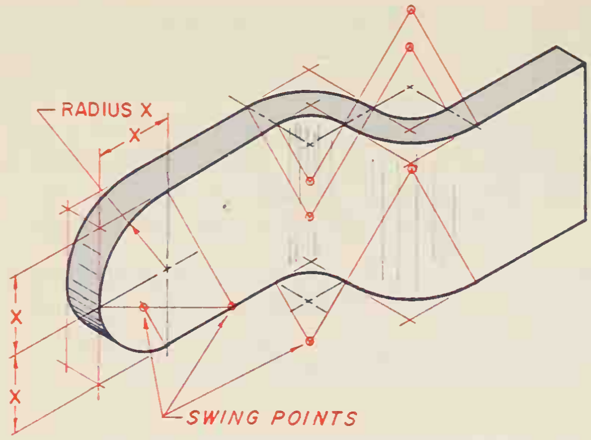


Figure 18-27 Drawing isometric arcs

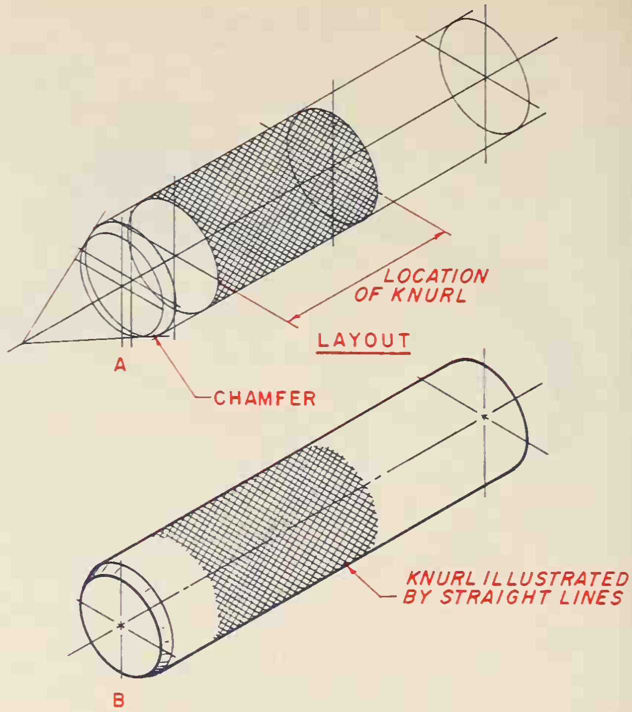


Figure 18-28 Isometric knurls

Isometric Knurls

Isometric knurls are usually drawn with straight lines, and are very seldom curved, Figure 18-28. Part A illustrates how to lay out the area for the knurl; Part B illustrates how it will look as a finished drawing. Notice the chamfer at the end of the object. This was drawn with an isometric template slightly smaller in size than the outside diameter of the object.

Isometric Screw Threads

In order to quickly draw thread representations, parallel partial ellipses, spaced approximately the thread pitch distance, are drawn, Figure 18-29. These ellipses represent the *crest* of the screw thread. These parallel partial ellipses can be drawn with either an ellipse template or by the four-center ellipse method as described.

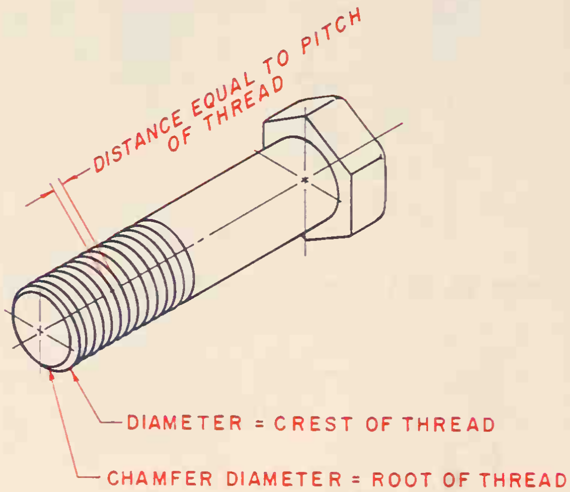


Figure 18-29 Isometric threads

Isometric Spheres

The layout and construction of an isometric sphere or various parts of a sphere are sometimes required. An *isometric sphere* is actually a true circle in three dimensions.

If a full sphere is needed, draw a circle equal in diameter to 1.22 times its actual diameter, Figure 18-30. If a half sphere is needed, draw an isometric circle of the required diameter and, from the center point, swing half a true circle, Figure 18-31. If a quarter sphere is needed, draw two half isometric circles at 90° to each other, and connect the two halves with an arc from the center point, Figure 18-32. If a three-quarter sphere is needed, draw two full isometric circles at 90° to each other, and connect the two arcs with an arc from the center point, Figure 18-33.

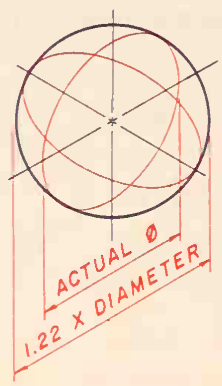


Figure 18-30
Isometric sphere

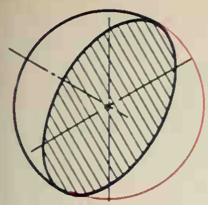


Figure 18-31 Isometric half sphere

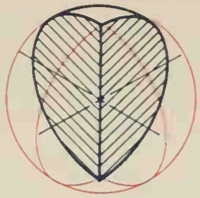


Figure 18-32 Isometric quarter sphere

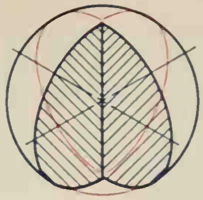


Figure 18-33 Isometric three-quarter sphere

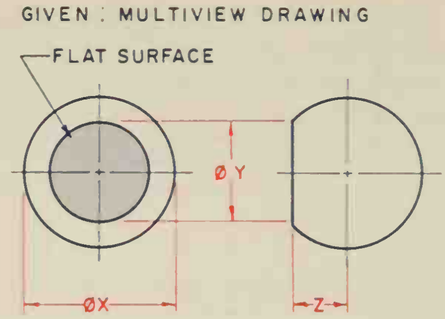


Figure 18-34 How to draw a flat surface on a sphere

How To Draw a Flat Surface on a Sphere

Given: Multiview drawing in Figure 18-34 with X diameter/Y diameter, flat surface Z, and distance from center of sphere to flat surface.

Step 1. Draw two isometric circles with a diameter of X and at 90° to each other. Connect the two isometric circles with an arc from the center point, Figure 18-35.

Step 2. Measure distance Z to locate the center point of the flat surface. From this point, draw the required center lines of the flat surface, and draw an isometric circle of a diameter of Y (refer again to Figure 18-35).

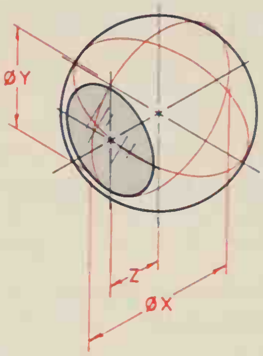


Figure 18-35 Steps 1 and 2

Isometric Intersections

To draw the intersection of a cylindrical hole in an oblique plane, draw the isometric circle in a projected top surface, Figures 18-36A and 18-36B. Project the 12 points down to the oblique plane A, B, C, and D, as shown. Each point is projected to the right-side view and over to the corresponding point in the front point. These points are then joined to form the intersection.

To draw the generated curve between two cylinders, see Figures 18-37A and 18-37B. Divide one circle into 12 equally spaced points. Find the true length of each of the 12 segments and transfer them to the isometric view. Connect the points to draw the intersection line. This is exactly the process for developments, Chapter 8.

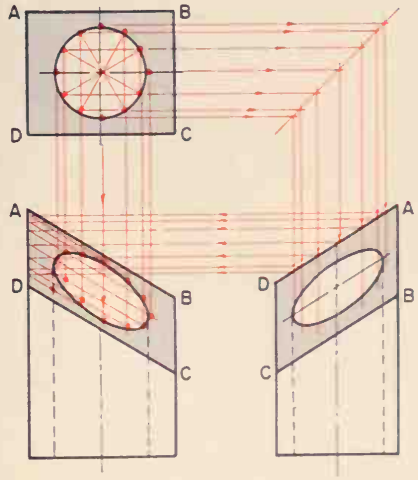


Figure 18-36A Isometric intersections — given: three views

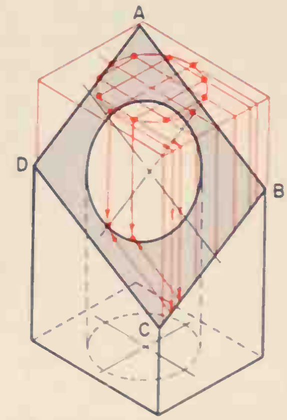


Figure 18-36B Isometric intersections

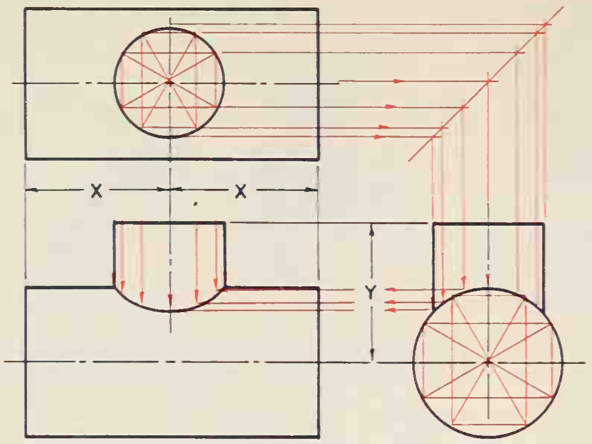


Figure 18-37A Isometric intersections – given: three views

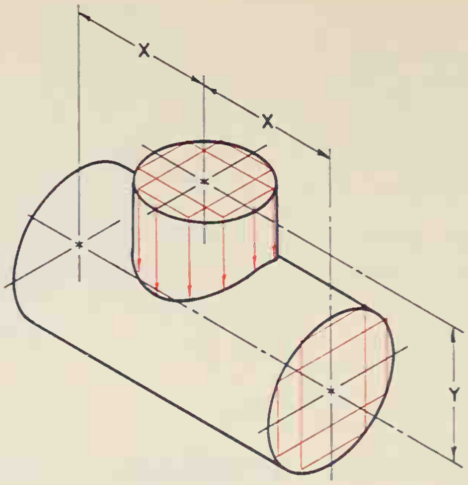


Figure 18-37B Isometric intersections

How To Draw an Ellipse on an Inclined Plane

Given: Multiview drawing in Figure 18-38A.

Step 1. Divide the top view into 12 equally spaced areas, 1 through 12. Project the 12 points into the front view to find the true length of each segment.

Step 2. Construct the isometric circle base using the offset measurement method in order to locate the 12 points around the base circle, Figure 18-38B.

Step 3. Project each of the 12 true length segments up from the base. Connect the ends of the segments to form the top surface – an ellipse on an inclined plane.

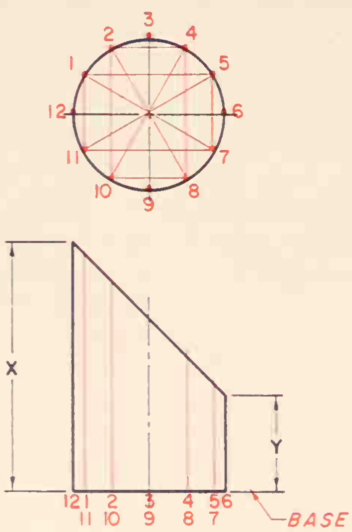


Figure 18-38A
How to draw an ellipse on an inclined plane – given: two views

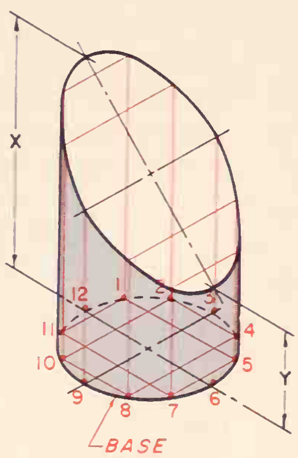


Figure 18-38B
An isometric ellipse on an inclined plane

How To Find the True Length of Nonisometric Lines

The true length of a nonisometric line can be found by using an ellipse radius.

Given: The side view of a simple box with its lid at 60° and 135°, Figure 18-39, Part A.

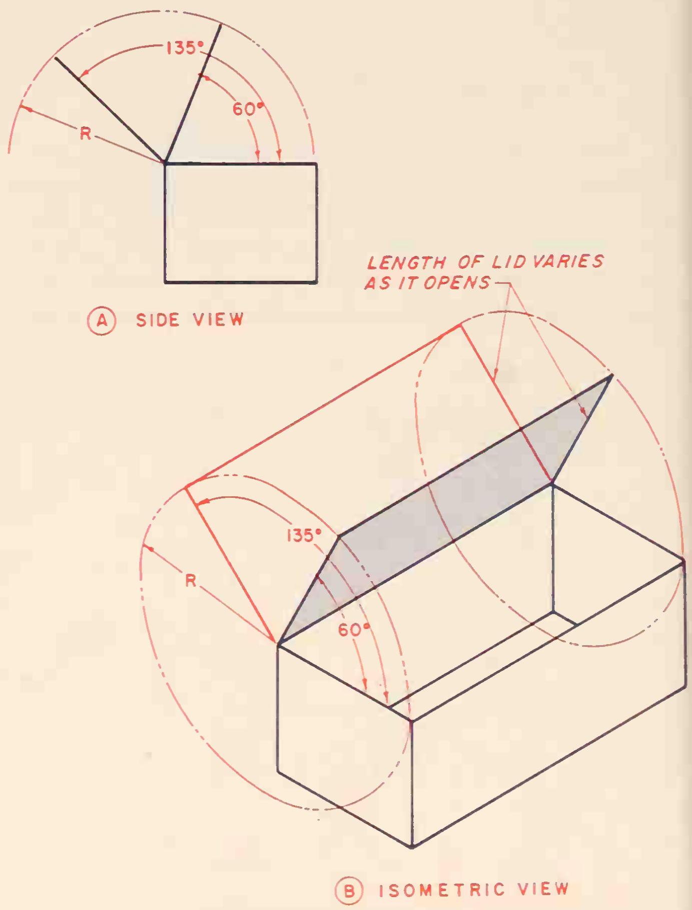


Figure 18-39 True length of nonisometric lines

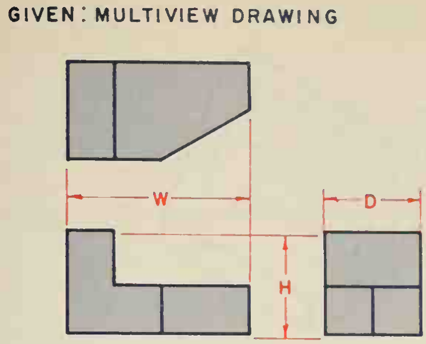


Figure 18-40A Centering an isometric view within the work area

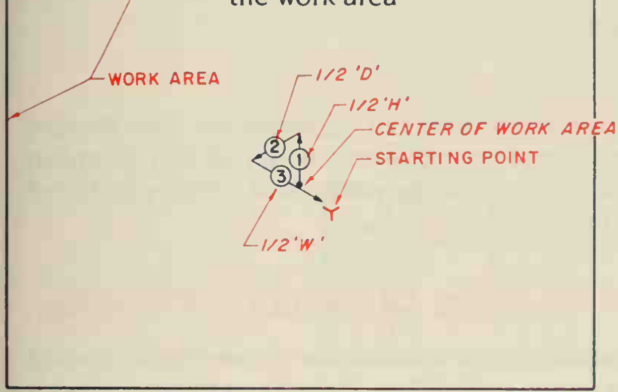


Figure 18-40B Step 1

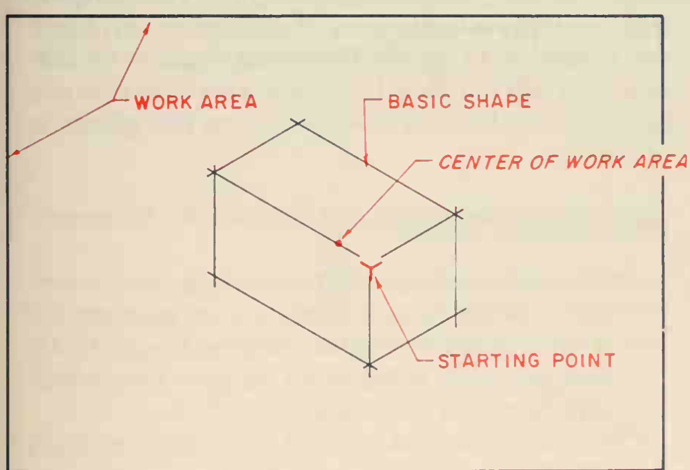


Figure 18-40C Step 2

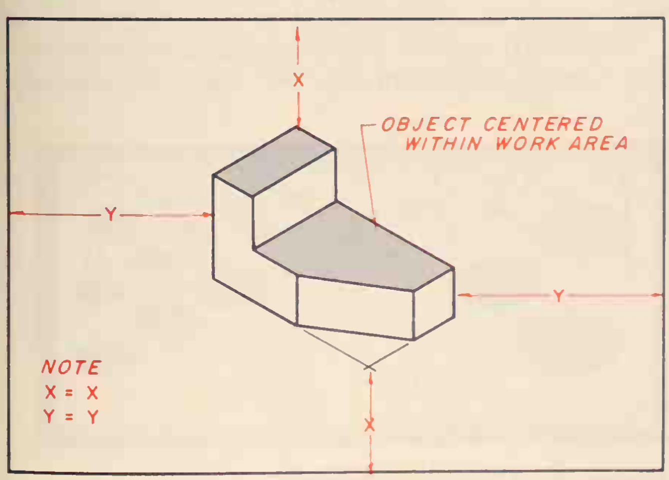


Figure 18-40D Completed isometric view

The true length of the lid can be found by drawing an ellipse with its center at the hinge point and its radius equal to the lid when *closed*, Figure 18-39, Part B. Notice how the length of the lid varies in relation to its position. At 60°, the lid is shorter than it is at 135°.

How To Center an Isometric Object

A quick method to center an isometric object within the work area is given in the following steps.

Given: Multiview drawing in Figure 18-40A.

Step 1. Locate the center point of the work area. From this center point, project straight upward *half the height* of the object. From this point, project to the left at 30° downward *half the depth* of the object. From this point, project to the right 30° downward *half the width* of the object. This is the *starting point* of the basic shape, Figure 18-40B.

Step 2. From the starting point as found in Step 1, lightly draw the basic shape of the object, Figure 18-40C.

Step 3. Construct the object within the basic shape, Figure 18-40D.

Notice that this method centers only the basic shape. If the object is irregularly shaped or has a part removed from the overall basic shape, it will not be 100% centered. Referring to Figure 18-40D, notice how a portion is cut off from the front surface; thus, this object is not 100% centered, but is considered to be close enough for most work.

Isometric Rounds and Fillets

Isometric rounds and fillets can be illustrated in various ways, Figure 18-41. Part A uses a solid line with solid arcs at the corners. Part B is similar, but uses a series of dashed lines. Part C uses a series of curved lines to indicate the rounds and fillets. The most important thing is to illustrate the object so that there is no question whatsoever as to where the rounded surfaces are.

Isometric Dimensioning

Generally, the exact same dimensioning standards, rules, and methods used to dimension a regular multiview drawing apply to an isometric drawing.

Today, the unidirectional system is used because it is much faster and easier to understand. Each dimension is placed at the center of the dimension line if possible.

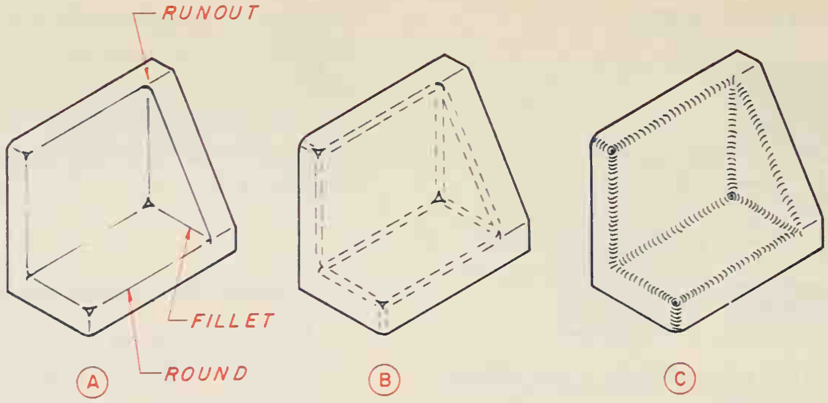


Figure 18-41 Isometric rounds and fillets

Extension lines are projected from the various surface features and at the same angle as the feature. All dimension lines are drawn parallel to the angle of the corresponding surface, Figure 18-42.

Isometric Templates

Various isometric templates are available to the drafter to speed up the drawing process. A unique template to help simplify isometric drawing is the Iso-Drafter, Figure 18-43. This template combines optical reference lines, 16 different isometric ellipses, and two scales. It also offers a right angle (90°) reference line, and isometric reference lines offset 30° on either side of it. These isometric reference lines are at precisely 120° angles to the main straight edges. Complete color instructions that clearly explain its many functions, operation, and uses are included with the template.

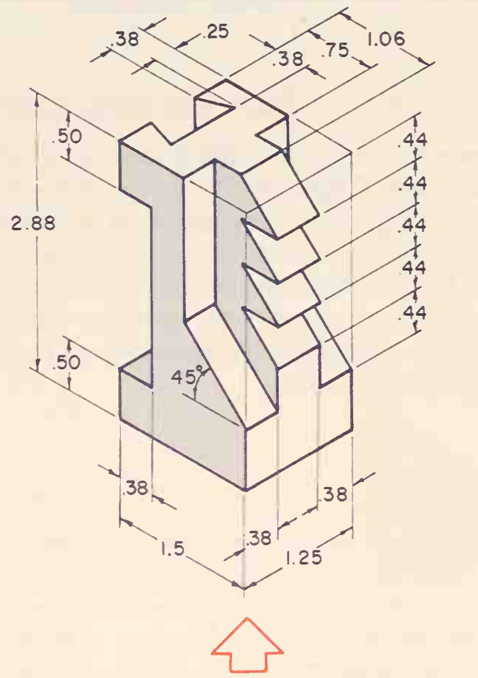


Figure 18-42 Isometric dimensioning

Perspective Drawing Procedures

A *perspective drawing* is a three-dimensional drawing of an object that shows it exactly as the eye views it from one particular viewing location. The perspective drawing is actually like a photograph of an object, see Figure 18-44. At the top of the figure is an outside view of a building; below it is an inside view of a room. Notice how all lines project to two points in space.

Perspective Terms

A full understanding of all terminology used in perspective drawing is very important in learning the layout procedures that follow. Refer to Figure 18-45.

Station point (SP) is the exact location from which the observer views the object.

Object to be viewed, as implied, is simply the object that is to be drawn.

Ground line (GL) is the edge view of the ground, or base upon which the object to be viewed rests.

Horizon (H) is a line at the level of the viewer; in this example, approximately 5'-0'' above the ground

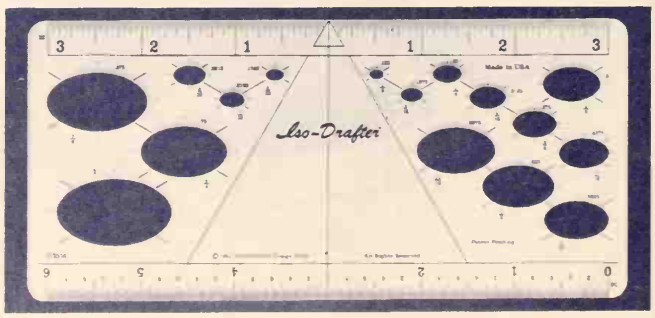
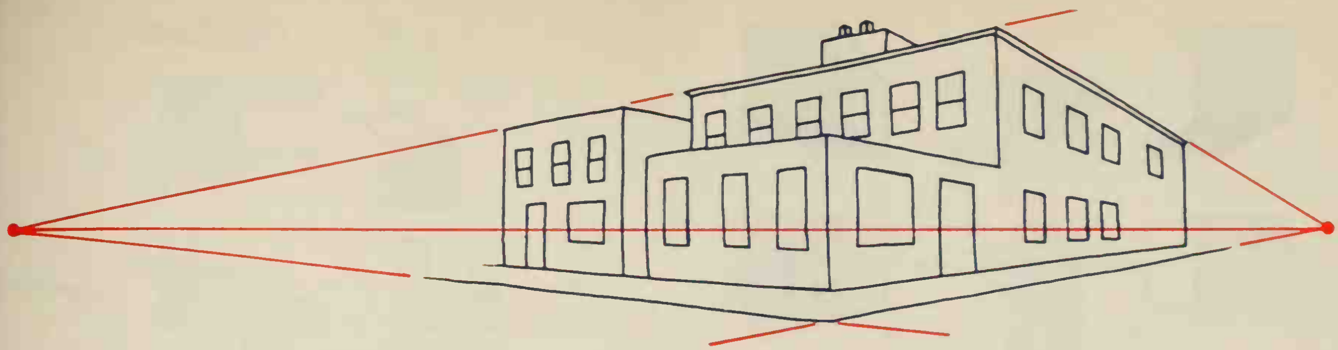
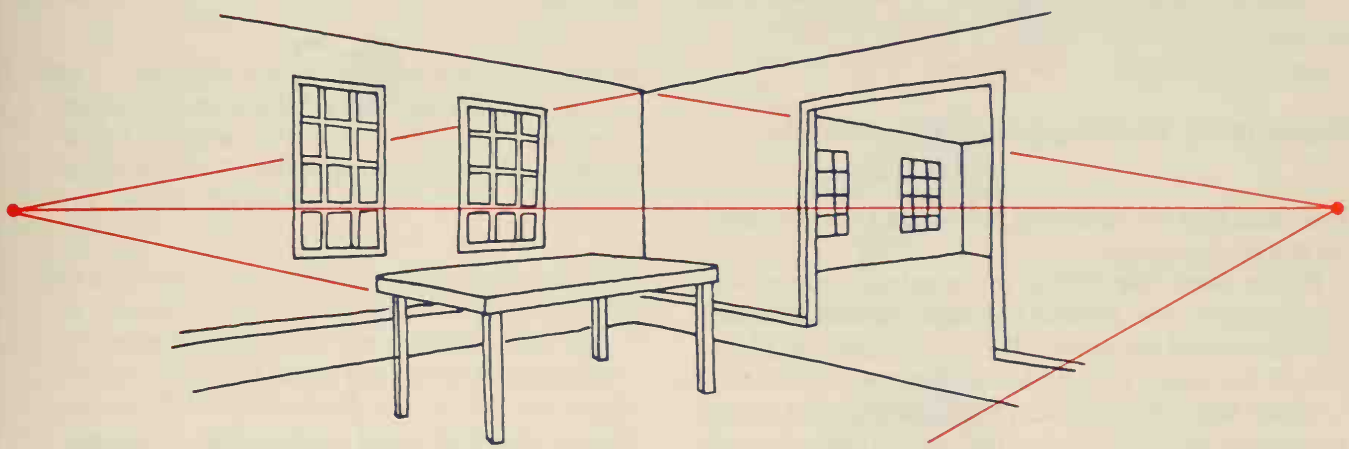


Figure 18-43 Isometric template (*Courtesy International Design Corporation*)



Outside view in two-point perspective



Inside view in two-point perspective

Figure 18-44 Outside and inside perspective view

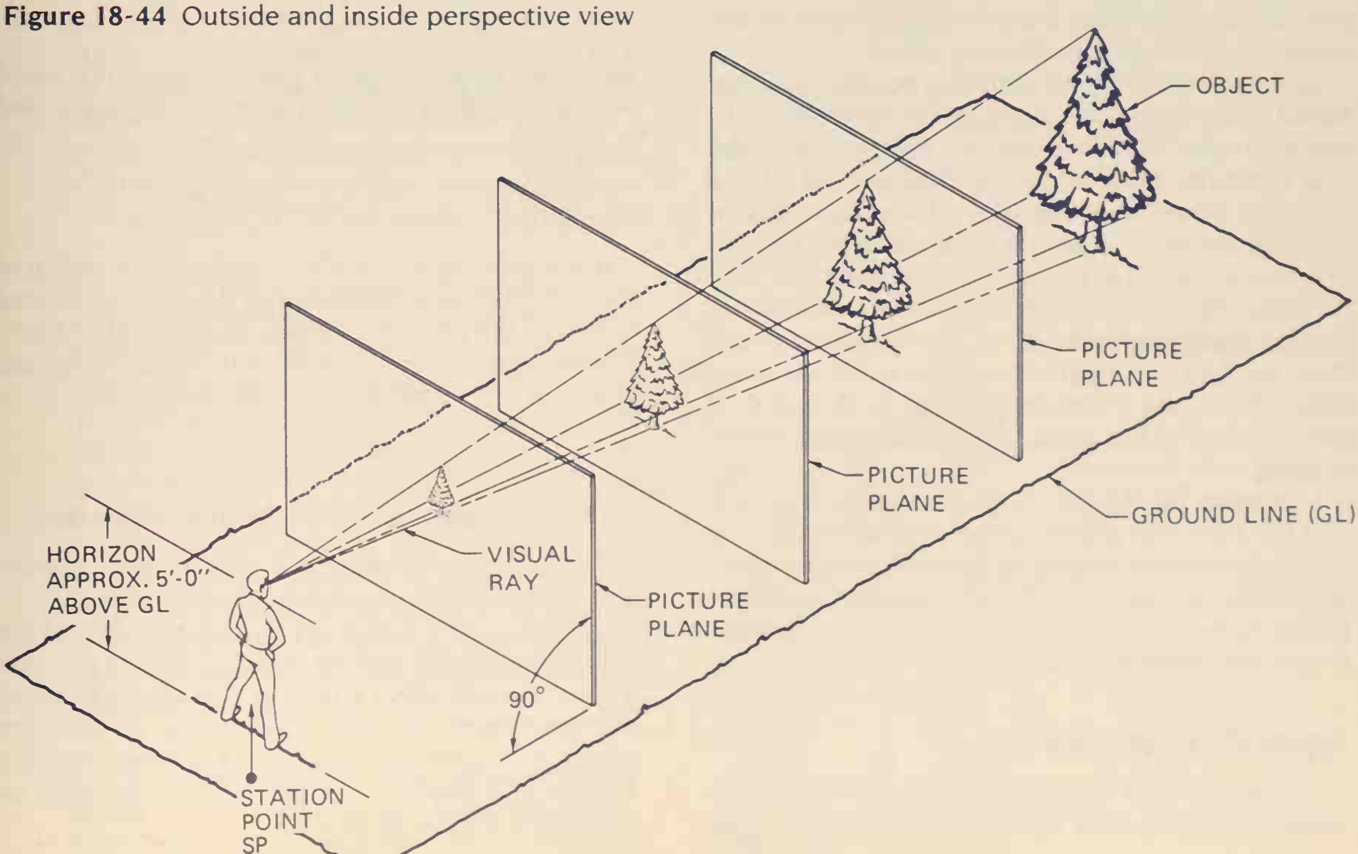


Figure 18-45 Perspective terms

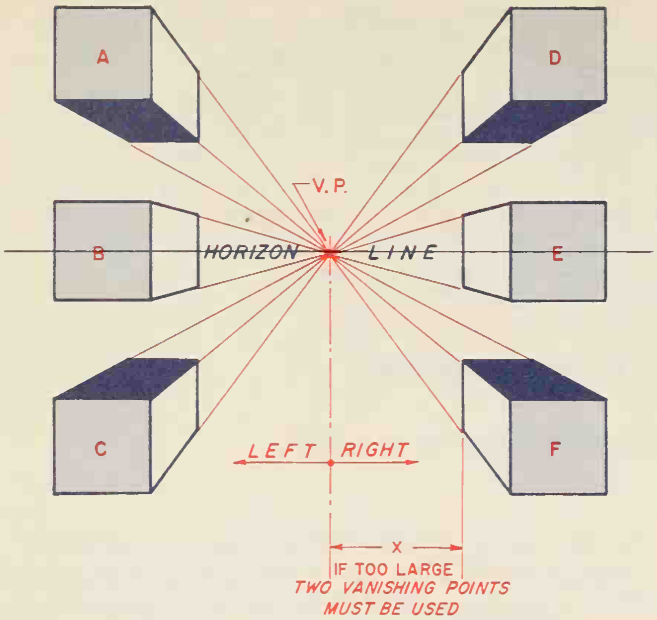


Figure 18-46 Vanishing point and horizon line

line. Note that the vanishing points are always located on the horizon line.

Picture plane line (PP) is an imaginary plane perpendicular to the ground line and located between the viewer and the object. Think of the picture plane line as the paper on which the object will be drawn.

Visual rays (VR) are lines projected from the eye of the viewer while standing at the station point to each and every point of the object. Notice how the visual rays project through the picture plane line. These rays, collectively, form the perspective view of the object upon the picture plane or paper.

Vanishing point (VP) the vanishing point(s) (not illustrated in the figure) is a point on the horizon line to which all other lines are projected, Figure 18-46. Cube A is *above* the horizon line and to the *left* of the vanishing point; thus, the bottom and right side of the cube are seen. Cube B is centered *on* the horizon line and to the *left* of the vanishing point; thus, only the right side of the cube is seen. Cube C is *below* the horizon line and to the *left* of the vanishing point; thus, the top and right side of the cube are seen. Cubes D, E, and F are opposite to A, B, and C. If dimension X is too great, a two-point perspective drawing must be used.

Measuring line (M) the measuring line is a vertical line 90° from the picture plane line, where all true length distances or heights are projected to and measured from. All true vertical heights must be projected to the measuring line and back into space to their respective vanishing points.

Types of Perspective Views

There are three types of perspective views: one-point, two-point, and three-point perspective, Figure 18-47. Only two-point perspective is discussed in this chapter, as it is the type most commonly used in industry.

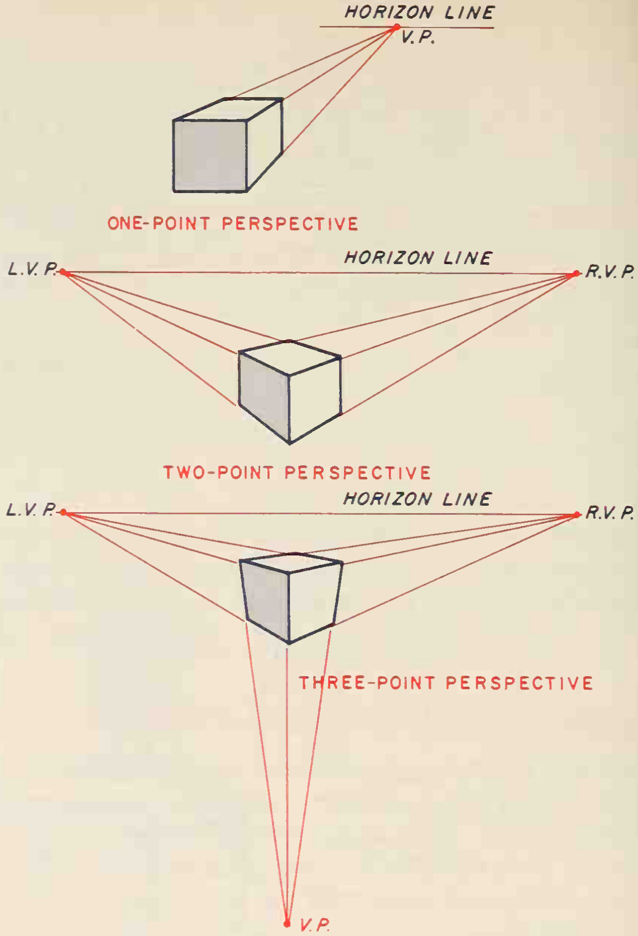


Figure 18-47 Kinds of perspective drawings

Sketching

It is a good idea to make a simple, quick sketch of the object before actually starting the drawing in order to choose the position that best illustrates the object. This also gives an indication as to the approximate direction and location of the vanishing points.

How To Sketch a Two-Point Perspective

The multiview drawing in Figure 18-48A is given, and various sketches are made, Figure 18-48B.

In setting up a two-point perspective, two of the regular multiviews must be used; usually, the top view (plan view) and either a front or side view. The views are sometimes changed, if necessary, to draw the object in a particular position. Multiview drawing 18-48A, and sketch C of Figure 18-48B are used for describing the following steps:

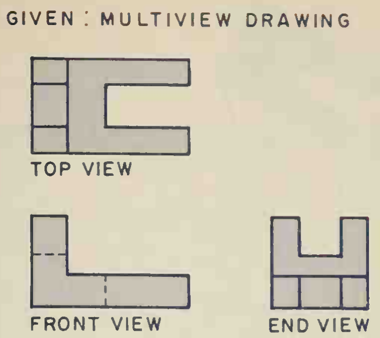


Figure 18-48A How to draw a two-point perspective drawing

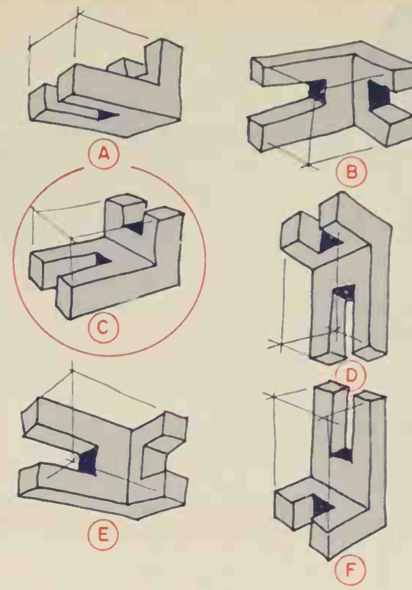


Figure 18-48B Sketch of object in various positions

Step 1. Draw the top view at the top of a sheet of paper at any angle; in this example, 30° in order to come close to the sketch. Draw the picture plane line tangent to the front edge of the object, Figure 18-48C.

Step 2. From the front edge of the object, where it is tangent to the picture plane line, project the measuring line 90° to the picture plane line, Figure 18-48D. Locate the station point anywhere on the measuring line so that the maximum inclusive angle is 30° or less.

Step 3. From the station point, construct lines parallel to the two edges of the top view above, Figure 18-48E. Think of these three steps as 1) an overall top view of the object, 2) a picture plane line on edge, and 3) a station point. In a regular two-point perspective there are actually two views superimposed over each other. This is the first of the two views.

Step 4. Draw a line to represent the horizon line at any convenient location. It is best to draw this horizon line away from the other construction work, if possible. If space is limited, it can be drawn over the original work, Figure 18-48F. From points 1 and 2 on the picture plane line, project downward to the horizon line to locate the left and right vanishing points. Locate the ground line and draw the side or front view of the object on the ground line. In this example, the object is viewed from above. If the object is to be viewed from below, the ground line would have been located *above* the horizon line (refer back to Figure 18-46).

Step 5. From the right-side view, project the true height to the measuring line. From the height on the measuring line, project back into space

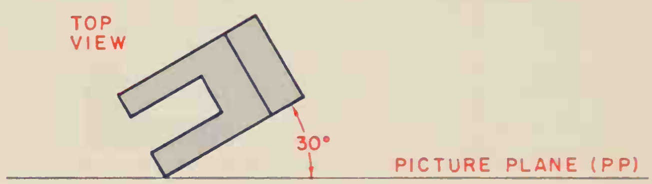


Figure 18-48C Step 1

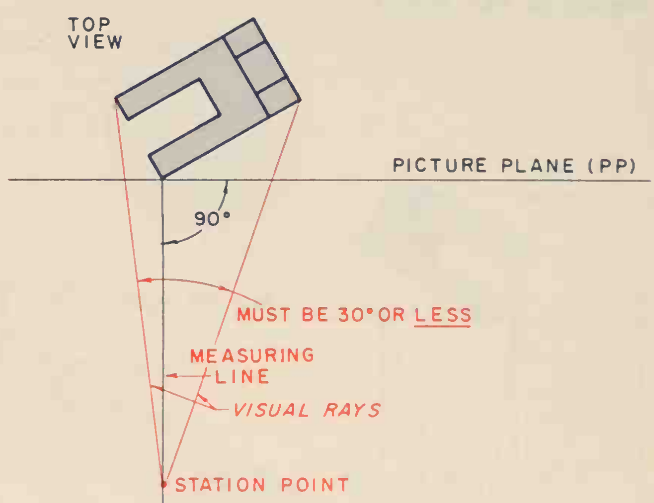


Figure 18-48D Step 2

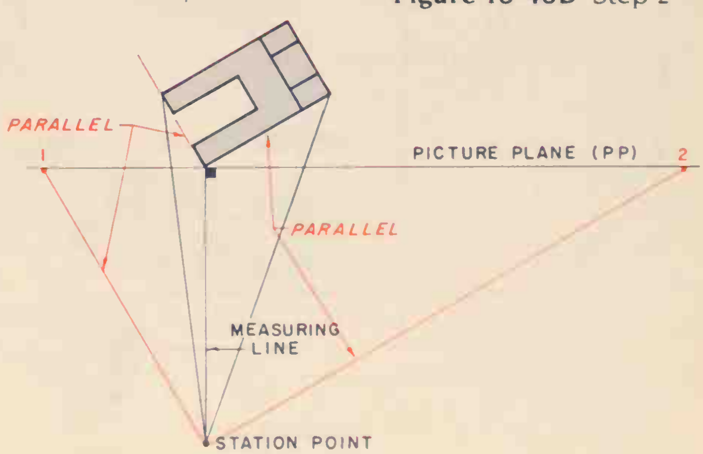


Figure 18-48E Step 3

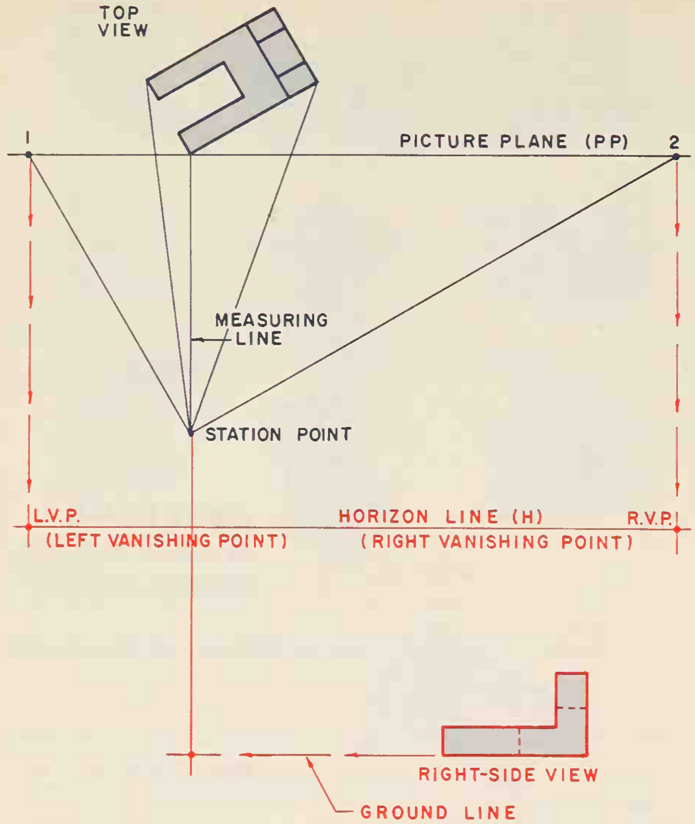


Figure 18-48F Step 4

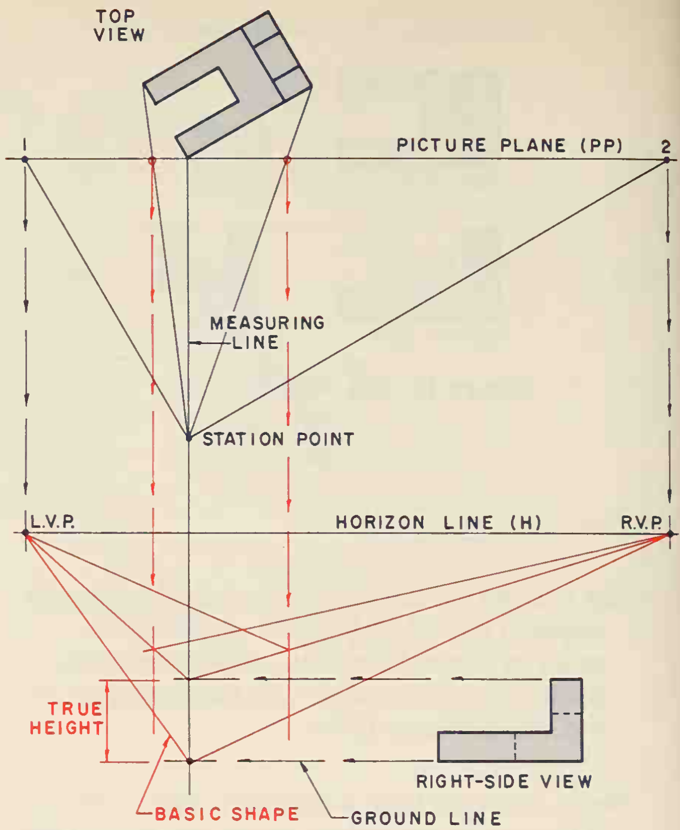


Figure 18-48G Step 5

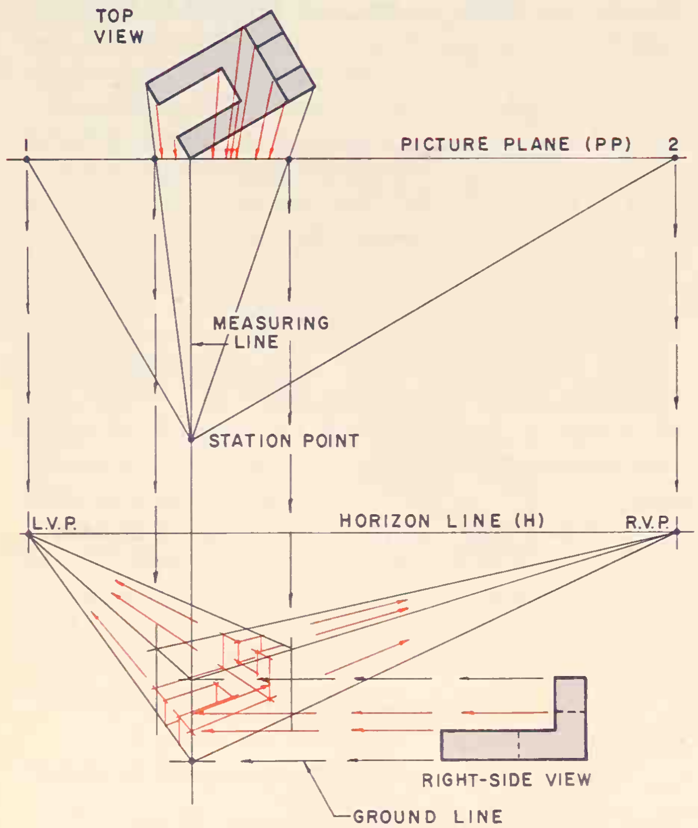


Figure 18-48H Step 6

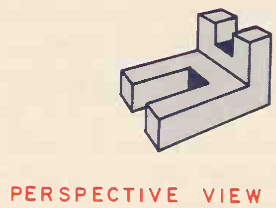


Figure 18-48I Completed two-point perspective drawing

to the left and right vanishing points, Figure 18-48G. Construct the perspective basic shape of the object. The basic shape projects back into space until it intersects a line projected downward from the picture plane line.

Step 6. Project the true heights of each feature from the right-side view to the measuring line and back toward the appropriate vanishing point to a point where the same feature intersects the picture plane line, Figure 18-48H. Lightly develop the various features of the object as would be done in an isometric view.

Step 7. Check all work, and, if correct, darken in the object using correct line thickness, Figure 18-48I. As a general rule, hidden lines are *not* usually drawn except to illustrate an important feature that would otherwise not be seen.

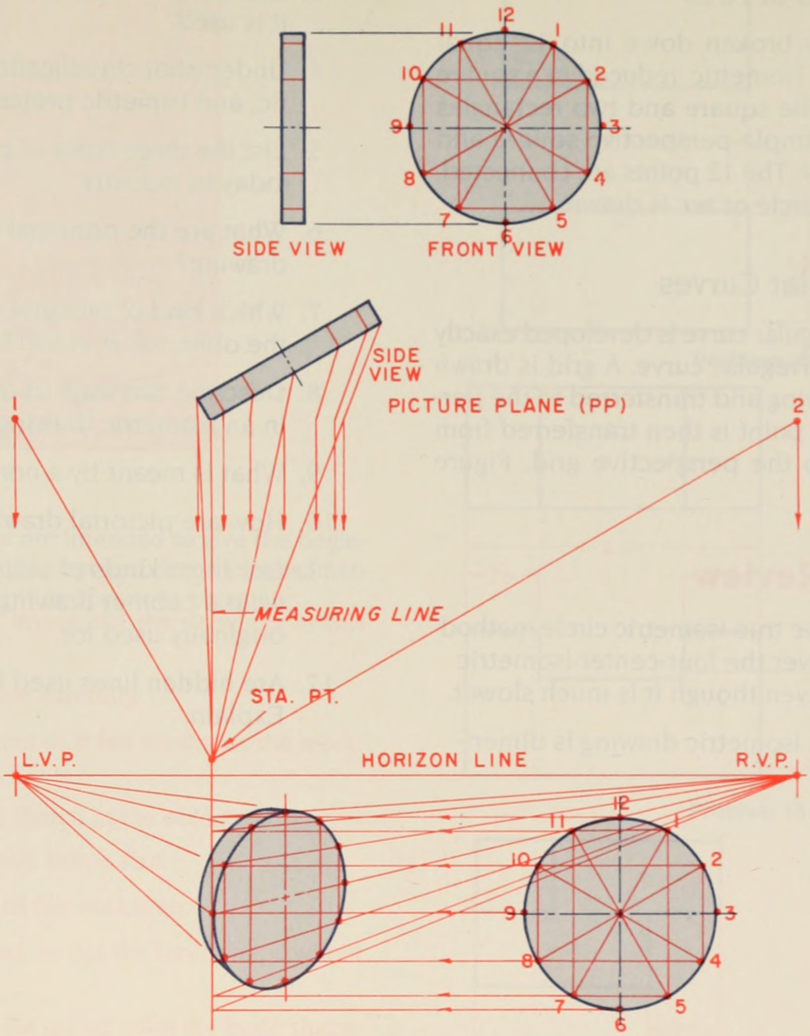


Figure 18-49 Perspective circles or arcs

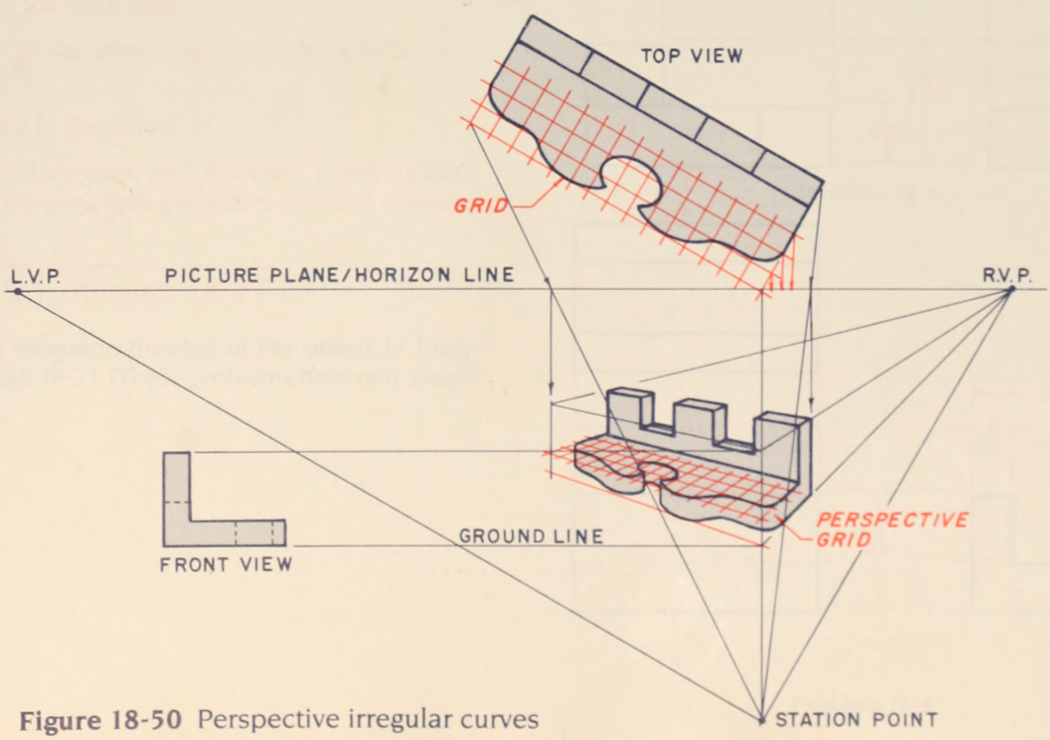


Figure 18-50 Perspective irregular curves

Perspective Circles or Arcs

The circle or arc is broken down into 12 equal spaces and, as with an isometric, reduced to a square and two rectangles. The square and two rectangles are now drawn as a simple perspective square and rectangle, Figure 18-49. The 12 points are connected, and the perspective circle or arc is drawn.

Perspective Irregular Curves

The perspective irregular curve is developed exactly as with an isometric irregular curve. A grid is drawn on the multiview drawing and transferred to the perspective layout. Each point is then transferred from the multiview grid to the perspective grid, Figure 18-50.

Review

1. Explain when the true isometric circle method must be used over the four-center isometric circle method even though it is much slower.
2. Explain how an isometric drawing is dimensioned.
3. Explain the use of box construction and why it is used.
4. Under what classification do isometric, dimetric, and trimetric projections fall?
5. List the three types of pictorial drawings used today in industry.
6. What are the principal edges of a pictorial drawing?
7. Which kind of pictorial drawing best illustrates the object as it would be viewed by the eye?
8. Describe two ways to draw an irregular curve in an isometric drawing.
9. What is meant by a nonisometric line?
10. How are pictorial drawings used today?
11. List three kinds of oblique drawings. Explain what a cabinet drawing is, and what it was originally used for.
12. Are hidden lines used in pictorial drawings? Explain.

Chapter Eighteen Problems

The following problems are intended to give the beginning drafter practice in laying out and developing isometric and perspective renderings of various objects.

The steps to follow in laying out the drawings in this chapter are:

Step 1. Study the problem carefully.

Step 2. Position the object so it *best* illustrates the most features.

Step 3. Make a pictorial sketch of the object.

Step 4. Calculate the basic shape size.

Step 5. Find the center of the work area.

Step 6. Lightly center and lay out the basic shape within the work area.

Step 7. Lightly develop the object *within* the basic shape.

Step 8. Check to see that the completed object is centered within the work area.

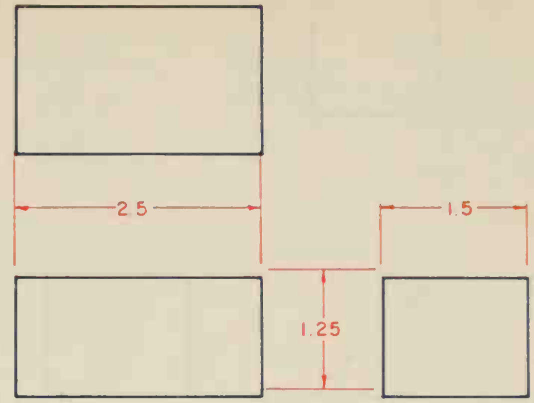
Step 9. Check all size dimensions, and check for accuracy of object.

Step 10. Darken in the object.

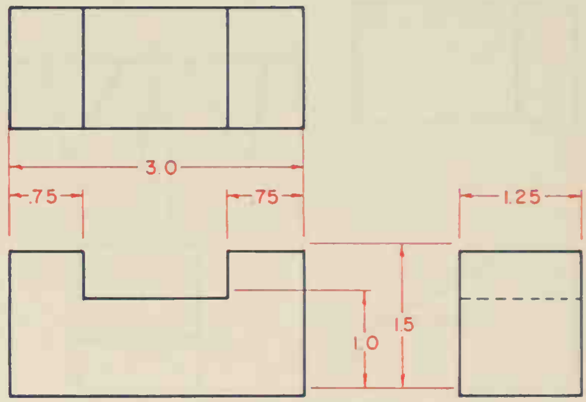
Step 11. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.

Problems 18-1 through 18-27

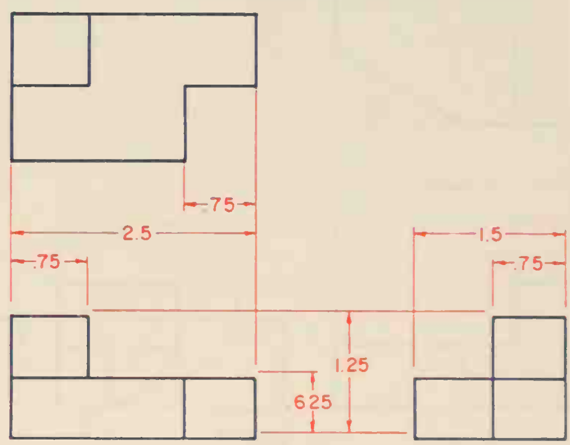
Construct an isometric drawing of the object in Problems 18-1 through 18-27. (These problems have only *straight* lines.)



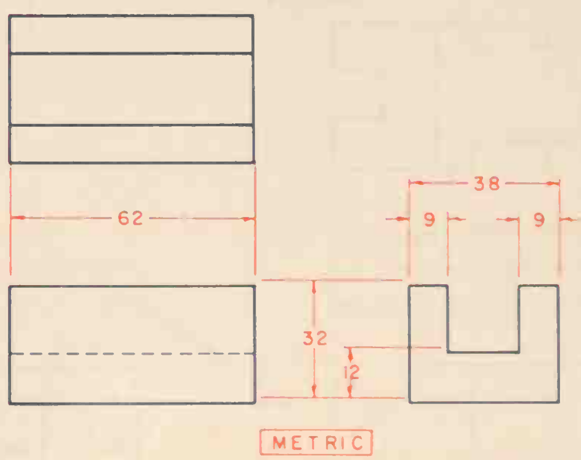
Problem 18-1



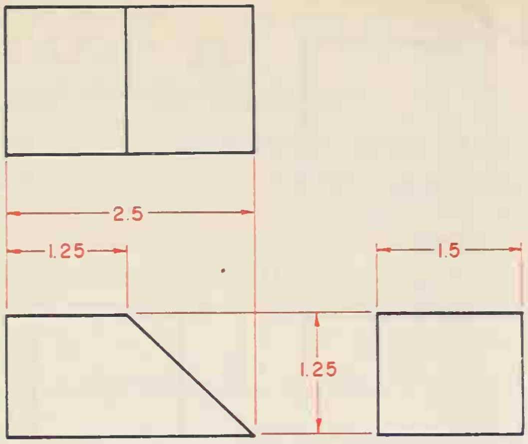
Problem 18-2



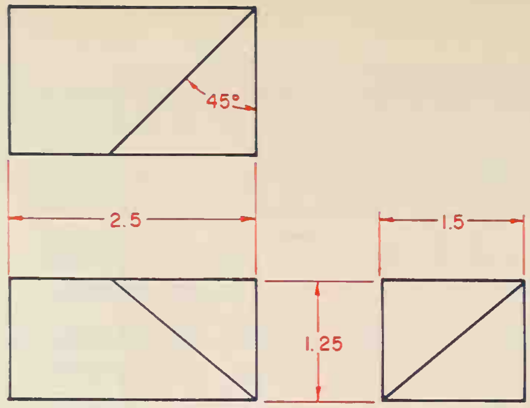
Problem 18-3



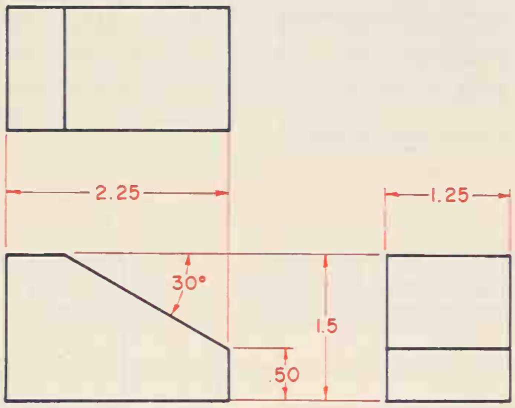
Problem 18-4



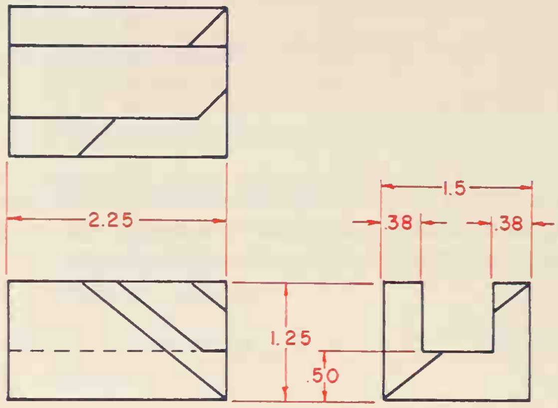
Problem 18-5



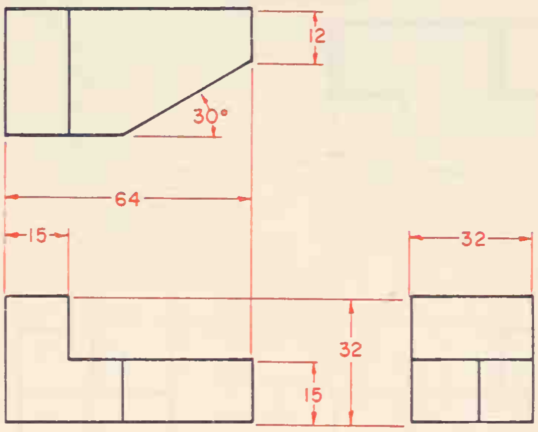
Problem 18-9



Problem 18-6

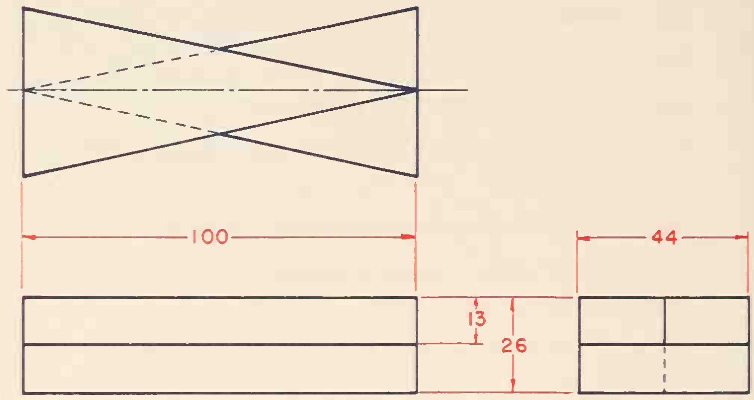


Problem 18-10

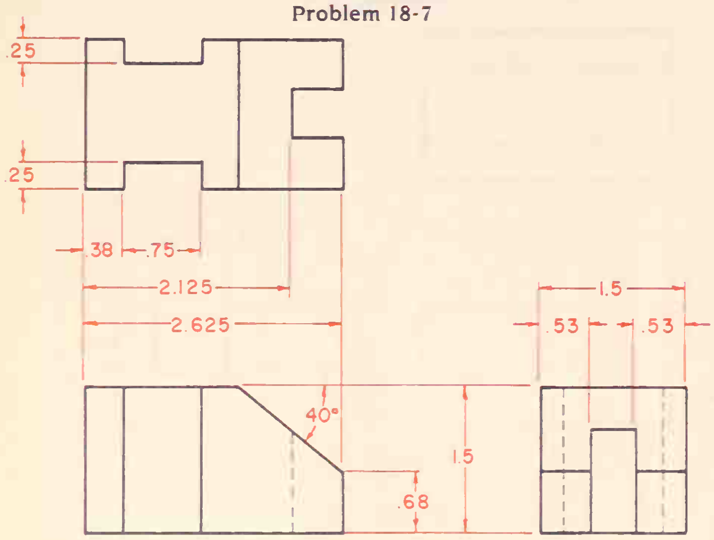


METRIC

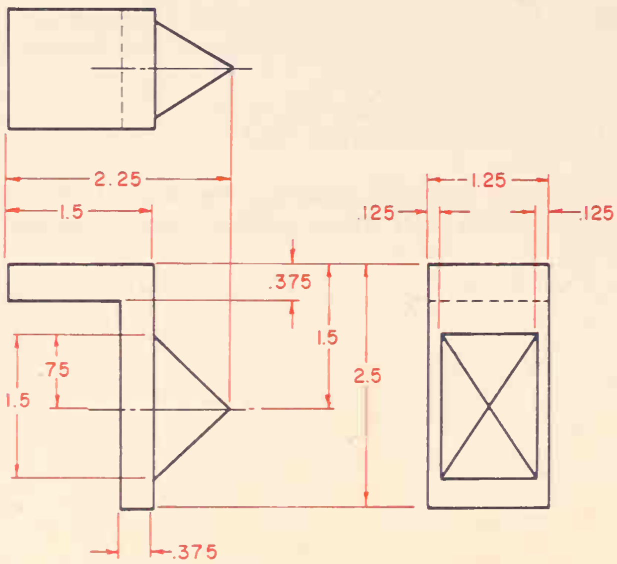
Problem 18-7



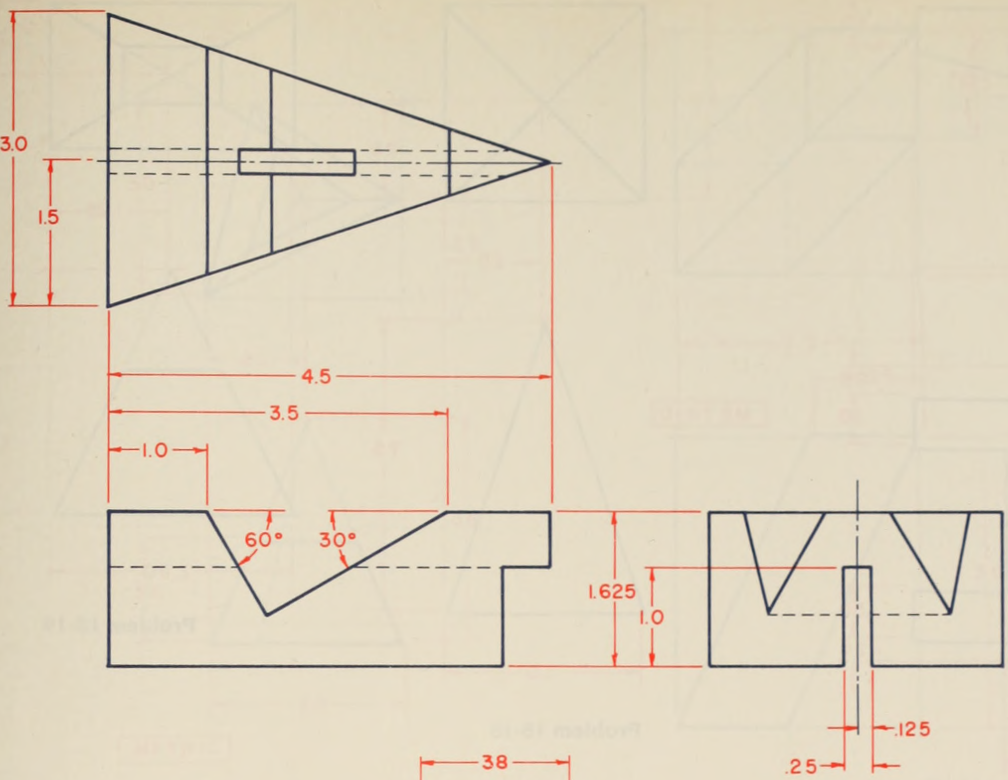
Problem 18-11



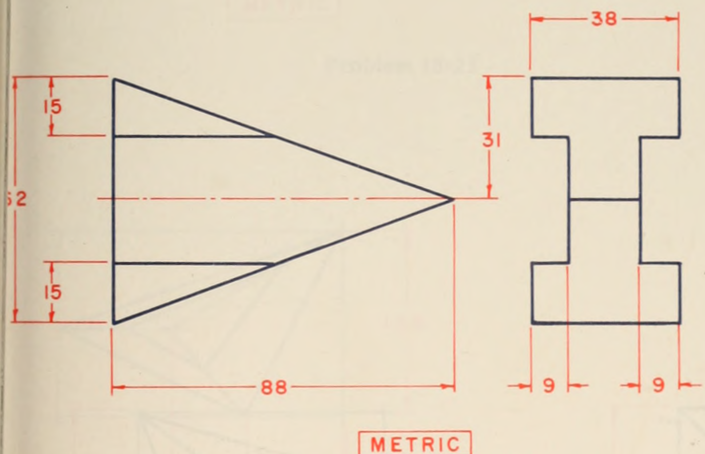
Problem 18-8



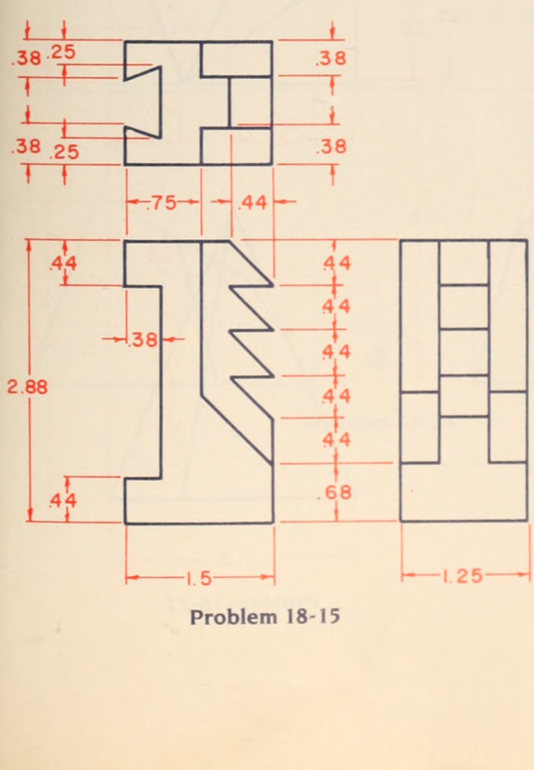
Problem 18-12



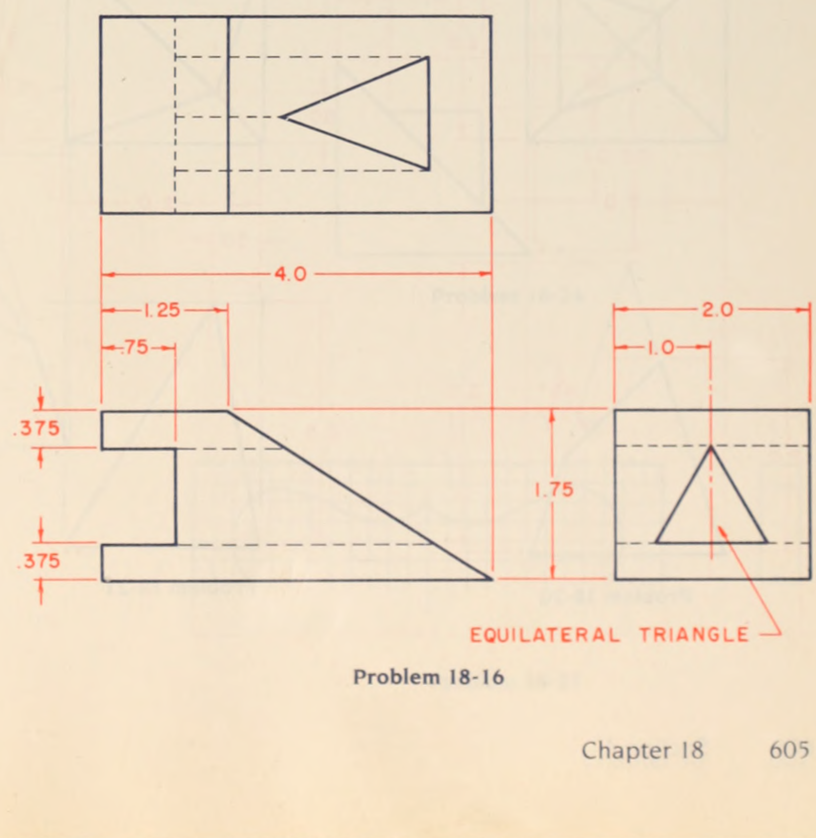
Problem 18-13



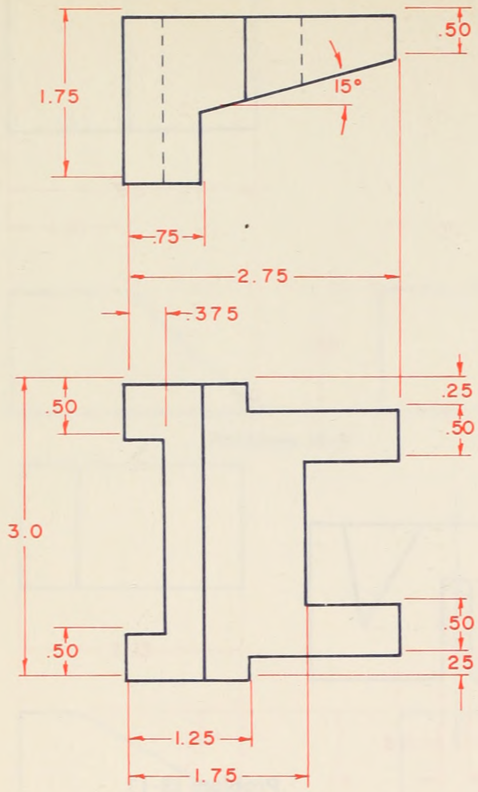
Problem 18-14



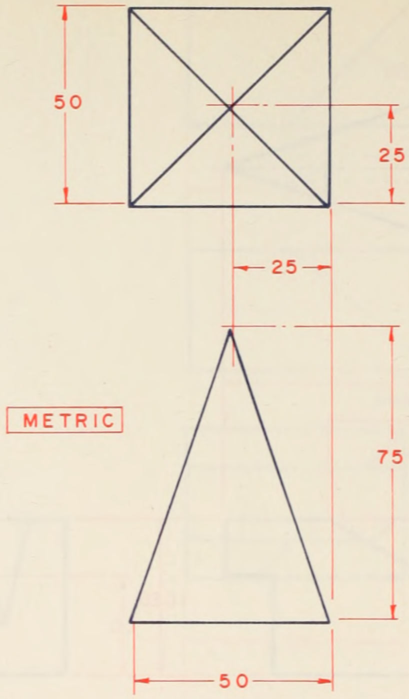
Problem 18-15



Problem 18-16



Problem 18-17



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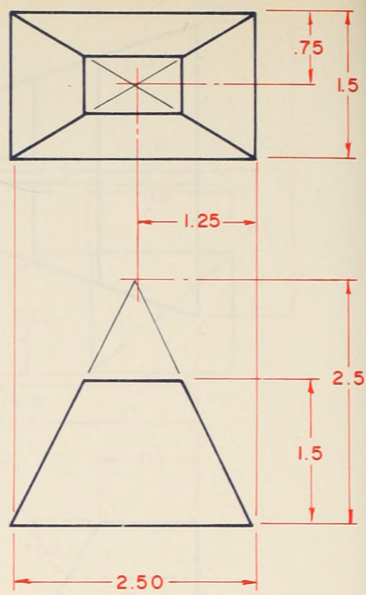

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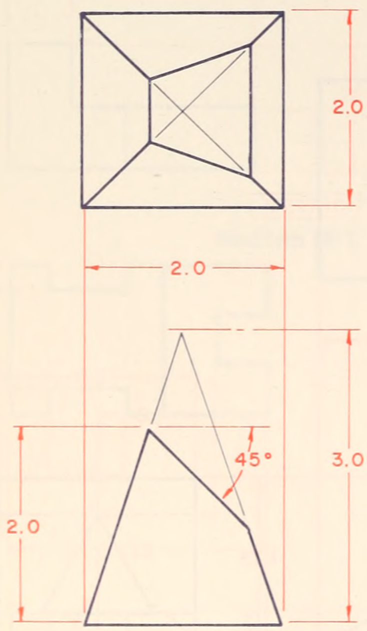

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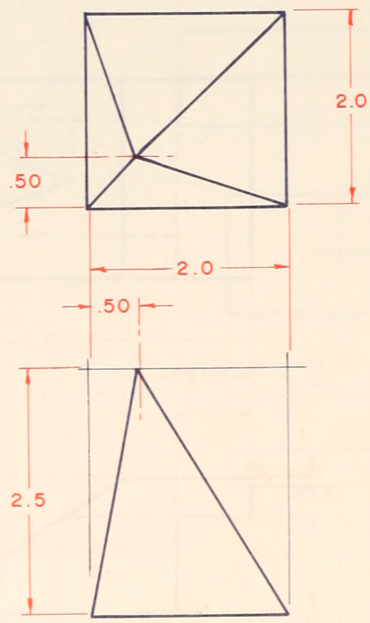

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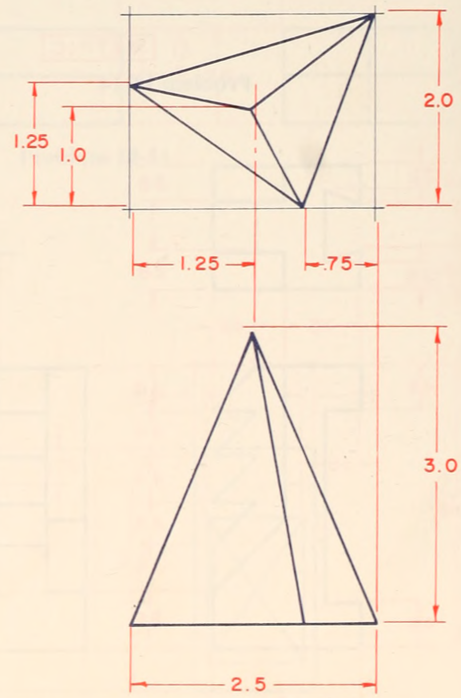

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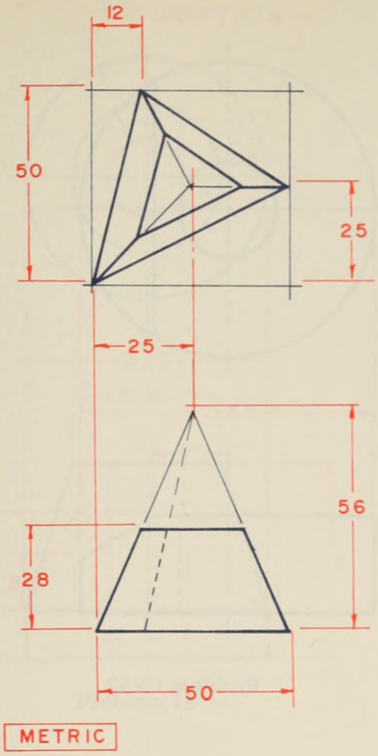

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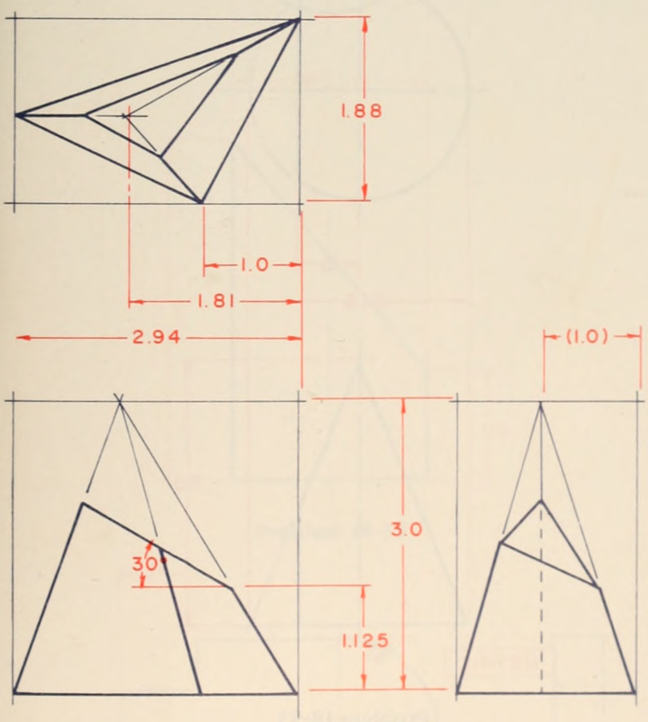

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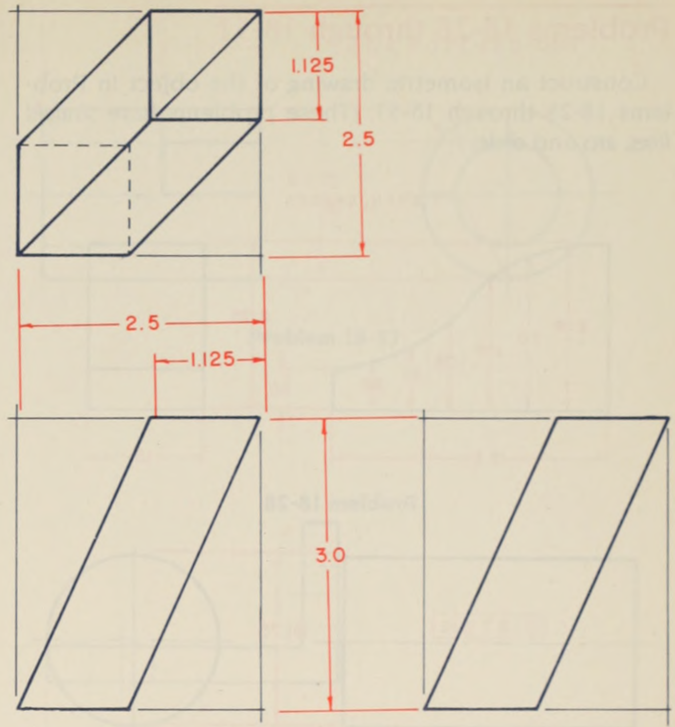

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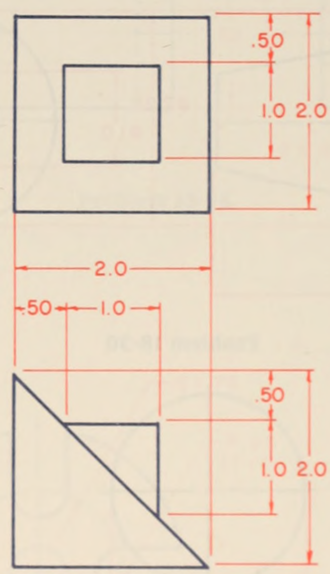
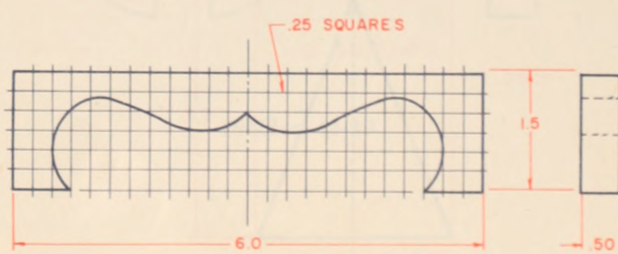


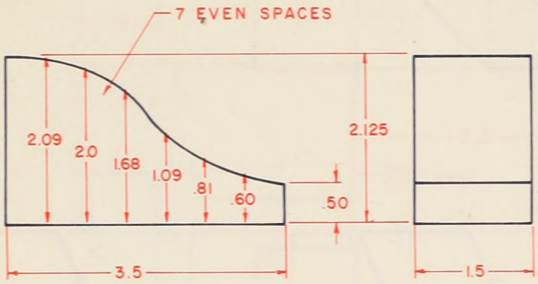
Problem 18-26



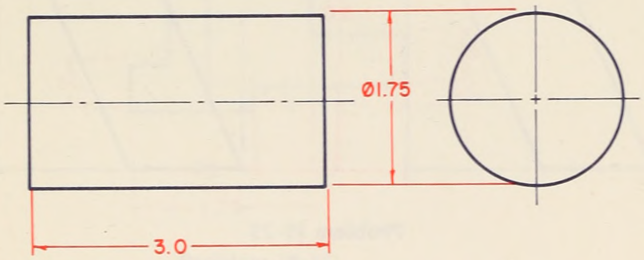
Problem 18-27

Problems 18-28 through 18-51

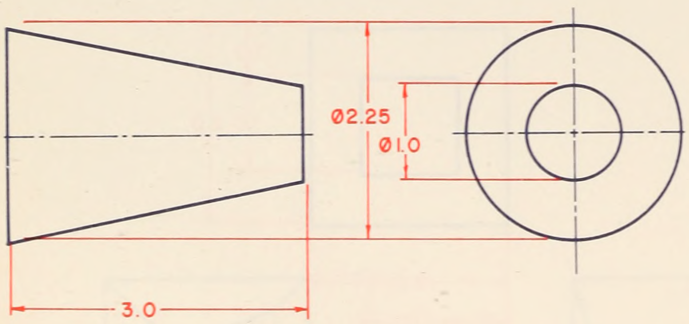
Construct an isometric drawing of the object in Problems 18-28 through 18-51. (These problems have *straight lines, arcs* and *circles*.)



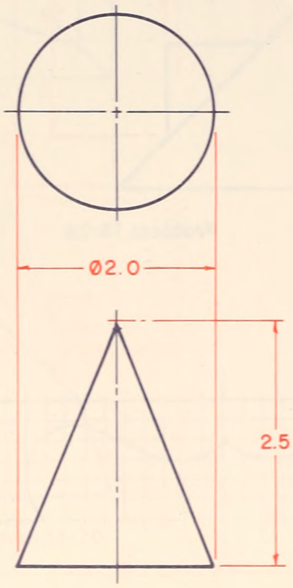
Problem 18-28



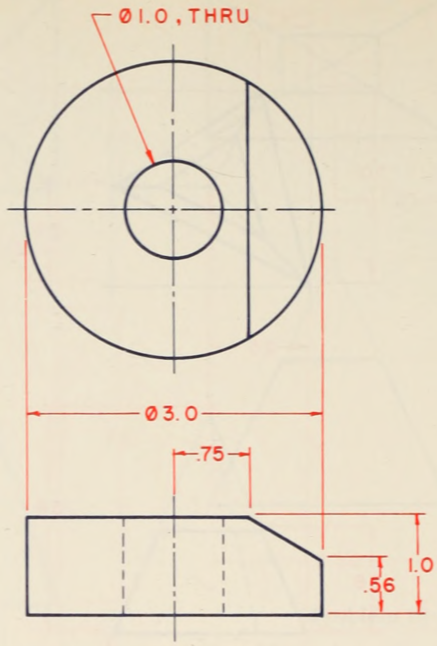
Problem 18-29



Problem 18-30



Problem 18-31



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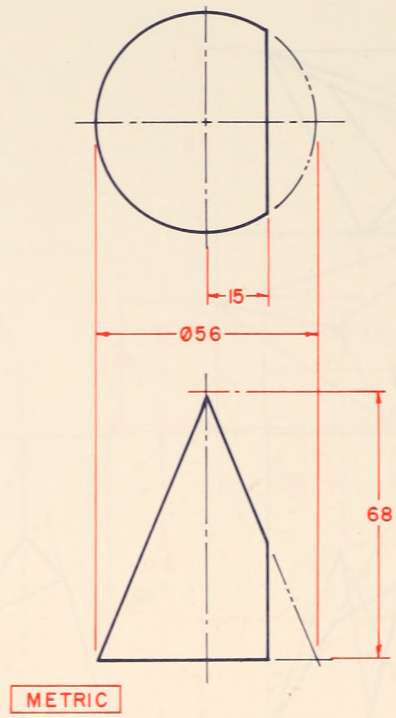

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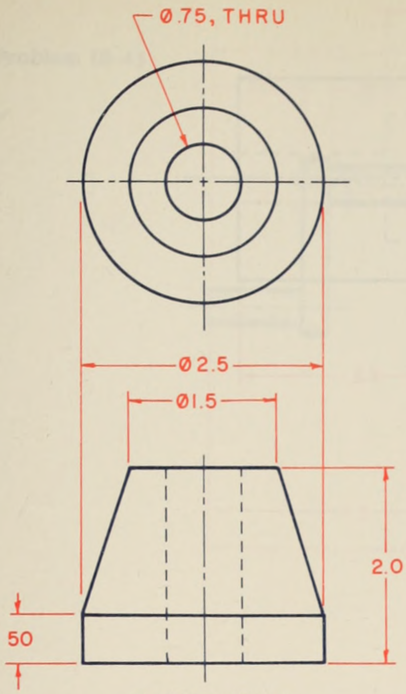

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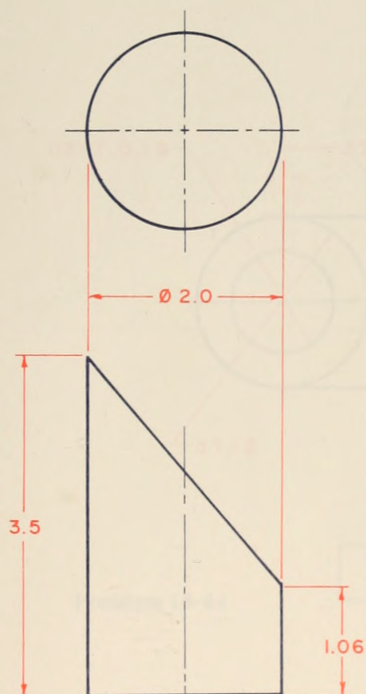

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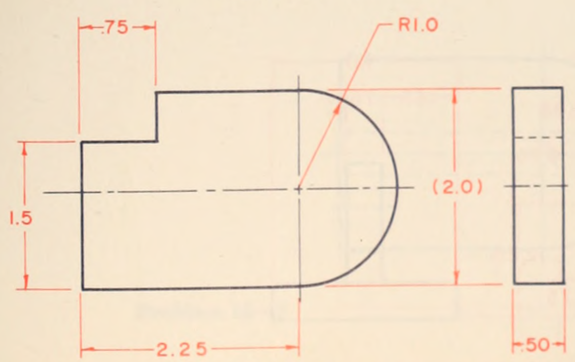
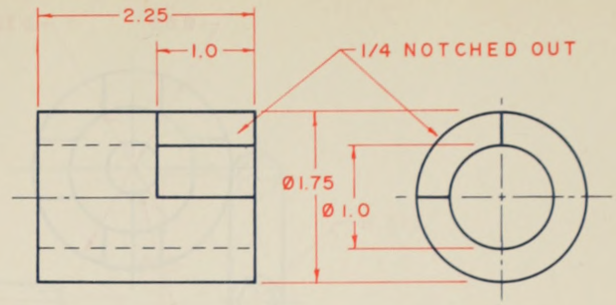
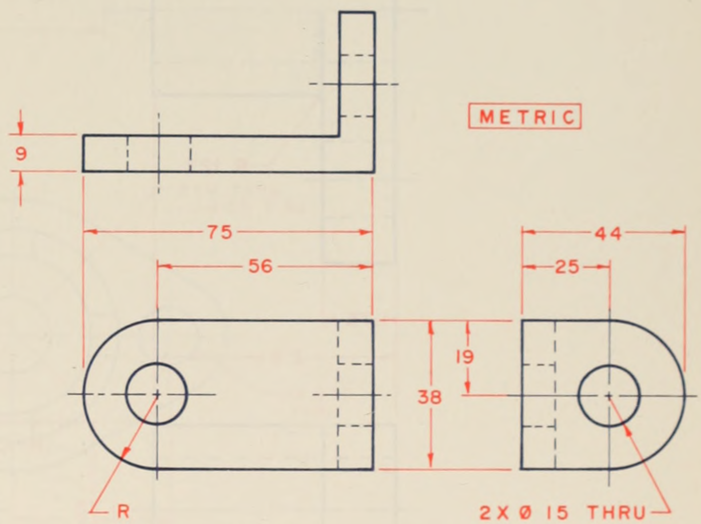


Problem 18-36



Problem 18-37



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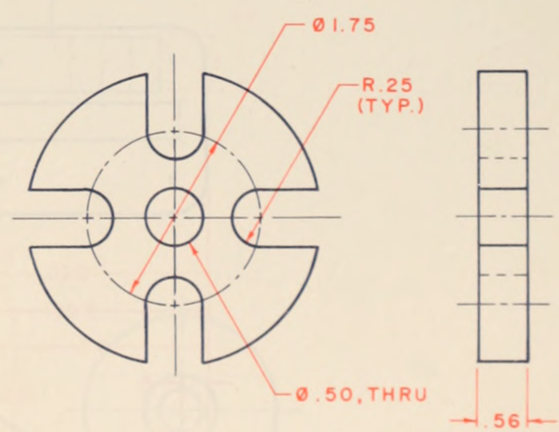
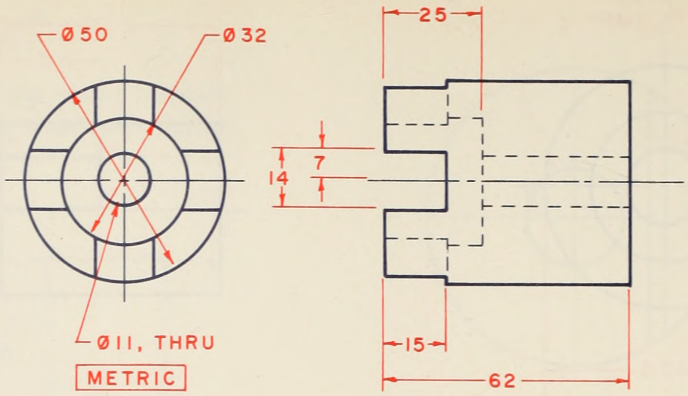
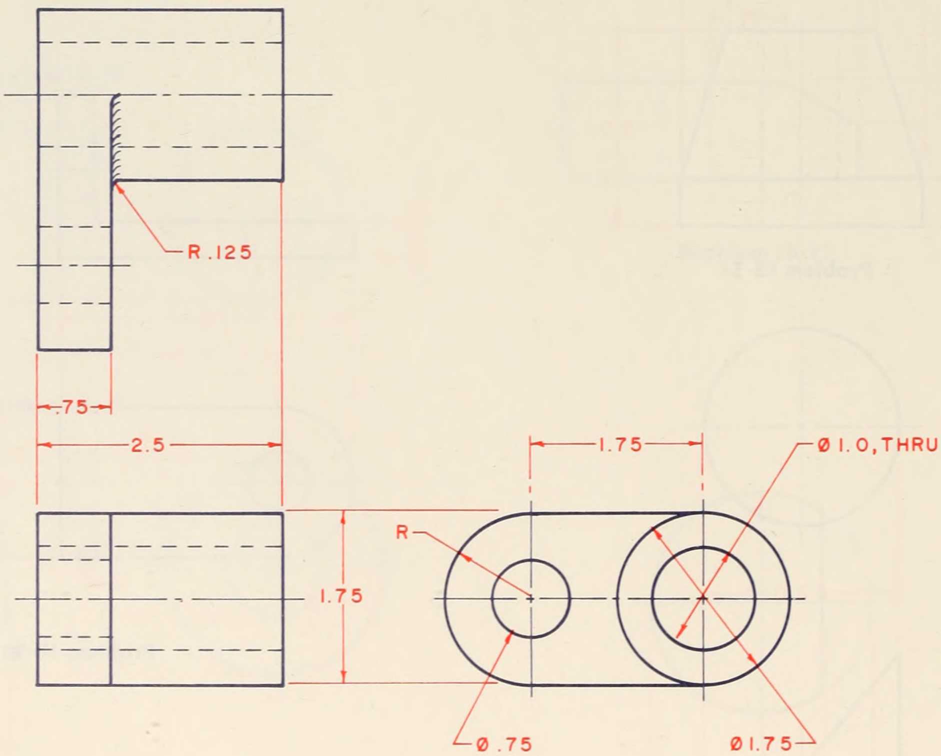


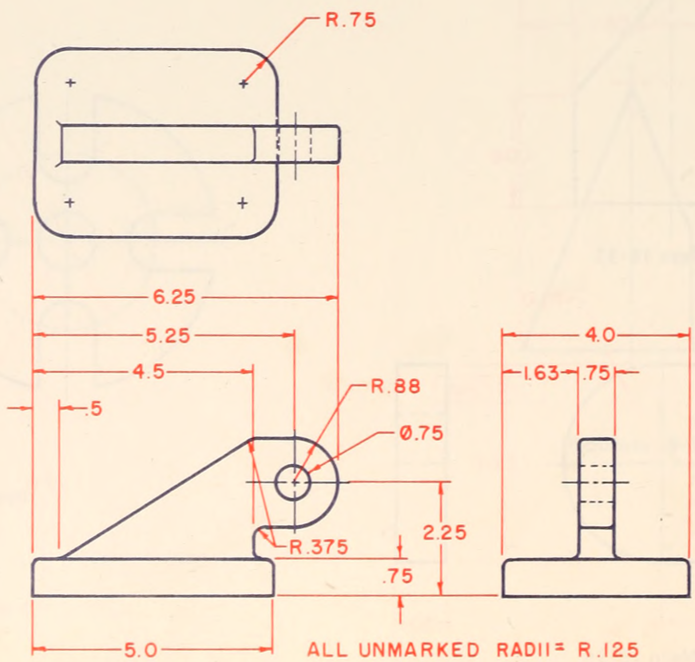
Problem 18-39



Problem 18-40

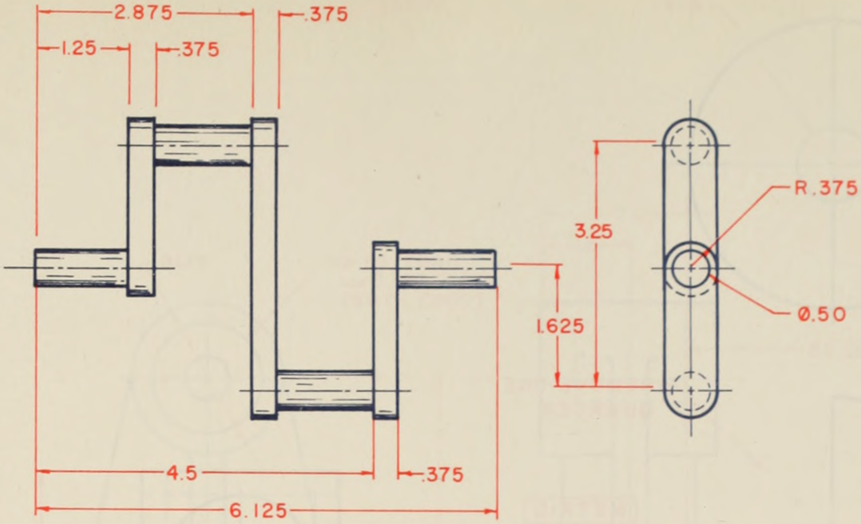


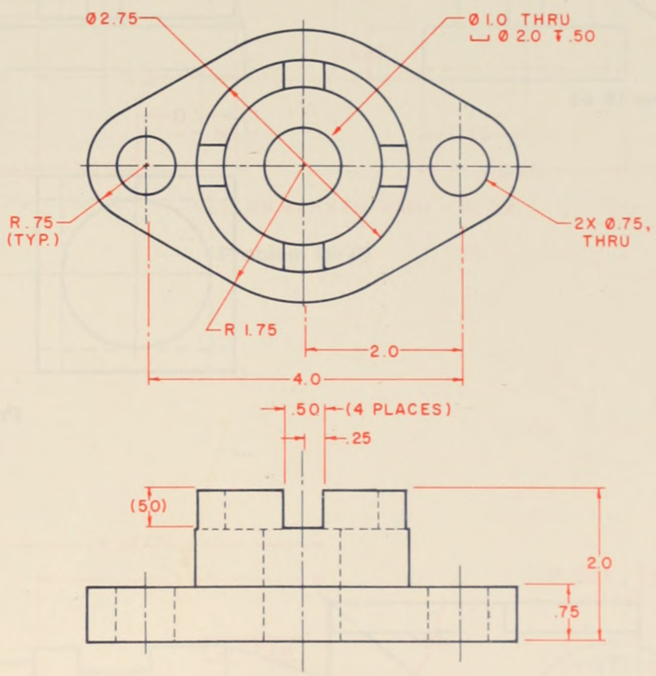
Problem 18-41



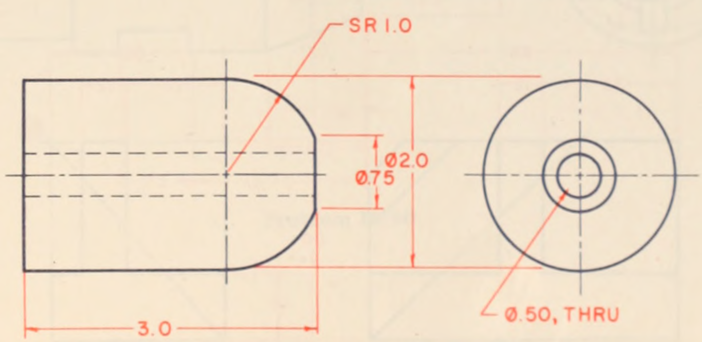
Problem 18-42

Problem 18-43

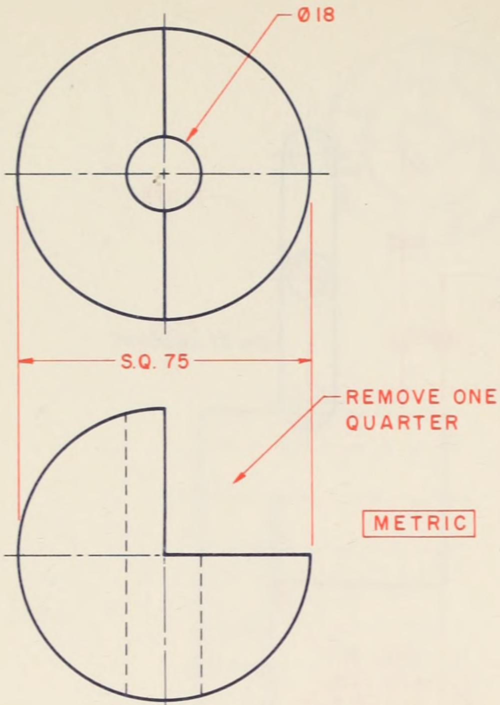




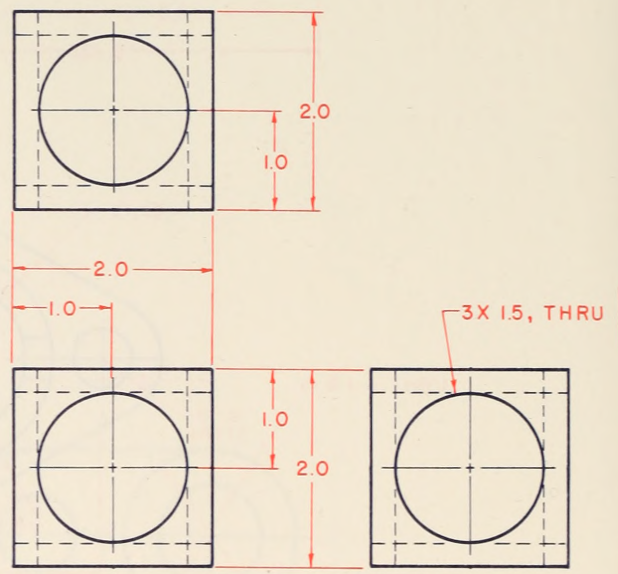
Problem 18-44



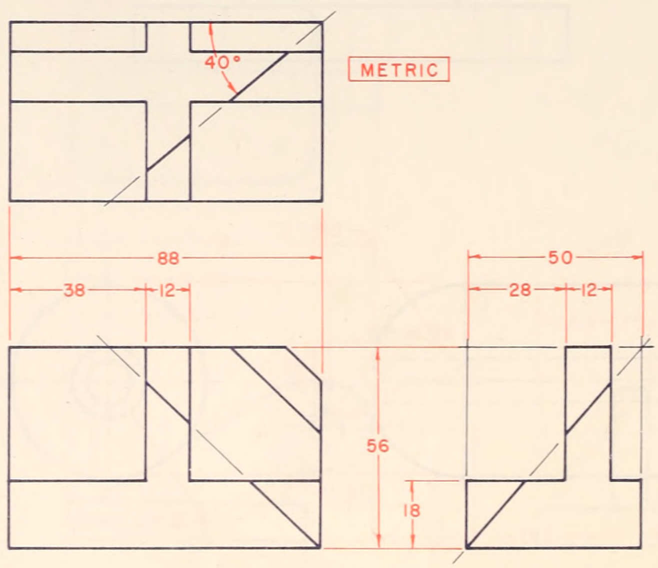
Problem 18-45



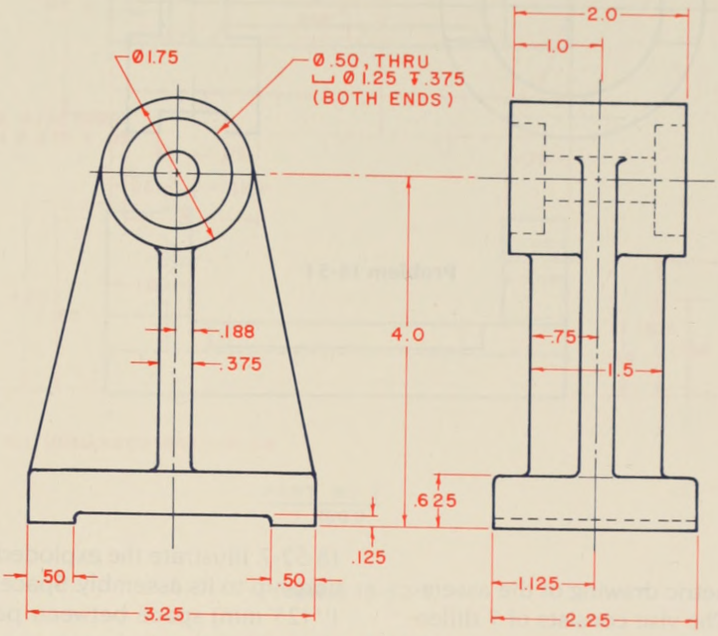
Problem 18-46



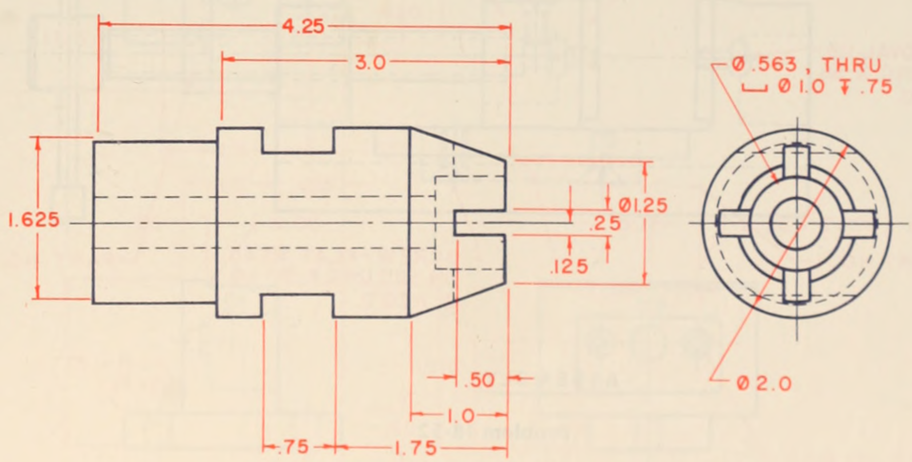
Problem 18-47



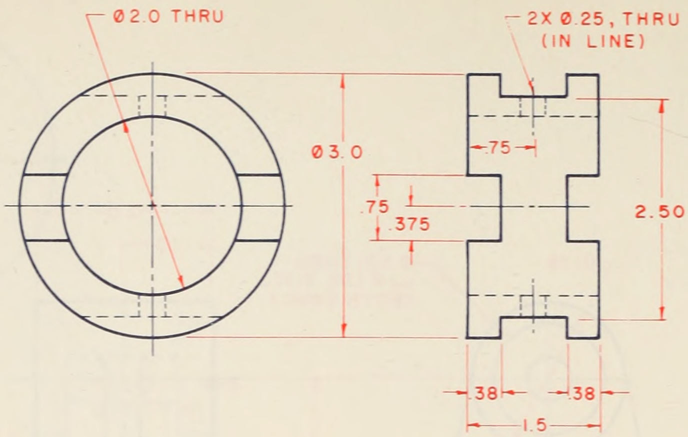
Problem 18-48



Problem 18-49



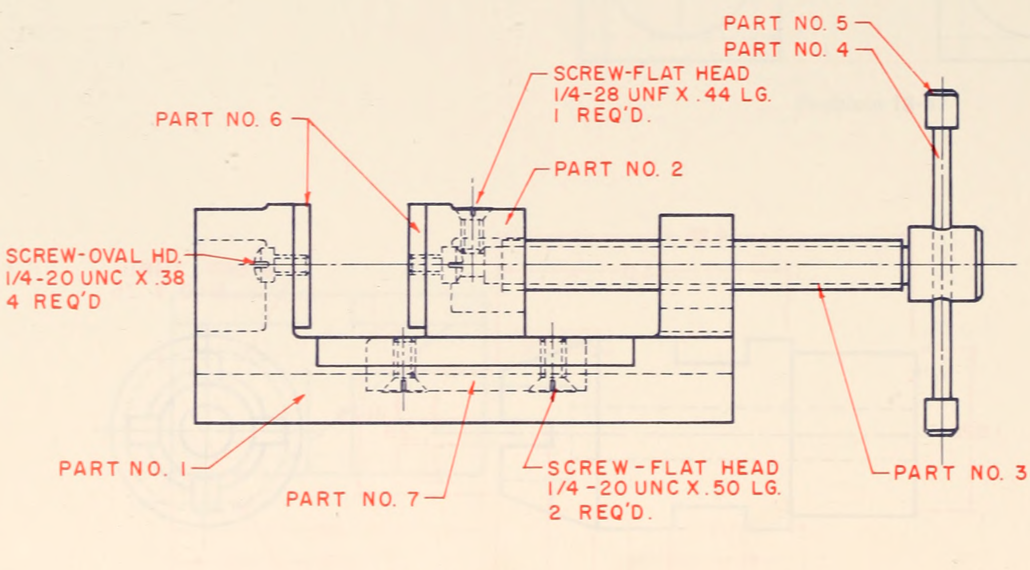
Problem 18-50



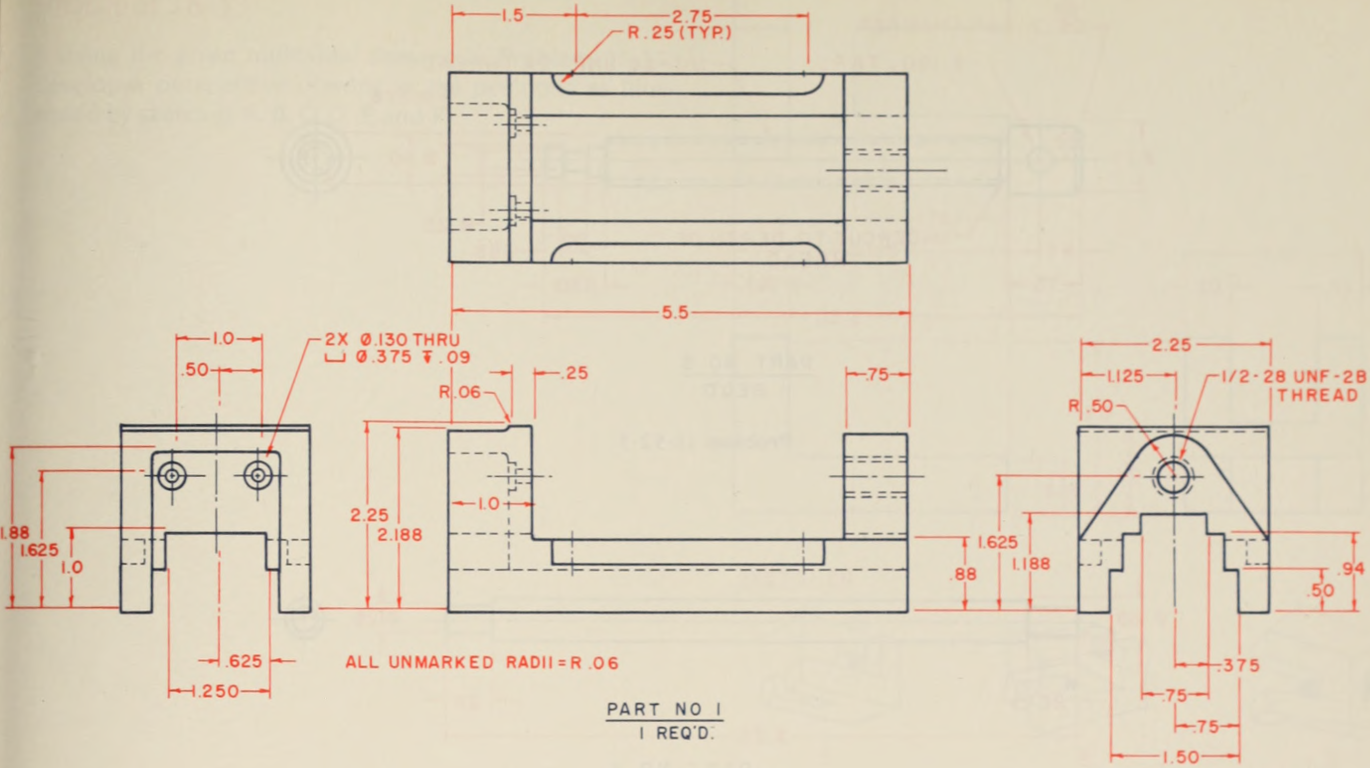
Problem 18-51

Problem 18-52

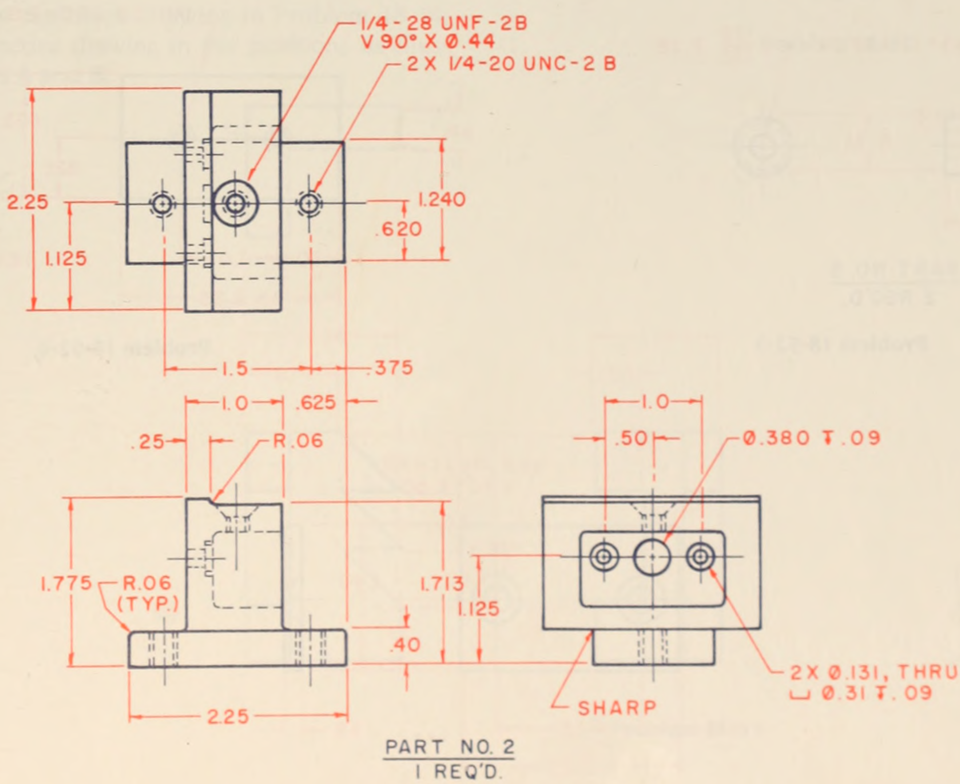
Construct an exploded isometric drawing of the assembly of a vise, Problem 18-52. The vise consists of 7 different parts and various fasteners, Problems 18-52-1 through 18-52-7. Illustrate the exploded view with the parts in relationship to its assembly. Space parts with an approximate 1'' (25 mm) space between parts. Center the completed view within the work area.



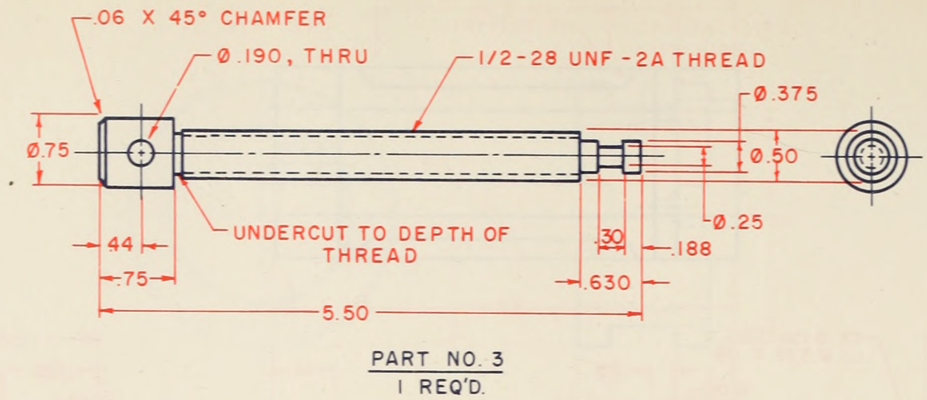
Problem 18-52



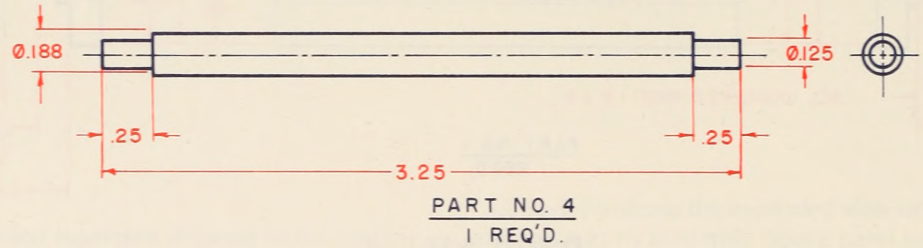
Problem 18-52-1



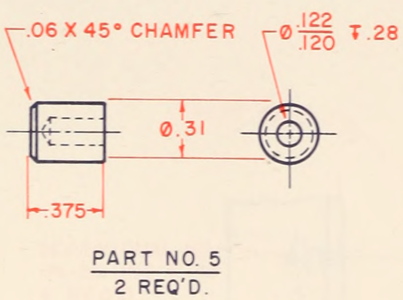
Problem 18-52-2



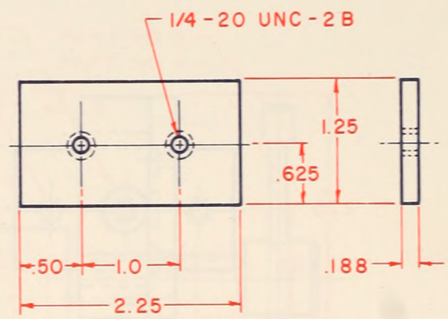
Problem 18-52-3



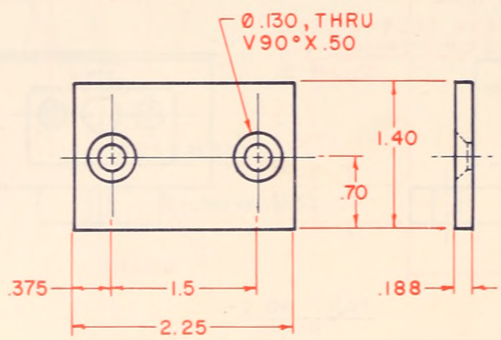
Problem 18-52-4



Problem 18-52-5



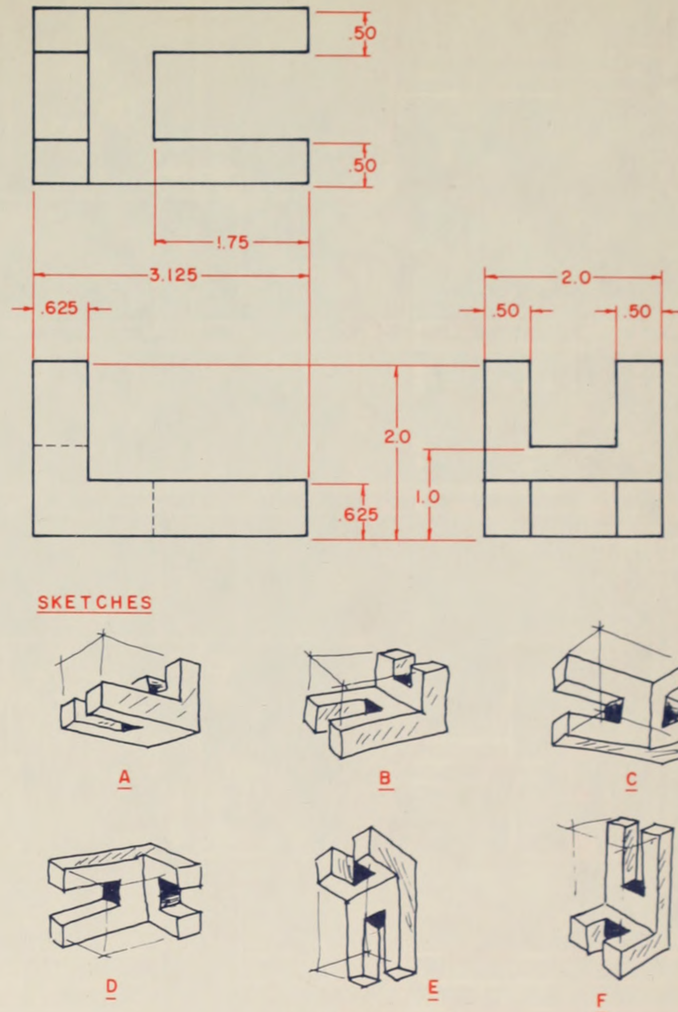
Problem 18-52-6



Problem 18-52-7

Problem 18-53

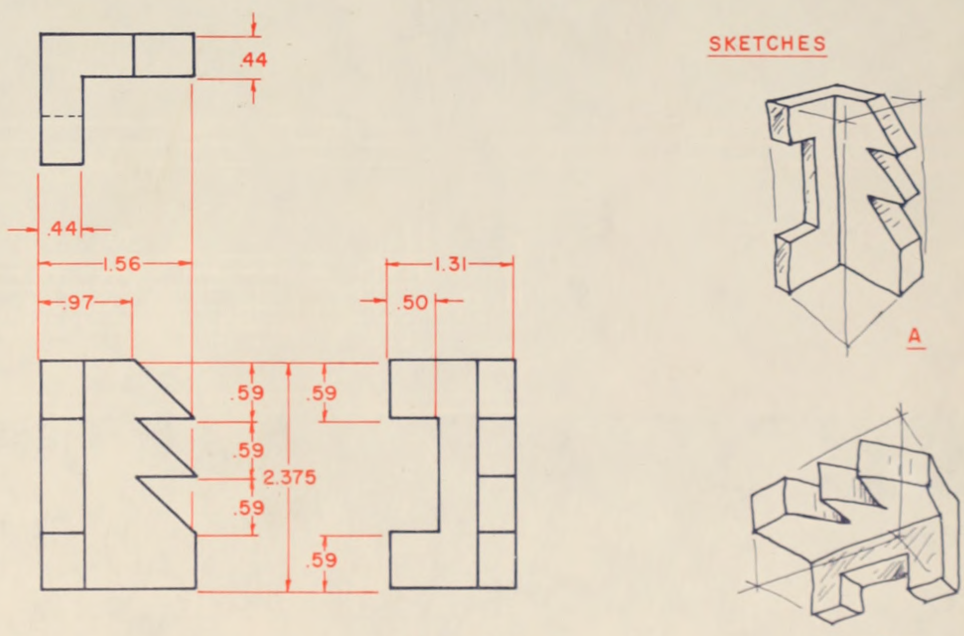
Using the given multiview drawing in Problem 18-53, develop a perspective drawing in the positions as illustrated by sketches A, B, C, D, E and F.



Problem 18-53

Problem 18-54

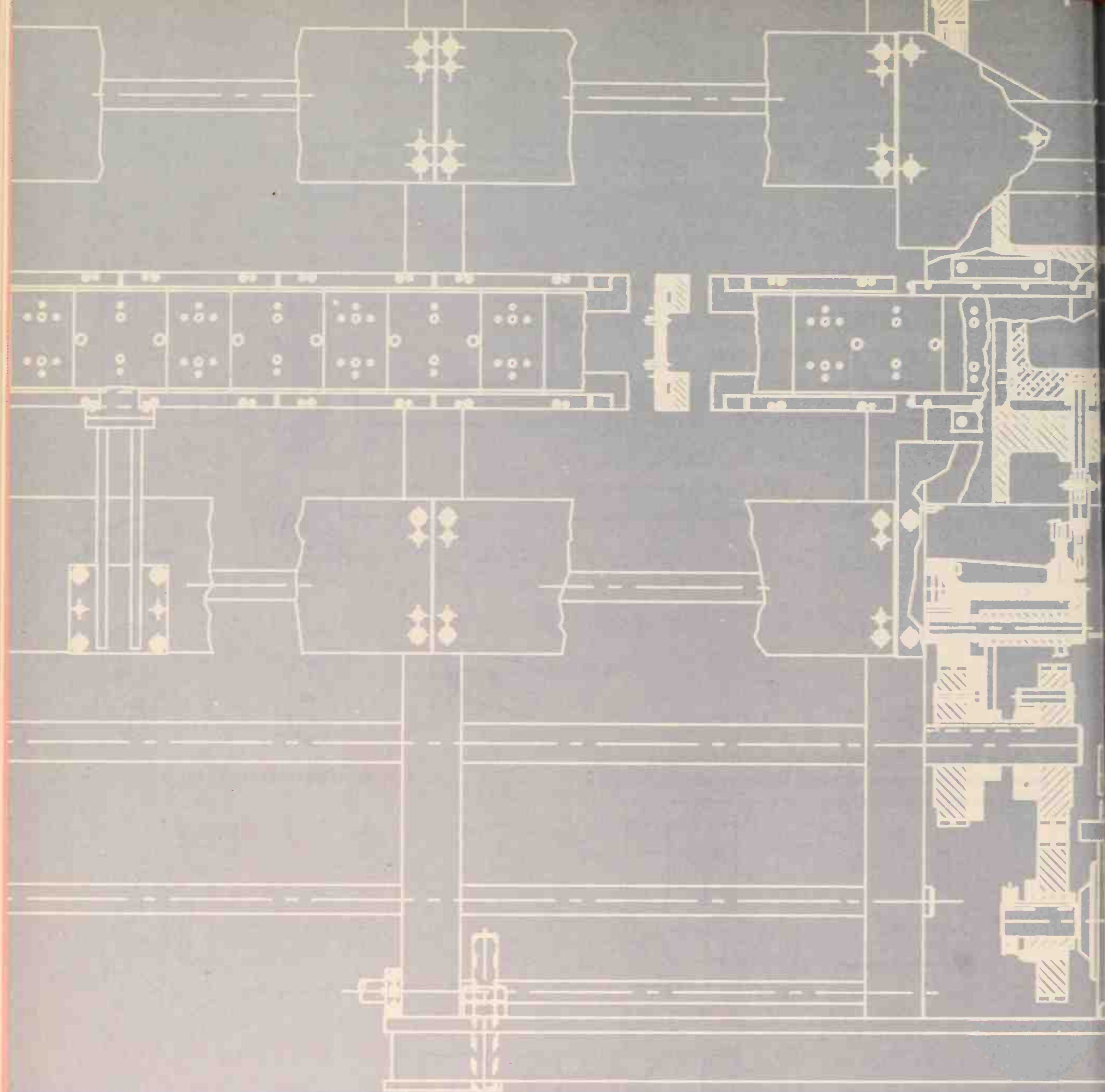
Using the given multiview drawing in Problem 18-54, develop a perspective drawing in the positions as illustrated by sketches A and B.



Problem 18-54

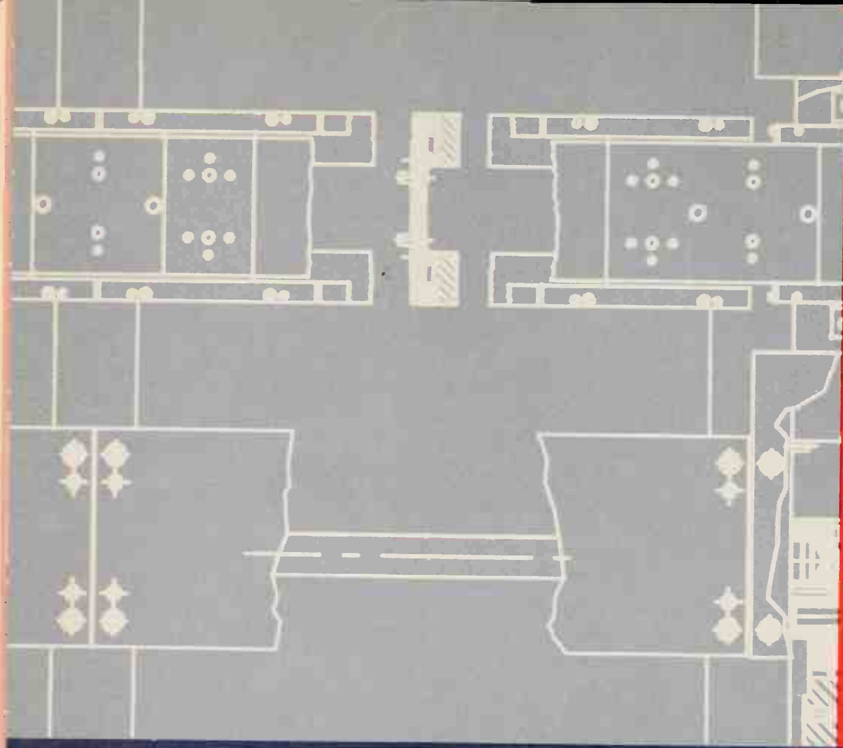
Problem 18-55

Choose various objects from Problems 18-1 through 18-51, and develop them into a perspective drawing. Compare the isometric view with the isometric drawing.



SECTION FIVE

RELATED TECHNOLOGY



CHAPTER 19

This chapter discusses the various types of welds. All welding symbols and their meanings are studied and fully illustrated. Also discussed are the size, length, and placement of welds; welding processes; welding joints; depth and actual size of welds; multiple reference lines; dimensioning of welds; spot welds; projection welds; seam welds; and weld templates.

WELDING

Welding Processes

Pieces of metal can be fastened together with mechanical fasteners as was discussed in Chapter 13, "Fasteners." They can also be held together by soldering or brazing, and some are fastened together by an adhesive. A permanent way to join pieces of metal together is by *welding*.

One method used to weld parts together is to heat the edges of the pieces to be joined until they melt and join or fuse together. When the pieces cool, they become one homogeneous mass, permanently joined together. A filler rod is sometimes used to mix with the molten metal to make the joint stronger. When a lot of heat is used to melt and fuse the joint, the weld is called a *fusion weld*. Heat for this process can come from a torch, burning gasses or with a high electric current. Because of the extremely high temperatures involved in welding, the part or parts may be distorted; thus, all machining is usually done after welding.

Another kind of weld used in years past was the pressure weld. In this process, the parts to be welded together are heated to a plastic state, and forced together by pressure or by hammering. This was done by the local blacksmith. This old method was called *forge welding*. Today, faster and better methods are used.

Welding assemblies are usually built-up from stock forms, such as plate steel, square bars, tubing, angle iron and the like. These parts are cut to shape and welded together. The various welding processes are illustrated in Figure 19-1. Welded assemblies are much less expensive and more satisfactory than the casting process, especially in a case where only one or only a few identical parts are required.

Welding is used on large structures that would be difficult or impossible to build in a manufacturing plant. Large structures such as building frames, bridges, and ships are welded into one large assembly.

Major welding methods classified by the American Welding Society include: brazing, gas welding, arc welding, resistance welding, and fusion welding. *Brazing* is the process of joining metals together with a nonferrous filler rod. A temperature above 1000°F, but just below the melting point, is used to join the parts. The most commonly used *gas* welding is oxyacetylene welding. Resistance welding and fusion welding, the two major processes, are explained in this text. Detailed information regarding the other types of welding processes can be obtained by writ-

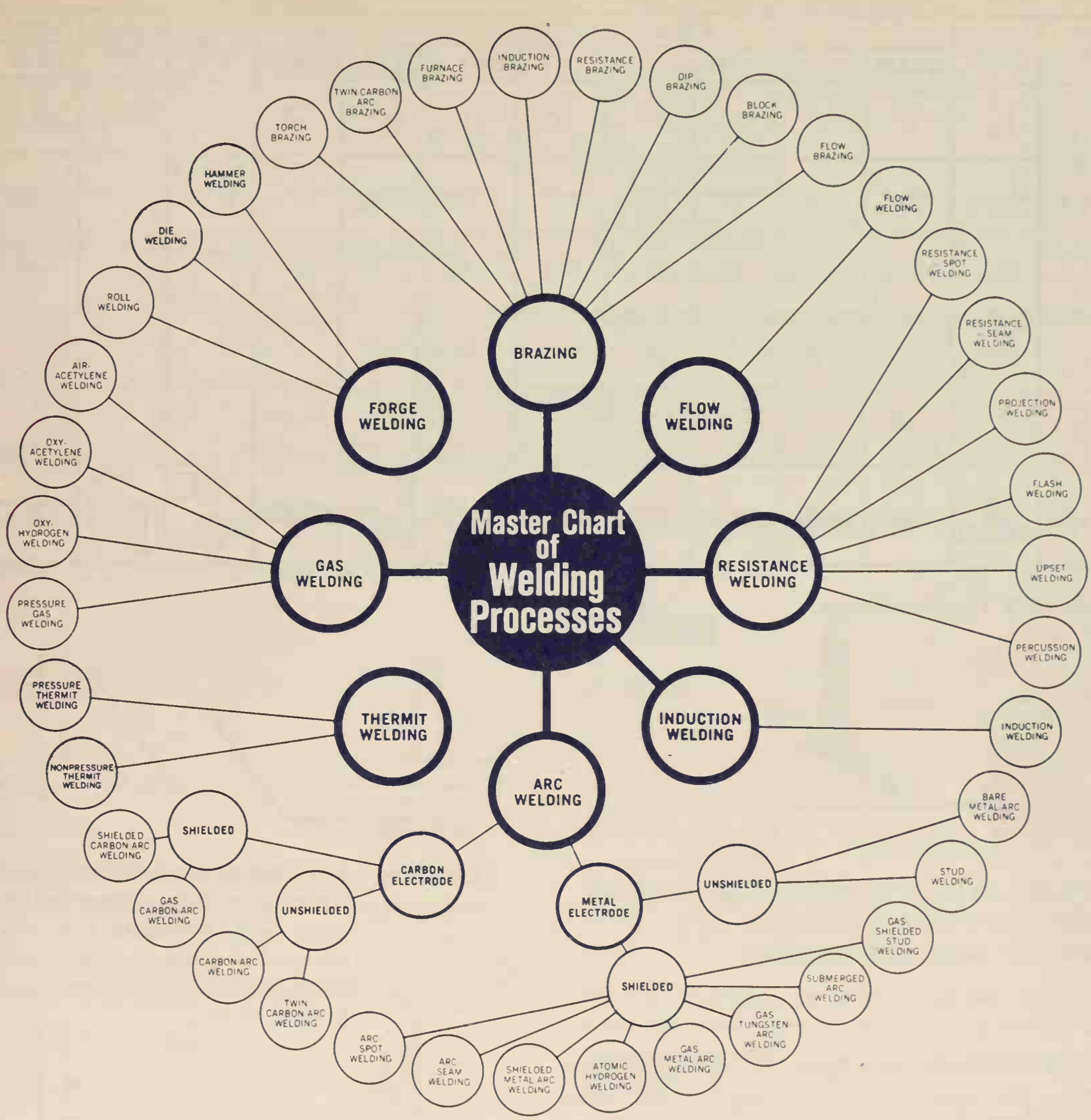


Figure 19-1 Master chart of welding processes (*Courtesy American Welding Society*)

ing to the American Welding Society, P.O. Box 351040, Miami, Florida 33125.

Resistance welding is the process of passing an electric current through the exact location where the parts are to be joined. This is usually done under pressure. The combination of the pressure and the heat generated by the electric current welds the parts together. This process is usually done on thin sheet metal parts.

Fusion welding is usually used for large parts. The fusion welding process uses many standard types of welds, Figure 19-2. Each is explained in full.

The next few figures use the fillet welding symbol as an example, but the same method applies, regardless of which welding symbol is used.

Basic Welding Symbol

The *basic welding symbol* consists of a reference line, a leader line and arrow, and, if needed, a tail, Figure 19-3. The tail is added for specific information or notes in regard to welding specifications, processes or reference information. The reference line of the basic welding symbol is usually drawn horizontally. Any welding symbol placed on the upper side of the reference line indicates WELD OPPOSITE SIDE, Figure 19-4. Any welding symbol placed on the lower side of the reference line indicates WELD ARROW SIDE, Figure 19-4. The direction of the leader line and arrow had no significance whatsoever to the reference line.

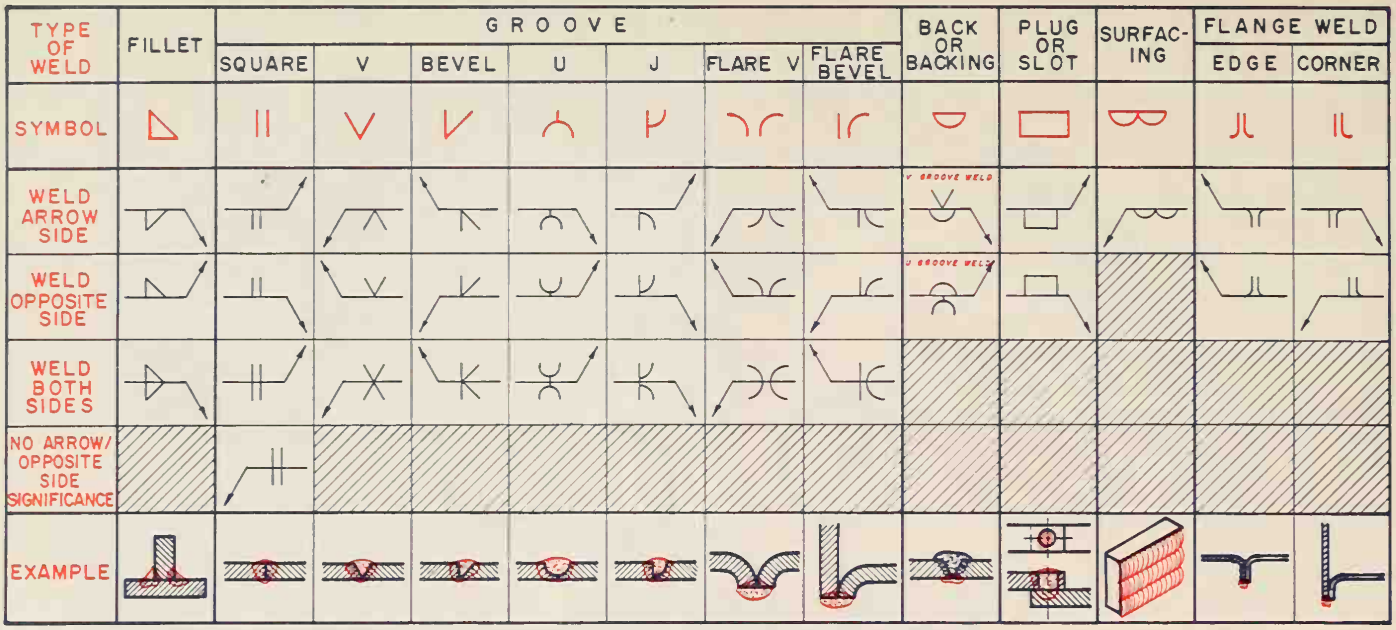


Figure 19-2 Fusion welding

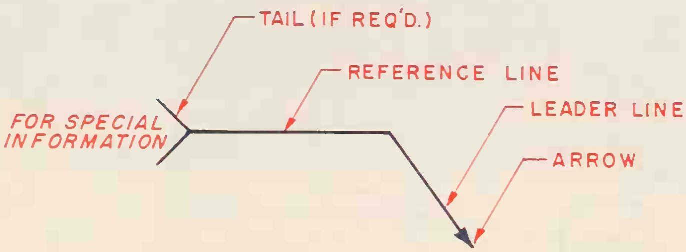


Figure 19-3 Basic welding symbol

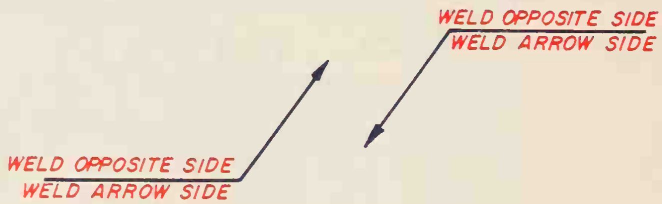


Figure 19-4 Any welding symbol placed on the upper side of the reference line indicates weld OPPOSITE side. Any welding symbol placed on the lower side of the reference line indicates weld ARROW side.

A fillet weld symbol (see Figure 19-2) is added above or below the reference line with the left leg always drawn vertical, Figure 19-5. A welding symbol placed *above* the reference line means to weld the OPPOSITE side, as illustrated in Figure 19-6. A weld symbol placed *below* the reference line means to weld ARROW side, as illustrated in Figure 19-6. The positions as drawn and as welded are shown in Figures 19-7 and 19-8. A weld symbol placed above and below the reference line means to weld both the OPPOSITE side and the ARROW side, as illustrated in Figure 19-9.

Figure 19-5 Left leg of welding symbol is always drawn vertical

Size of Weld

The weld must be fully dimensioned so that there is no question whatsoever as to its intended and designed size. The size of a weld refers to the length of the leg or side of the weld. The size is placed directly to the left of the welding symbol. The two

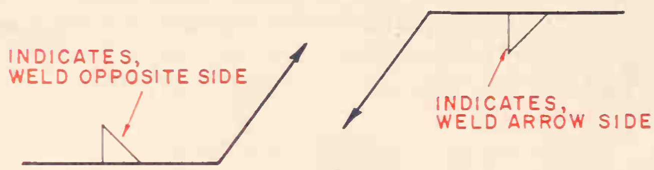


Figure 19-6 Welding symbol placed *above* the reference line means to weld OPPOSITE side. Welding symbol placed *below* the reference line means to weld ARROW side.

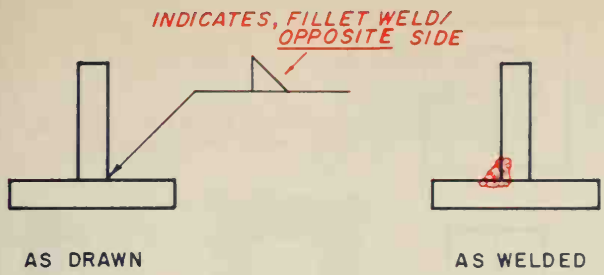


Figure 19-7 Position as drawn and as welded

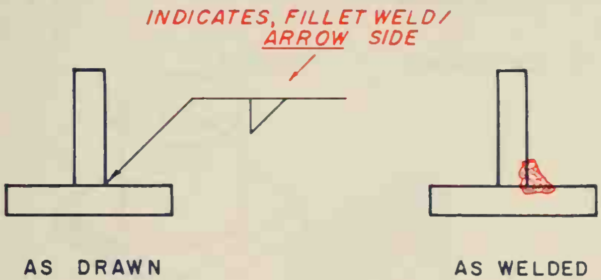


Figure 19-8 Position as drawn and as welded

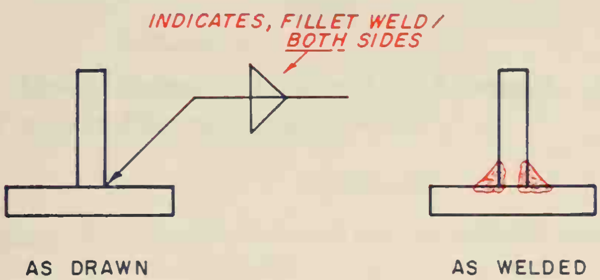


Figure 19-9 Welding symbol placed above and below the reference line means to weld both sides

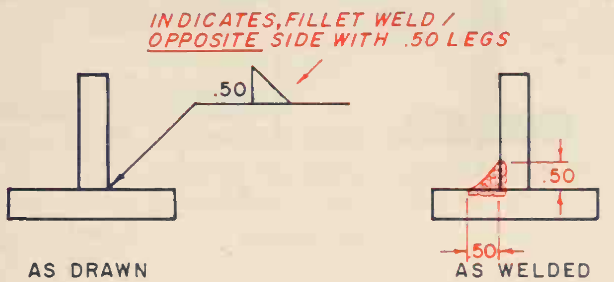


Figure 19-10 Dimension to the left of welding symbol indicates length of leg or side of weld

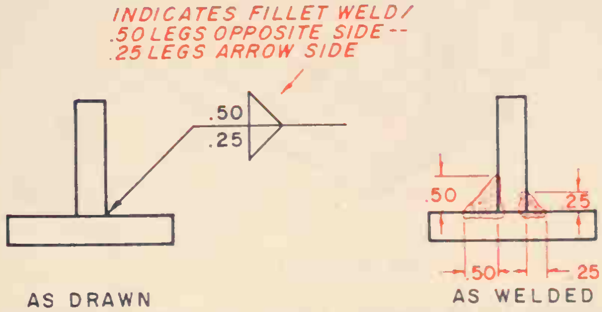


Figure 19-11 Size of each weld is required

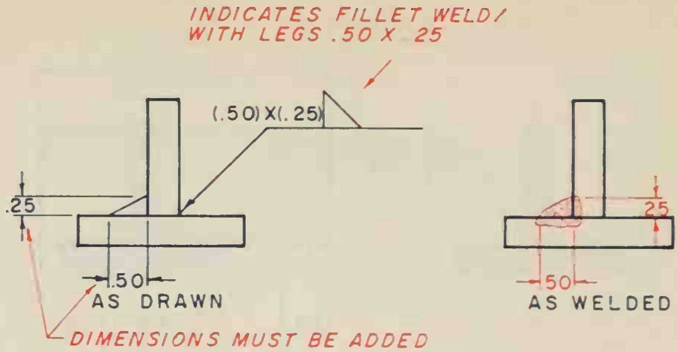


Figure 19-12 Welds with legs or side of different sizes

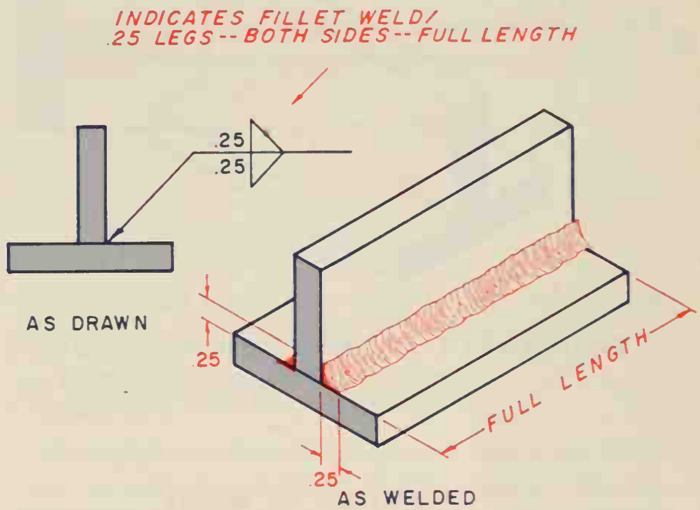


Figure 19-13 If weld length is not specified, it is assumed to be continuous full length

legs are assumed to be equal in size unless otherwise dimensioned, Figure 19-10. If a double weld is needed, the size of each weld must be included as illustrated in Figure 19-11.

If the legs or sides of the weld are to be different, the dimensions of the sides must be indicated to the left of the welding symbol in parentheses, as reference only dimensions, Figure 19-12. Because the symbol does not indicate which is the .50 leg and which is the .25 leg, the detail drawing must include the dimensions.

Length of Weld

When a weld length is not specified it is assumed to be continuous the full length, Figure 19-13. If a weld must be made to a special length, it must be indicated. This is done by a dimension directly to the right of the weld symbol, Figure 19-14.

When a weld is to be made continuously all around an object, it is indicated on the welding symbol by adding a small circle between the reference line and the leader line, Figure 19-15.

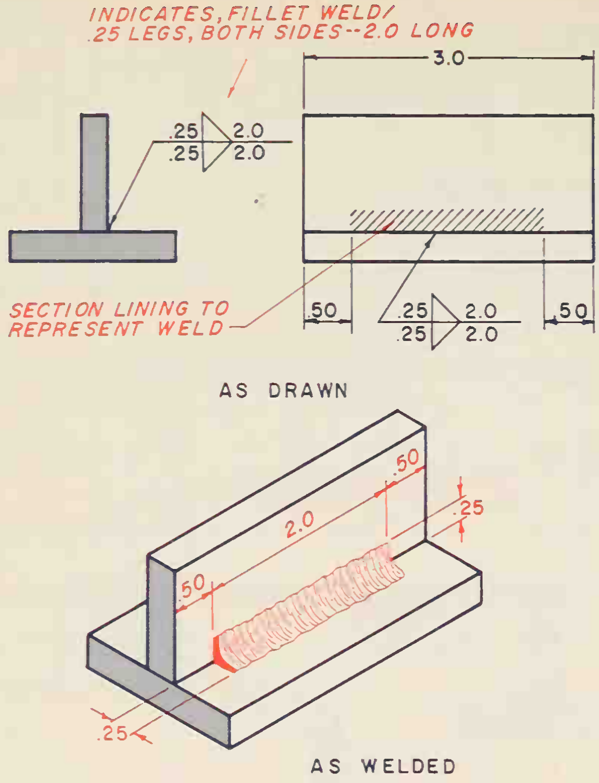


Figure 19-14 Length of weld must be noted to the right of the welding symbol

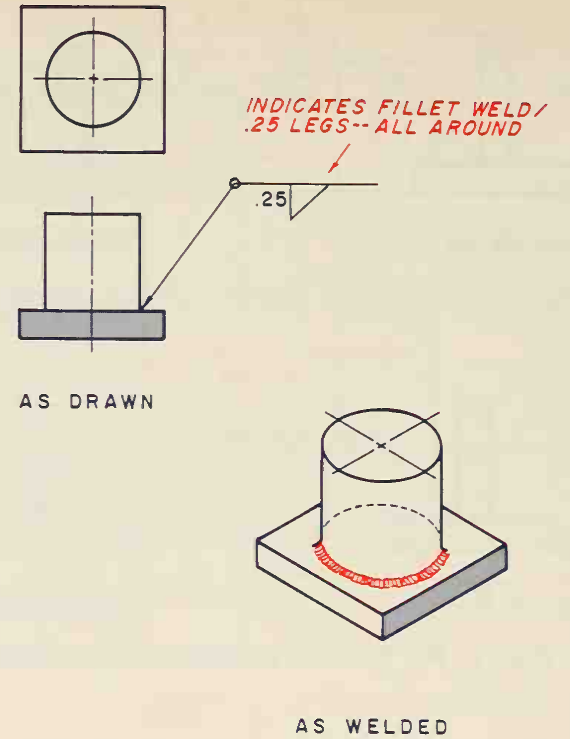


Figure 19-15 A small circle indicates weld continuously around an object

Placement of Weld

When a weld is not continuous and is needed in only a few areas, *section lining* is used to indicate where the weld is to be placed, Figure 19-16. If a weld is to be placed in a few areas, this is indicated by the use of multiple leader lines and arrows, Figure 19-17.

Intermittent Welds

Intermittent welds are a series of short welds. When this type of weld is needed, an extra dimension is added to the welding symbol, Figure 19-18. The usual size of leg is noted to the left of the symbol, and the length of the weld is indicated to the right of the welding symbol followed by a dash line and the pitch of the intermittent welds. See Figure 19-19. An *increment* is the length of the weld; the *pitch* is the center-to-center distance between increments.

Chain Intermittent Weld

A *chain intermittent weld* is a weld where each weld is applied directly opposite to each other on opposite sides of the joint, Figure 19-20. Note the welding symbol is applied above and below the reference line in line with each other.

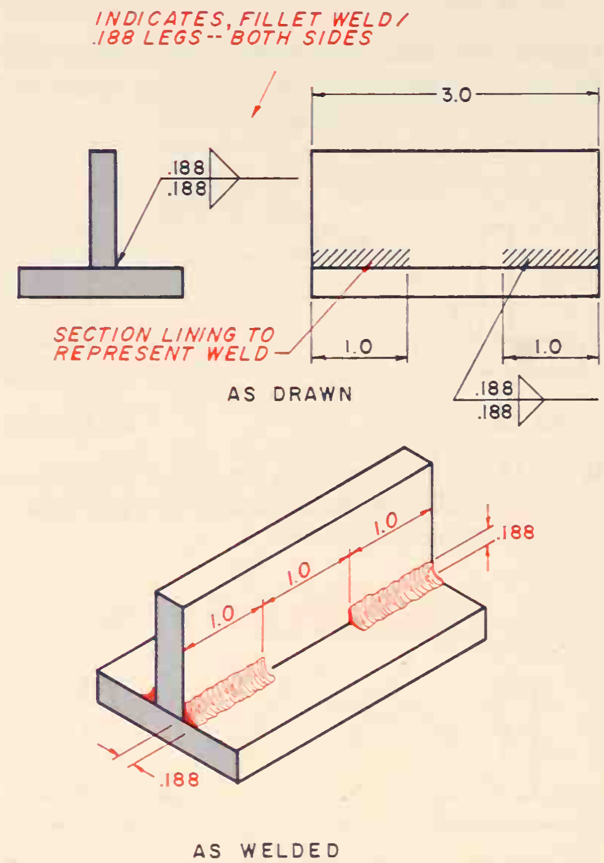


Figure 19-16 Section lining indicates location of weld

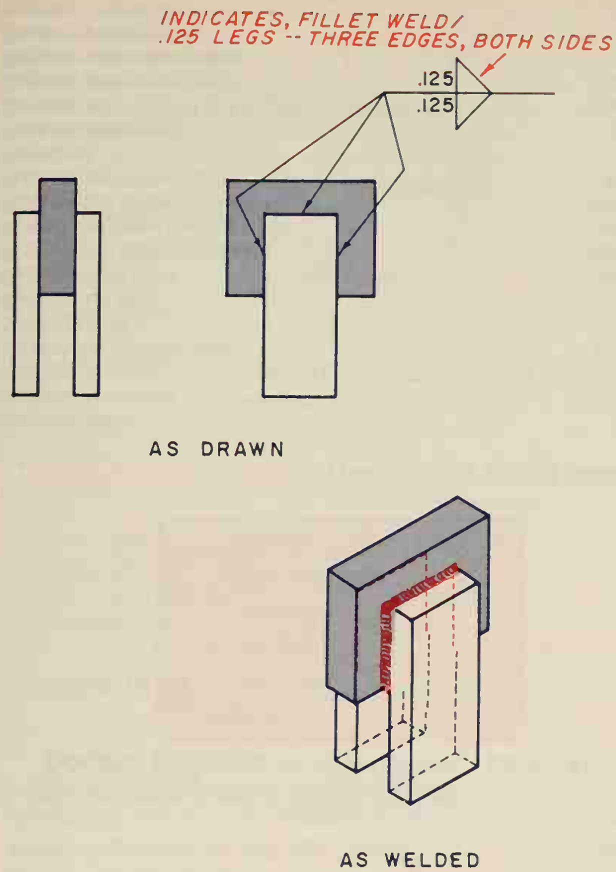


Figure 19-17 Leader line and arrows indicate location of weld

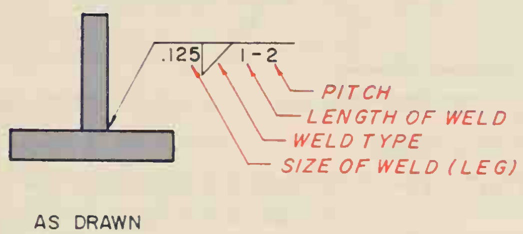


Figure 19-18 Intermittent welds are noted by dimensions to the right of the welding symbol

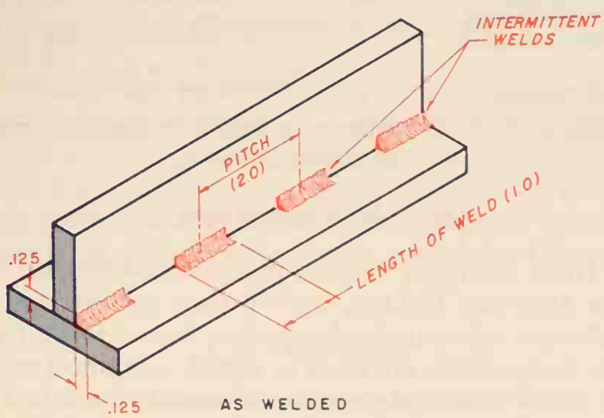


Figure 19-19 Pitch is the center-to-center distance between welds

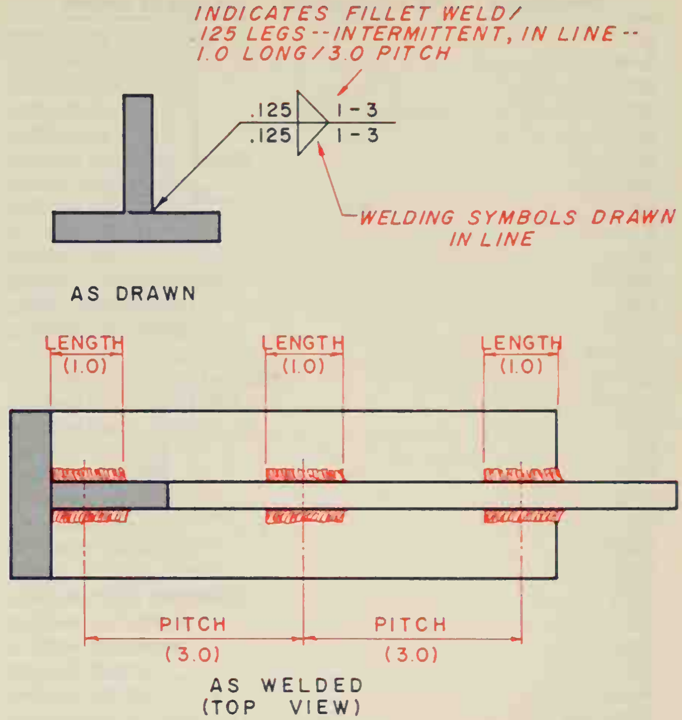


Figure 19-20 Chain intermittent welds are applied directly opposite to each other

Staggered Intermittent Weld

A *staggered intermittent weld* is similar to the chain intermittent weld except the welds are staggered directly opposite to each other on opposite sides. Figure 19-21. Note the welding symbol is applied above and below the reference line staggered to each other.

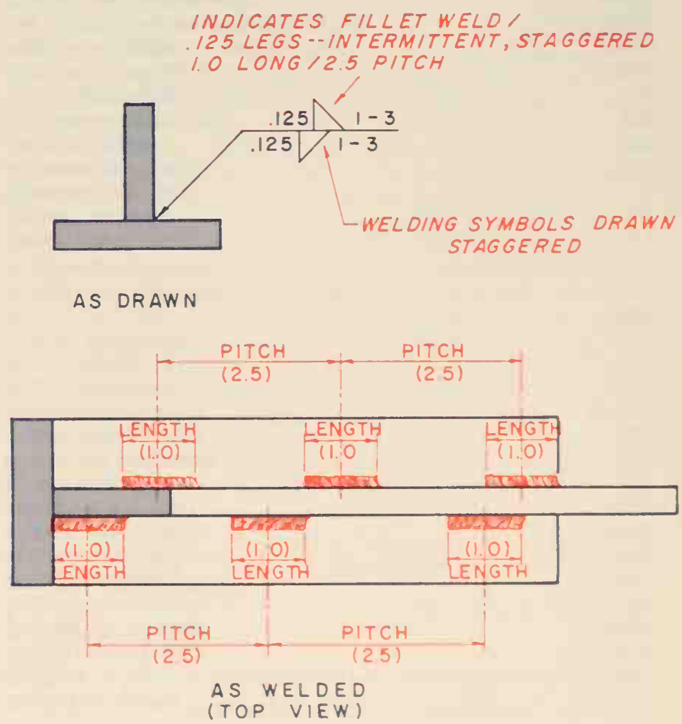


Figure 19-21 Staggered intermittent welds are placed staggered opposite each other

Designation of Welding and Allied Processes by Letters

AAC	air carbon arc cutting
AAW	air acetylene welding
ABD	adhesive bonding
AB	arc brazing
AC	arc cutting
AHW	atomic hydrogen welding
AOC	oxygen arc cutting
AW	arc welding
B	brazing
BB	block brazing
BMAW	bare metal arc welding
CAC	carbon arc cutting
CAW	carbon arc welding
CAW-G	gas carbon arc welding
CAW-S	shielded carbon arc welding
CAW-T	twin carbon arc welding
CW	cold welding
DB	dip brazing
DFB	diffusion brazing
DFW	diffusion welding
DS	dip soldering
EASP	electric arc spraying
EBC	electron beam cutting
EBW	electron beam welding
ESW	electroslag welding
EXW	explosion welding
FB	furnace brazing
FCAW	flux cored arc welding
FCAW-EG	flux cored arc welding—electrogas
FLB	flow brazing
FLOW	flow welding
FLSP	flame spraying
FOC	chemical flux cutting
FOW	forge welding
FRW	friction welding
FS	furnace soldering
FW	flash welding
GMAC	gas metal arc cutting
GMAW	gas metal arc welding
GMAW-EG	gas metal arc welding—electrogas
GMAW-P	gas metal arc welding—pulsed arc
GMAW-S	gas metal arc welding—short circuiting arc
GTAC	gas tungsten arc cutting
GTAW	gas tungsten arc welding
GTAW-P	gas tungsten arc welding—pulsed arc
HFRW	high frequency resistance welding
HPW	hot pressure welding
IB	induction brazing
INS	iron soldering
IRB	infrared brazing
IRS	infrared soldering
IS	induction soldering
IW	induction welding
LBC	laser beam cutting
LBW	laser beam welding
LOC	oxygen lance cutting
MAC	metal arc cutting
OAW	oxyacetylene welding
OC	oxygen cutting
OFC	oxyfuel gas cutting
OFC-A	oxyacetylene cutting
OFC-H	oxyhydrogen cutting
OFC-N	oxynatural gas cutting
OFC-P	oxypropane cutting
OFW	oxyfuel gas welding
OHW	oxyhydrogen welding
PAC	plasma arc cutting
PAW	plasma arc welding
PEW	percussion welding
PGW	pressure gas welding
POC	metal powder cutting
PSP	plasma spraying
RB	resistance brazing

Figure 19-22 Designation of welding and allied processes by letters (abbreviations)

RPW	projection welding
RS	resistance soldering
RSEW	resistance seam welding
RSW	resistance spot welding
ROW	roll welding
RW	resistance welding
S	soldering
SAW	submerged arc welding
SAW-S	series submerged arc welding
SMAC	shielded metal arc cutting
SMAW	shielded metal arc welding
SSW	solid state welding
SW	stud arc welding
TB	torch brazing
TCAB	twin carbon arc brazing
TW	thermit welding
USW	ultrasonic welding
UW	upset welding

Figure 19-22 (continued)

LETTER	METHOD
C	CHIPPING
G	GRINDING
H	HAMMERING
R	ROLLING
M	MACHINING

Figure 19-23 Abbreviation of standard method used to obtain a particular contour

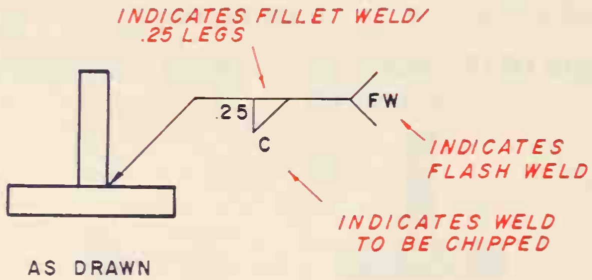


Figure 19-24 Process abbreviations are placed in the tail of the basic welding symbol

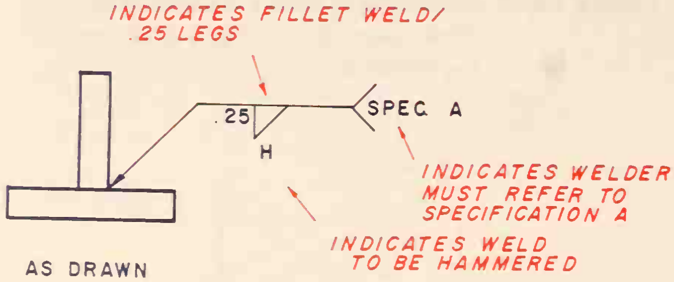


Figure 19-25 Sometimes, a note is indicated somewhere on the drawing.

Process Reference

There are many welding processes developed by the American Welding Society. Each process has a standard abbreviation designation, Figure 19-22. Letter designations are used to specify a method used to obtain a particular contour of a weld, Figure 19-23. These abbreviations are taken from the latest American Welding Society's standard #AWS-2.4-79,71.

Figure 19-26 Contour symbol

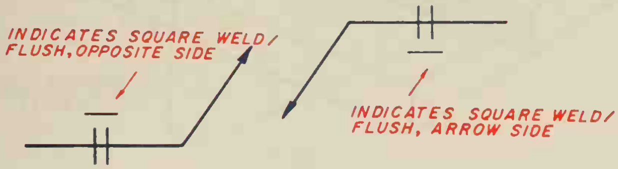


Figure 19-27 Contour symbol is added to the welding symbol

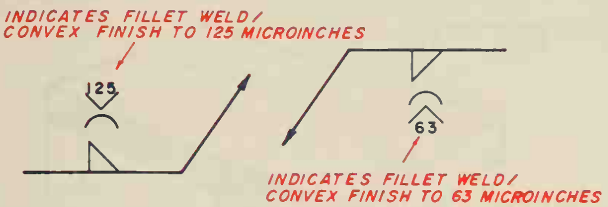


Figure 19-28 Finish number specifies finish required

The standard process abbreviations or letter designations are usually added to the tail of the basic welding symbol as required, Figure 19-24. Sometimes, they are called-off in a note somewhere on the drawing, Figure 19-25.

Contour Symbol

If a special finish must be made to a weld, a contour symbol must be added to the welding symbol. There are three kinds of contour symbols used: flush, convex, or concave, Figure 19-26. The contour symbol is added directly above or below the welding symbol. If the welding symbol is *above* the reference line, the contour symbol is placed *above* the welding symbol. If the welding symbol is placed *below* the reference line, the contour symbol is placed *below* the welding symbol, Figure 19-27. The degree of finish is not usually included, but, if a specific finish is desired, a finish number designation must be added, Figure 19-28.

Figure 19-29 represents that the finish weld must be concave and ground to a 125-microinch surface finish. Figure 19-30 represents that the finish weld must be machined flat on the top surface to a surface finish of 125 microinches. The weld must be convex on the bottom surface with a hammered finish.

Field Welds

Any weld not made in the factory, that is, it is to be made at a later date, perhaps at final assembly on site, is called a *field weld*. Its symbol is added to the

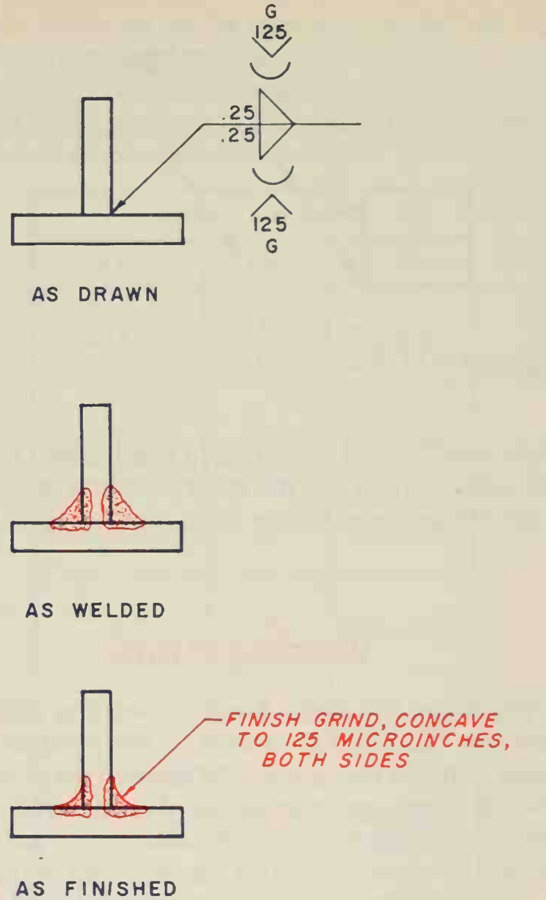


Figure 19-29 Finish weld is to be concave and ground to a 125 micro-inch surface finish

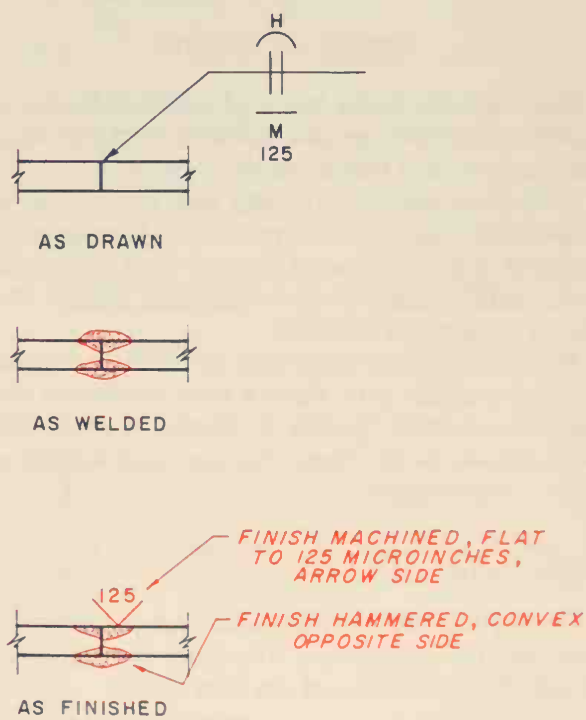


Figure 19-30 Finish weld is to be machined flat on top surface to 125-microinch surface and convex on the bottom surface with a hammered finish

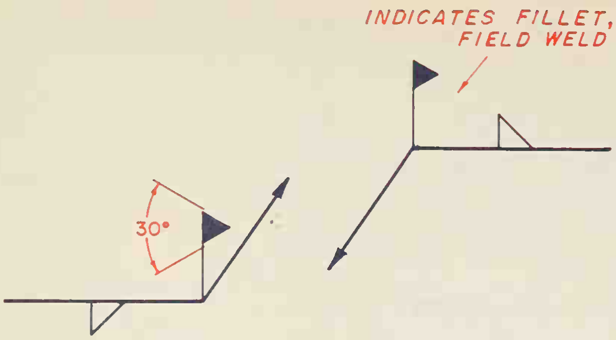


Figure 19-31 Field weld

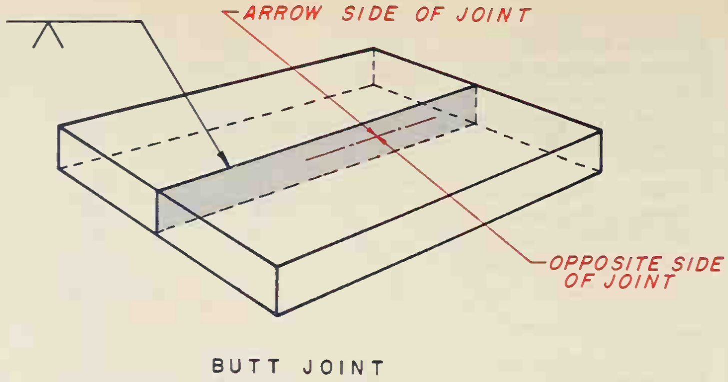


Figure 19-32A Butt joint

basic weld symbol by a filled-in flag, located between the reference line and the leader line and drawn using a 30°-60° triangle, Figure 19-31.

Welding Joints

There are five basic kinds of welding joints and they are classified according to the position of the parts that are being joined, Figures 19-32A through 19-32E. There are many types of welds used to weld these joints together. Considerations as to which type of weld to use are based on the particular application, thickness of material, required strength of the joint, and available welding equipment, among others.

Types of Welds

There are six major types of welds (refer back to Figure 19-2): fillet, groove, back or backing, plug or slot, surface, and flange welds.

More than one type of weld may be applied to a single joint – usually for strength or appearance. For example, a groove V weld may be used on one side, and a backing weld on the other side, Figure 19-33. This is known as a *multiweld*.

The same type of weld may be used on opposite sides of a single joint. Such a joint is called a *double weld*; for example, double V, double U or double J weld, Figure 19-34. These too, are used for strength and/or appearance.

Fillet Welds

Up to this point, the fillet weld and its symbol have been used as an example. The other five major types of welding symbols used are very similar.

Groove Weld

Seven types of welds are considered to be *groove welds*: square, V, bevel groove, J, U, flare V, and flare

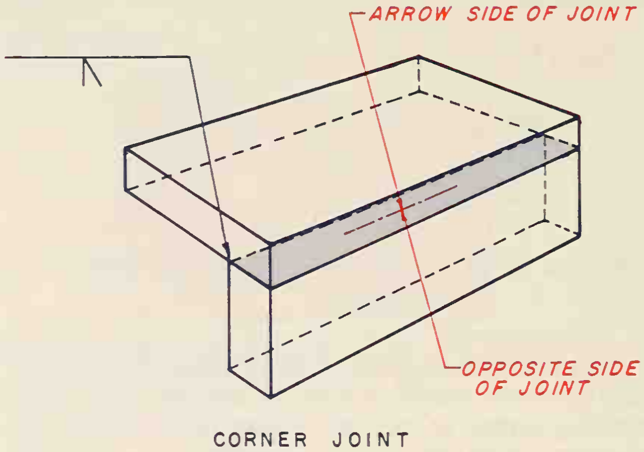


Figure 19-32B Corner joint

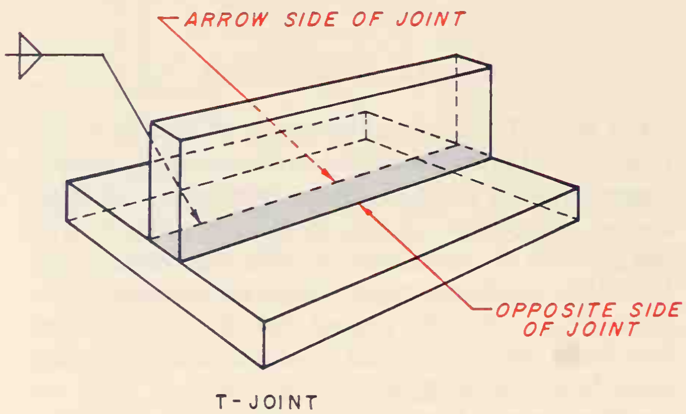


Figure 19-32C T-joint

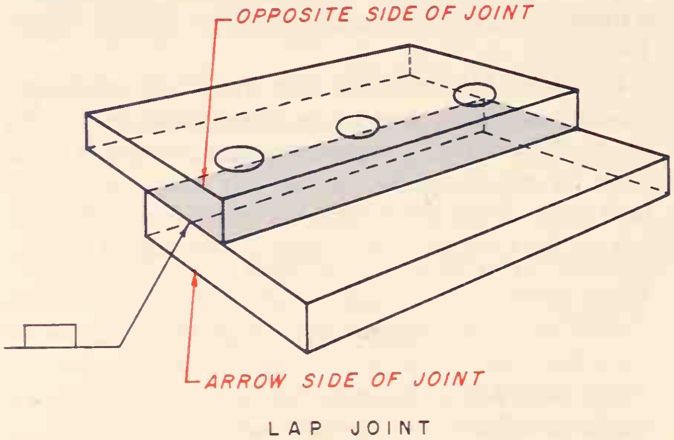


Figure 19-32D Lap joint

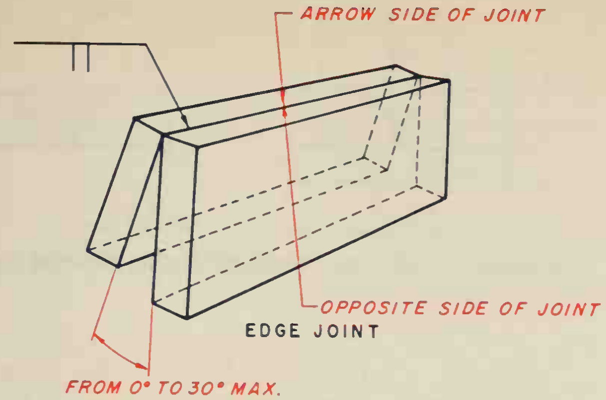


Figure 19-32E Edge joint

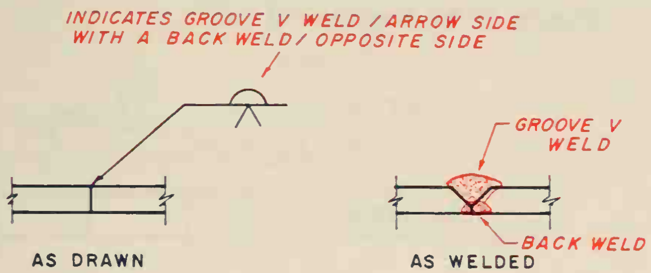


Figure 19-33 Multiwelds (different type of welds)

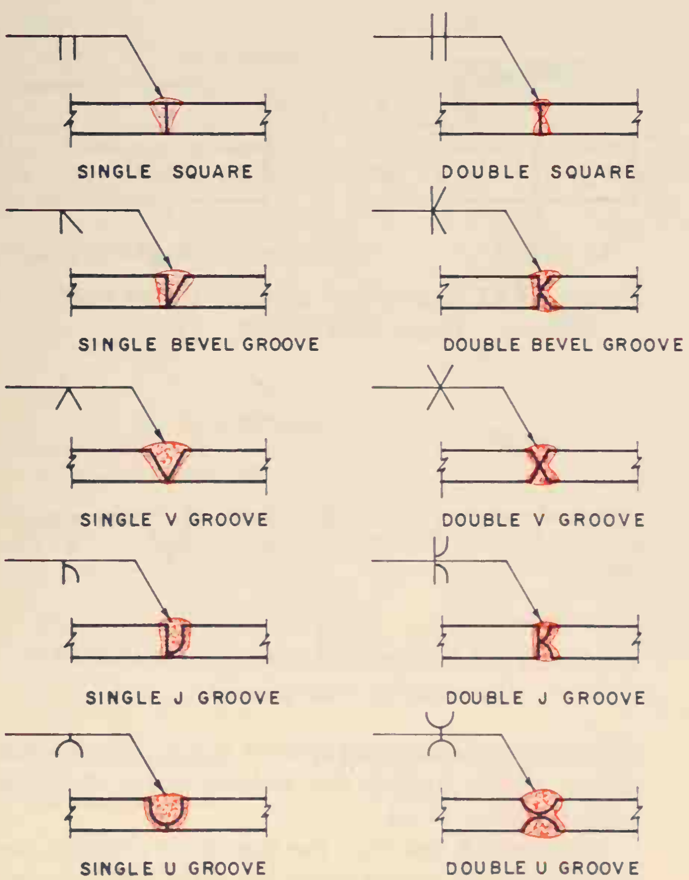


Figure 19-34 Double welds (same type of welds)

bevel. Each type has its own welding symbol, Figure 19-35. In the bevel groove and J welds, only one part is actually chamfered or grooved. To do this, the leader line and arrow point toward the part that has the bevel groove or J groove, Figure 19-36. Note that

GROOVE WELDS		
TYPE	SYMBOL	AS SEEN
SQUARE		
V		
BEVEL GROOVE		
U		
J		
FLARE V		
FLARE BEVEL		

Figure 19-35 Groove welds

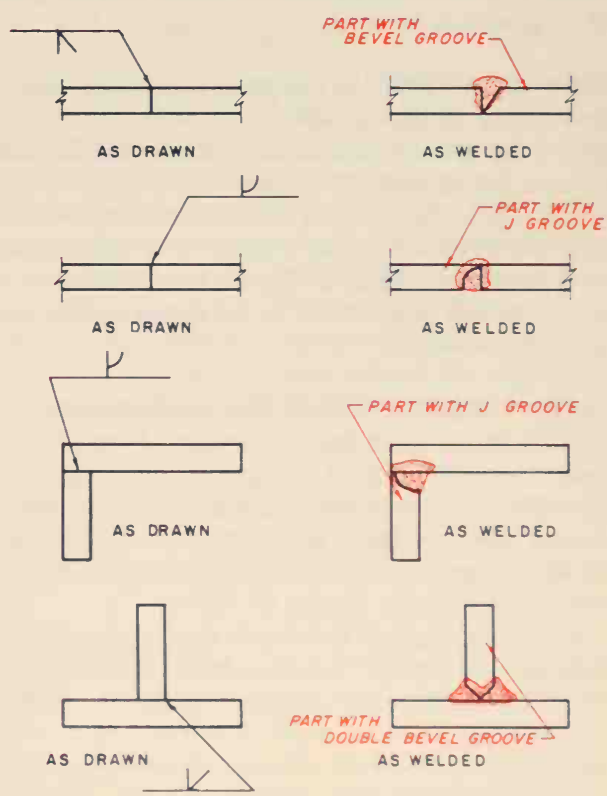


Figure 19-36 Groove weld illustrations

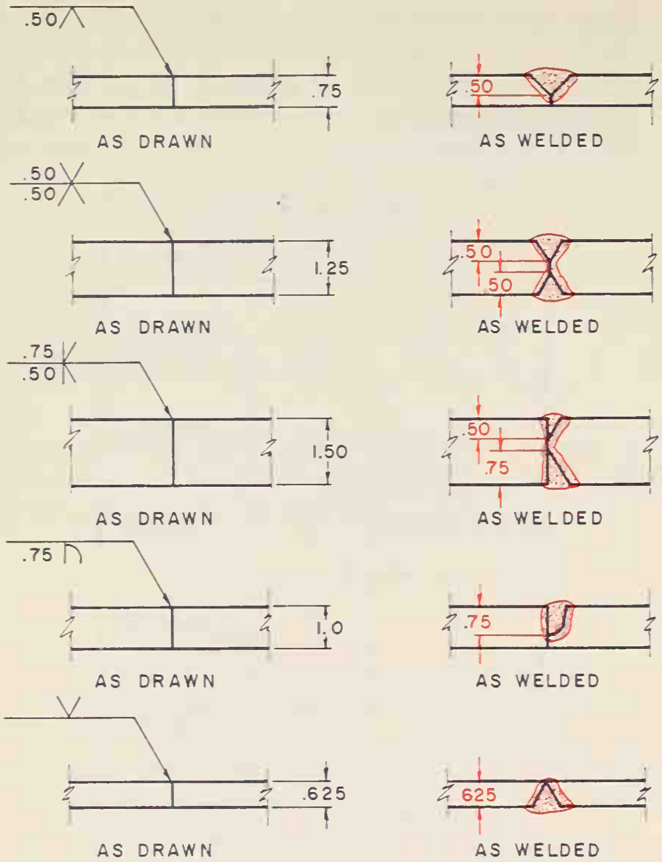


Figure 19-37 Groove welds with dimensions

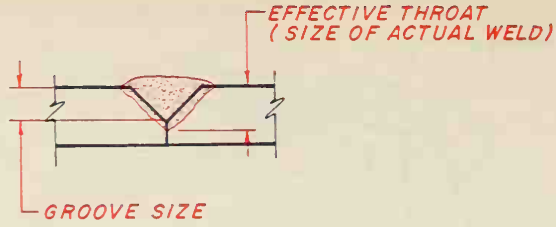


Figure 19-38 Depth or actual size of weld

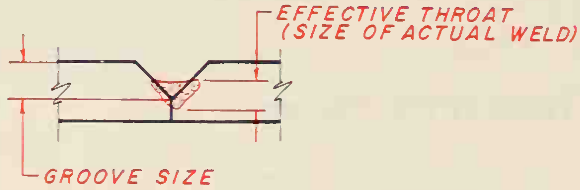


Figure 19-39 Size of weld only

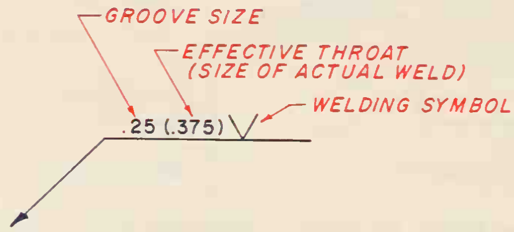


Figure 19-40 Size of weld is added to the left of the welding symbol in parentheses

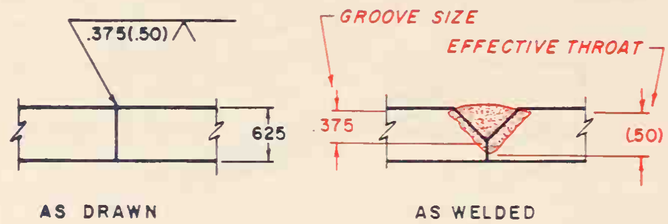


Figure 19-41 Example of effective throat-weld larger than groove

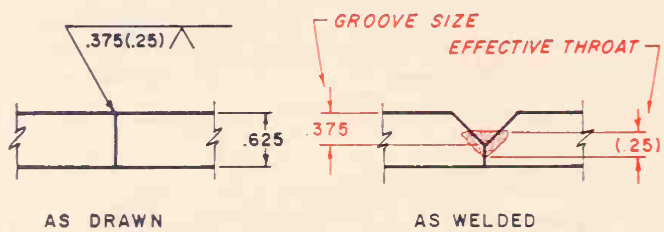


Figure 19-42 Example of effective throat-weld smaller than groove

the welding symbol is placed above or below the reference line, as usual, to indicate which side the chamfer or groove is located.

Size of Groove Weld. In the groove weld, the dimension refers to the actual depth of the chamfer or groove *not* the size of the weld. With the fillet weld, the size of the chamfer or groove is located directly to the left of the welding symbol and on the same side of the reference line, Figure 19-37. If a V groove weld symbol is shown without a size dimension, the size or depth is assumed to be equal to the thickness of the pieces.

Depth or Actual Size of Weld. The depth or actual size of the weld includes the penetration of the complete weld. This is illustrated in Figure 19-38. Note in this example that the depth or actual size of the weld is deeper than the depth of the chamfer. Occasionally, the depth or actual size of the weld is less than the size of the chamfer, Figure 19-39.

In order to call-off the depth or actual size of the weld *and* the size of the chamfer or groove, a dual dimension is used and both are added to the *left* of the welding symbol. In order to differentiate between the two, the size of the chamfer or groove is added to the extreme left of the welding symbol. The size of the depth or actual size of the weld is added directly to the left of the welding symbol, but in parentheses, Figure 19-40. Usually the weld is larger than the groove, Figure 19-41.

If the weld is less than the size of the chamfer, the dimensions are added to the left of the welding symbol in the exact same manner, Figure 19-42.

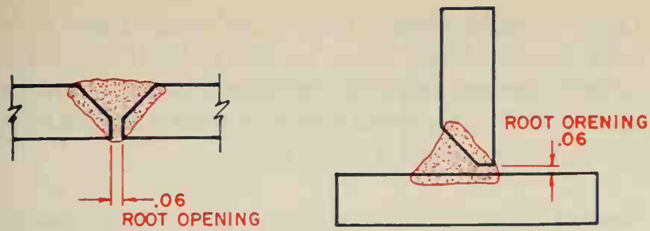


Figure 19-43 Root opening

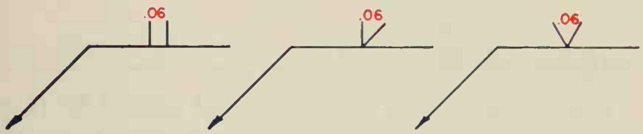


Figure 19-44 Size of root opening

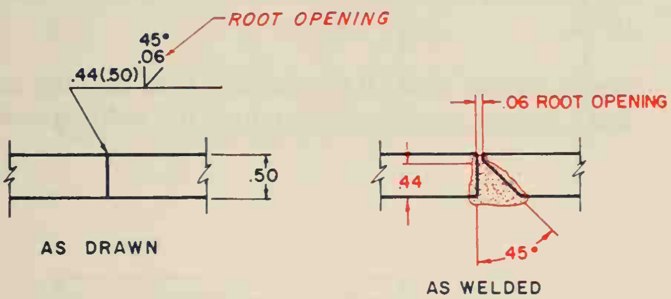


Figure 19-45 Chamfered angle

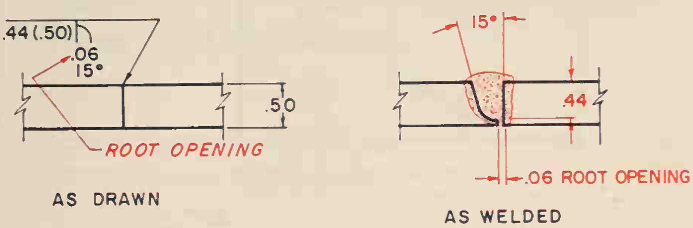


Figure 19-46 Required radius

Figure 19-47 Back weld symbol/melt-thru weld symbol

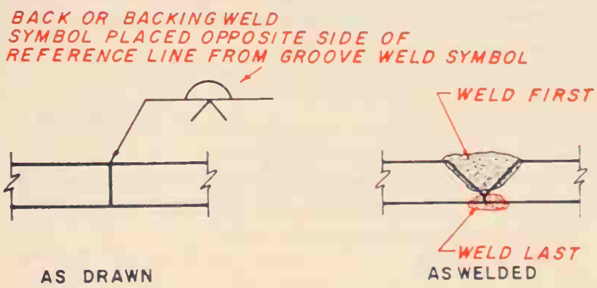


Figure 19-48 Illustration of back weld symbol

Root Opening. The allowed space between parts is called the *root opening*, Figure 19-43. The root opening is applied *inside* the welding symbol, Figure 19-44.

The root opening may be called-off as a general note. For example, "unless otherwise noted, root opening for all groove welds is .06." If there is *no* opening between parts, a zero is added inside the welding symbol.

Chamfer Angle. In a groove weld, a V or bevel groove must be held to tight tolerances. The angle must also be included with the size dimension in order to obtain the exact required geometric size and shape of all manufactured parts. The angle is also added inside the welding symbol, Figure 19-45. Note that the leader line and arrow point toward the part with the chamfer. Because the welding symbol is placed *above* the reference line, the chamfer and weld are on the side opposite from the arrow.

Groove Radius. If a J or U groove weld must be held to tight tolerances, the angle and radius must be included with the size dimensions in order to obtain the exact required geometric size and shape of all manufactured parts. The angle is also added inside the welding symbol and the required radius is called off as a note, Figure 19-46. Note that the leader line and arrow point toward the part with the groove. Because the welding symbol is placed *below* the reference line, the groove and weld is on the side of the arrow.

Back Weld – Backing Weld

A *back weld* is a weld applied to the opposite side of the joint *after* the major weld has been applied. A backing weld is a weld applied *first*, followed by the major weld. Both use the same welding symbol and both are used to strengthen a weld (refer back to Figure 19-2). The back weld is also used for appearance.

If a welding melt-through is required, the same symbol is used, except it is filled in solid, Figure 19-47. When the back weld or backing weld symbol is used, it is placed on the opposite side of the reference line from the groove weld symbol, Figures 19-48 and 19-49.

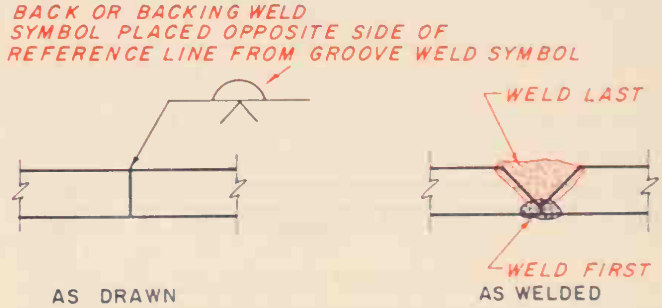


Figure 19-49 Illustration of back weld symbol

Plug and Slot Welds

The *plug* and *slot welds* both use the same welding symbol. The only difference between the two welds is the shape of the hole through which the weld is applied. A *plug weld* is made through a round hole. A *slot weld* is made through an elongated hole (refer back to Figure 19-2).

The plug or slot welding symbol is applied to the basic welding symbol and interpreted in exactly the same way. If the welding symbol is applied *above* the reference line, the hole or slot is on the *opposite* side of the arrow. If *below* the reference line, the hole or slot is on the *same side* as the arrow, Figure 19-50.

Size of Plug or Slot Weld. The given dimension for a plug or slot weld refers to the diameter of the plug or slot at the *base* of the weld. The required dimension is placed directly to the left of the plug or slot weld symbol, Figure 19-51. The size of the slot weld is drawn and dimensioned directly on the detail drawing.

Depth of Weld. Unless noted, the plug or slot weld hole is completely filled by the weld. If filling the hole is not necessary, the full depth of weld must be called off. The required depth of weld is added *inside* the welding symbol, Figure 19-52.

Tapered Plug or Slot. If the plug or slot hole is tapered, the taper inclusive angle is added directly above or below the welding symbol, Figure 19-53.

Surface Weld

If a surface must have material added to it or built-up, a *surface weld* is added (refer back to Figure 19-2). This welding symbol is *not* used to indicate the joining of parts together; therefore, the welding symbol is simply added below the reference line, Figure 19-54.

Size of Surface Weld. If the surface is to be built-up and a special height is *not* required, the welding sym-

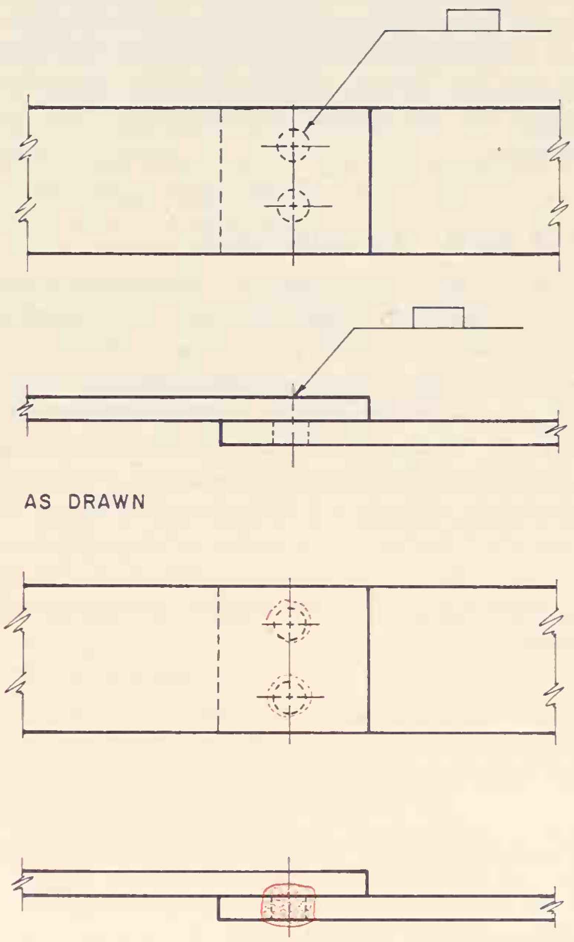


Figure 19-50 Plug and slot welds

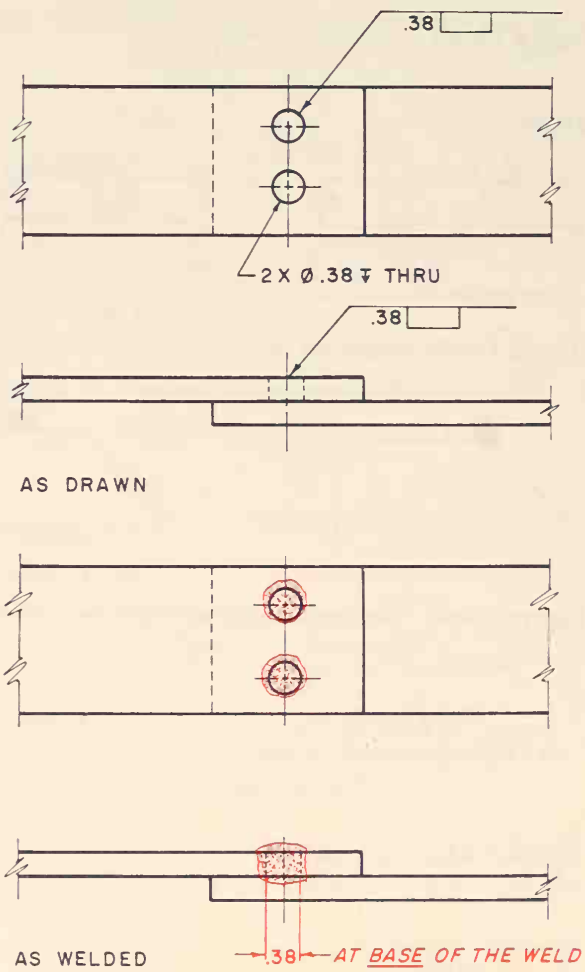


Figure 19-51 Size of plug or slot weld

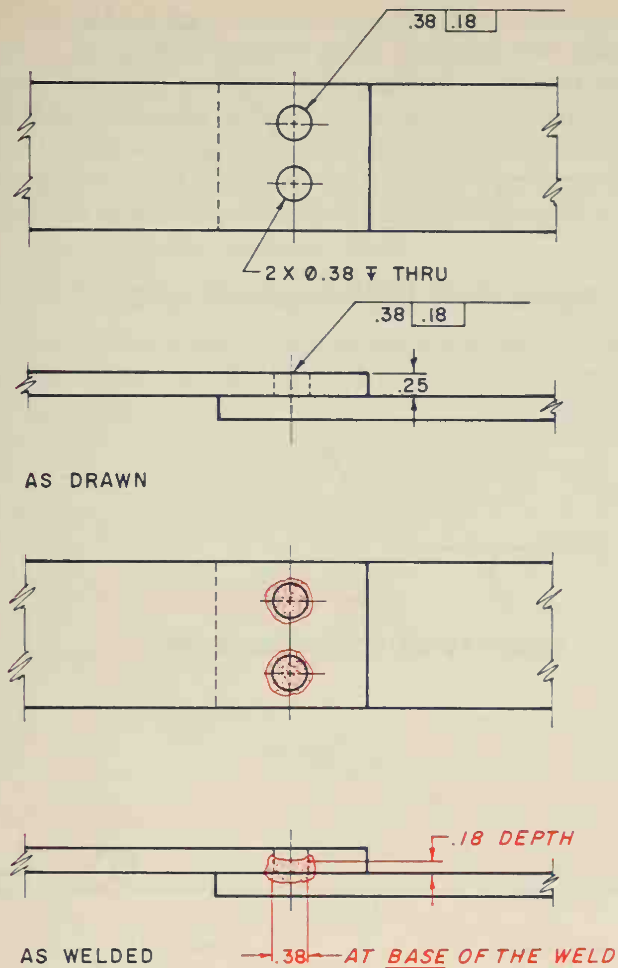


Figure 19-52 Depth of weld

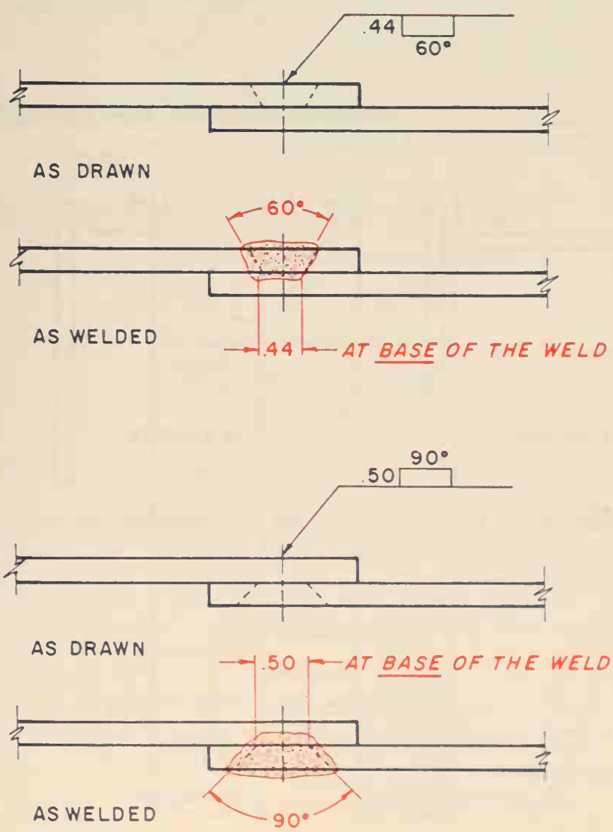


Figure 19-53 Tapered plug or slot

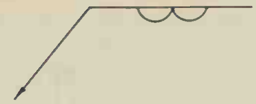


Figure 19-54 Surface weld

Figure 19-55 Size of surface weld

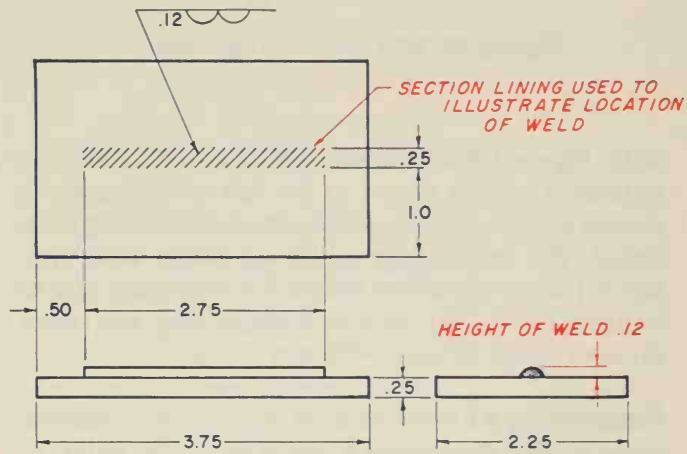


Figure 19-56 Illustration of a surface weld

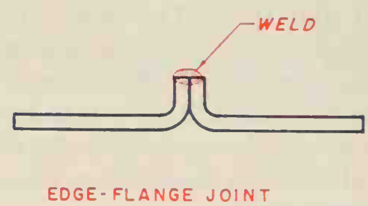


Figure 19-57 Edge-flange weld

bol is drawn as illustrated in Figure 19-54. If the surface is to be built-up and a *specific* height is required, the required height is added directly to the left of the welding symbol, Figure 19-55. If only a *portion* of the surface is to be built-up, that portion must be illustrated and dimensioned on the detail drawing, Figure 19-56. The actual weld is represented by section lining.

Flange Weld

A *flange weld* is used to join thin metal parts together. Instead of welding to the surfaces of the parts to be joined, the weld is applied to the edges of thin material. A weld applied to thin metal could burn right through.

There are two distinct flange weld symbols (refer back to Figure 19-2): the first is called an edge-flange weld, Figure 19-57; the other is called a corner-flange

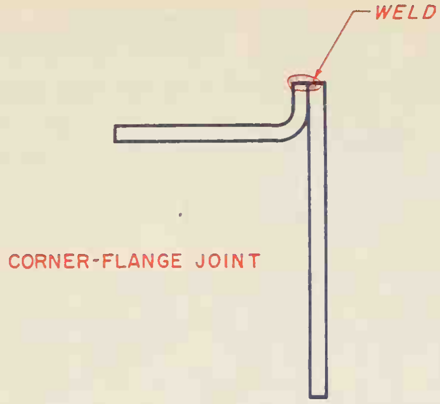


Figure 19-58 Corner-flange weld

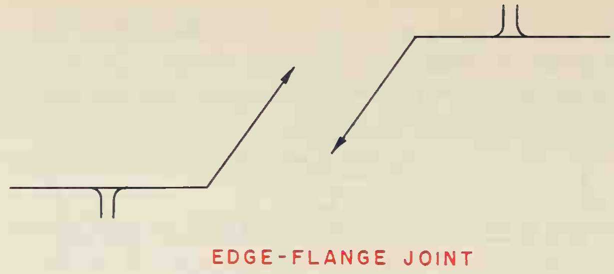


Figure 19-59 Edge-flange weld symbol

weld, Figure 19-58. The straight line of this welding symbol is always drawn to the left of the partially curved line, regardless of the actual joint being illustrated. The edge-flange or corner-flange weld symbol is placed above or below the reference line to indicate OPPOSITE side or ARROW side, but never on both sides, Figure 19-59 and 19-60.

Dimensioning a Flange Weld. It requires three dimensions to fully dimension a flange weld: the radius of the flange, the height above the point of tangency between parts, and the size of the weld itself, Figures 19-61 and 19-62. The three dimensions are added to the welding symbol as indicated previously. The welding symbol should appear at the peak of the joint as illustrated. If there is to be a root opening, that is, a space between parts, the required space must be indicated on the drawing, *not* on the welding symbol, Figure 19-63.

Multiple Reference Line

If there is more than one operation on a particular joint, these operations are indicated on *multiple reference lines*. The first reference line closest to the arrow is for the first operation, the second reference line is for the second operation or supplemental data, and the third reference line is for the third operation or test information, Figure 19-64.

Spot Weld

Spot welding is a resistance welding process done by passing an electric current through the exact location where the parts are to be joined. Spot welding is usually done to hold thin sheet metal parts together. The resistance weld process uses three standard types of welds, Figure 19-65. Each is explained in full.

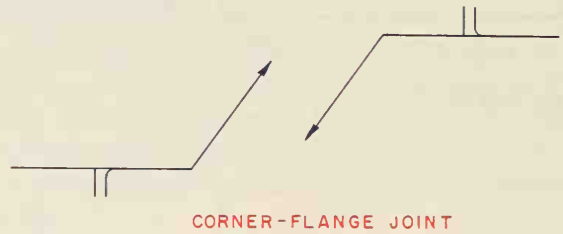


Figure 19-60 Corner-flange weld

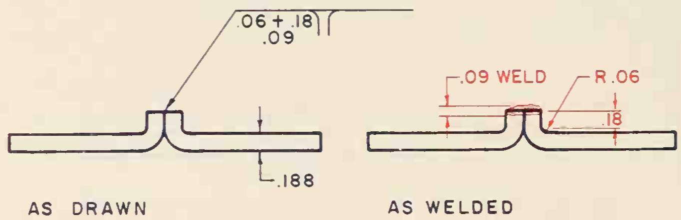


Figure 19-61 Dimensioning a flange weld

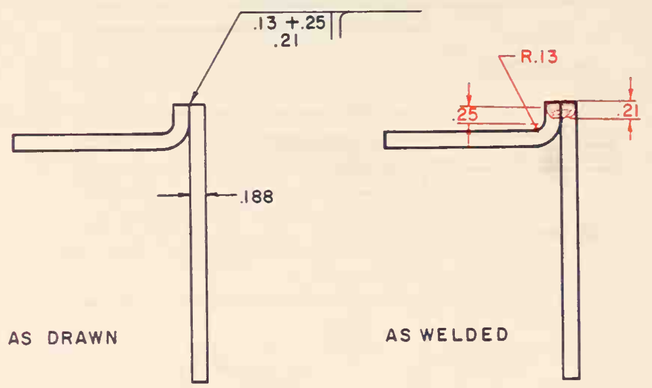


Figure 19-62 Dimensioning a corner-flange weld

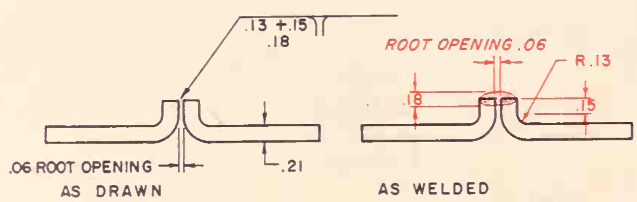


Figure 19-63 Root opening

The symbol for a spot weld, as illustrated in Figure 19-66, is located tangent to or touching the reference line, and uses the same added supplemental data symbols and dimensions as are illustrated with the fusion welding process, Figure 19-67. The tail is *always* included, in order to indicate the process required to make the weld (refer back to Figure 19-22).

Dimensioning the Spot Weld

The diameter size of the spot weld is added directly to the left of the weld symbol, Figure 19-68. Sometimes the diameter size is omitted, and a required shear strength is inserted in its place. In this condition, an explanation of the value is added to the drawing by a note, Figure 19-69.

The spacing of the spot weld is called-off by a number directly to the right of the weld symbol. This number is the pitch, and refers to the center-to-center distance between spots, Figure 19-70. The number of welds for a particular joint is added above or below the welding symbol in parentheses.

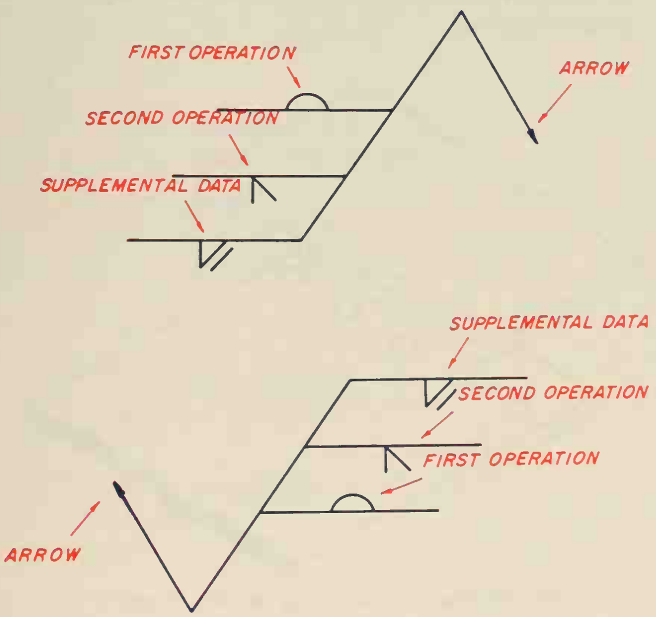


Figure 19-64 Multiple reference line

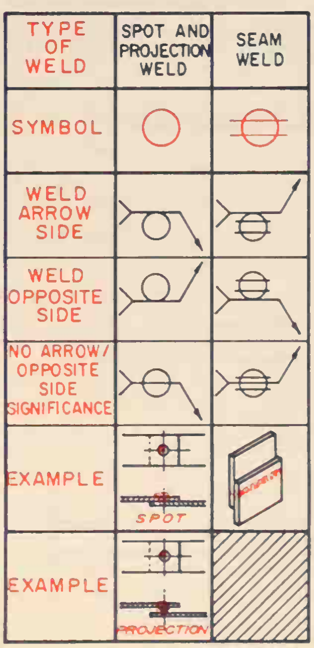


Figure 19-65 Spot welds

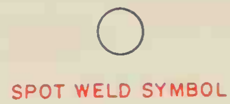


Figure 19-66
Spot weld symbol

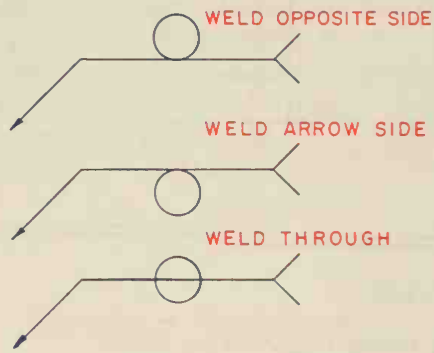


Figure 19-67 Spot weld symbol used with reference line

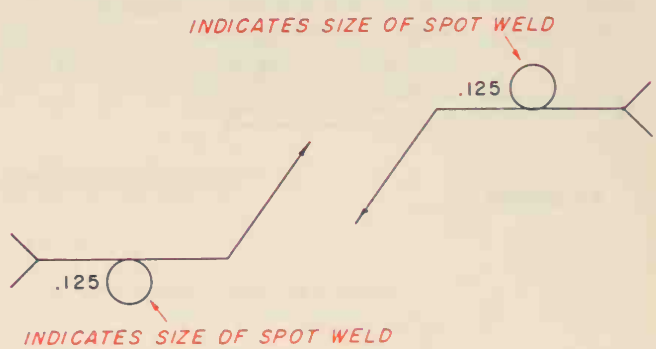


Figure 19-68 Diameter of spot weld

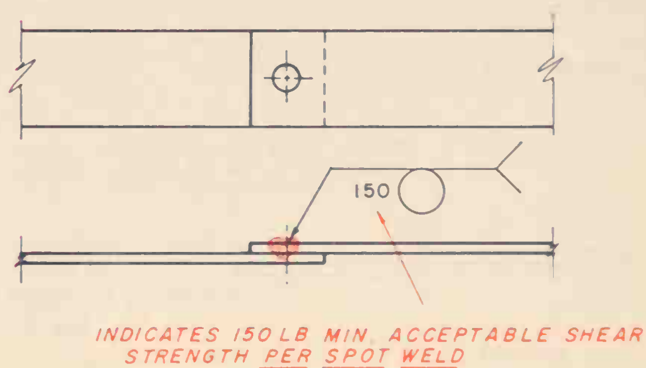


Figure 19-69 Shear strength of spot weld

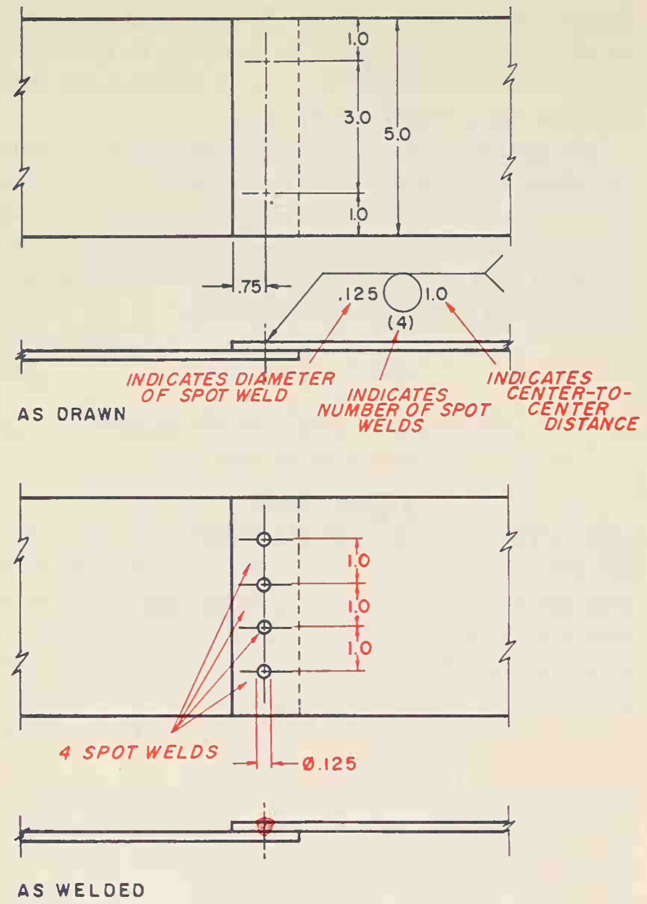


Figure 19-70 Pitch of spot welds

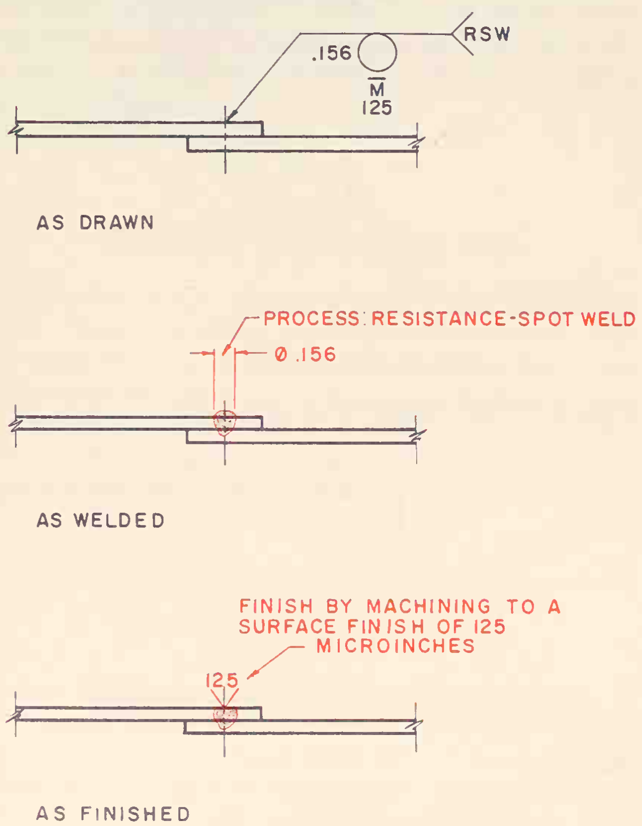


Figure 19-71 Contour and finish symbols

Contour and Finish Symbols

Contour and finish symbols are added to the welding symbol exactly as is done in the fusion welding symbol, Figure 19-71.

Projection Weld

A *projection weld* is similar to a spot weld and uses the exact same welding symbol. One of the two parts has a series of evenly spaced dimples stamped into it. Each stamped dimple is the location of an individual spot weld, Figure 19-72. A projection weld allows more penetration and, as a result, a much better weld. Note, the dimples are *not* illustrated on the detail drawing.

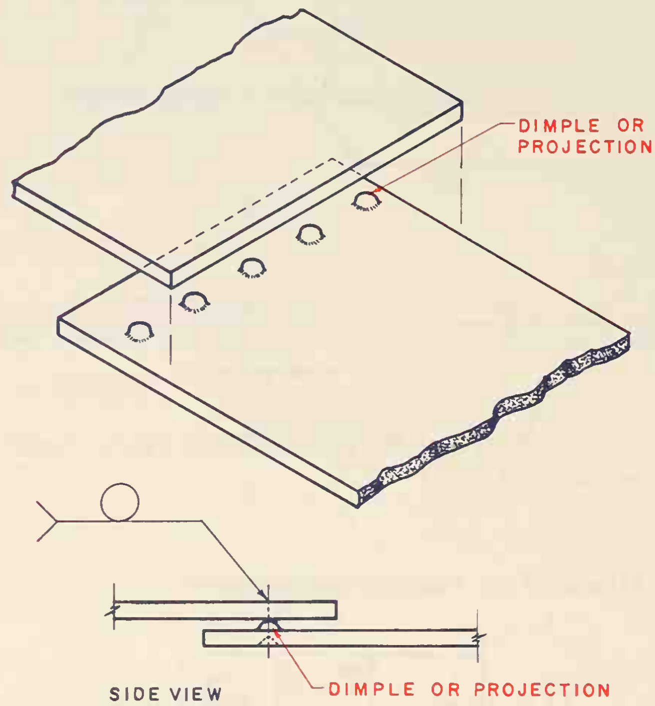


Figure 19-72 Projection weld

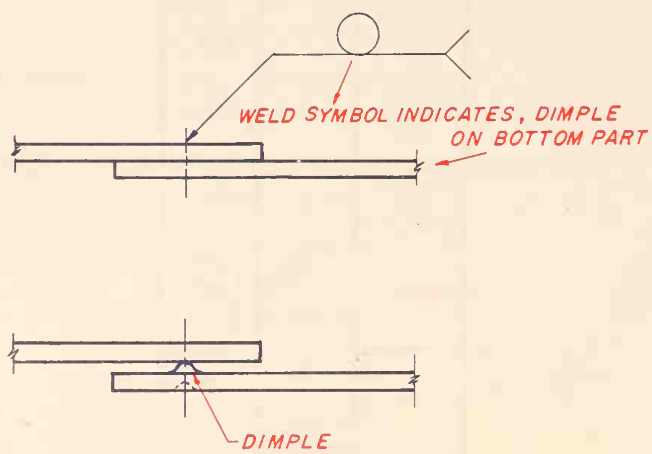


Figure 19-73 Projection weld symbol

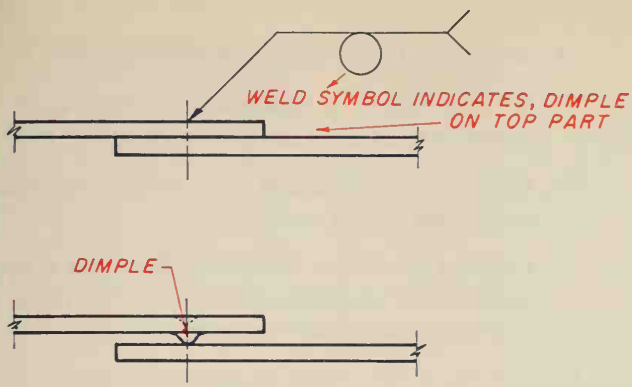


Figure 19-74 Projection weld symbol

Figure 19-75
Seam weld symbol

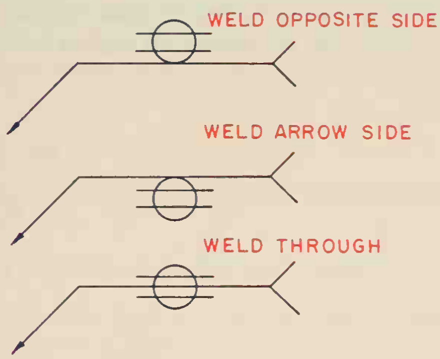


Figure 19-76 Seam weld symbol used with reference line

The reference line (OPPOSITE side-ARROW side significance) is changed slightly as used for a projection weld. The OPPOSITE side-ARROW side indicates which of the two parts to be joined has the dimples on it, Figures 19-73 and 19-74.

Dimensioning, Contour, and Finish Symbols

Dimensioning, contour, and finish symbols are applied to projection welds exactly as they are for spot welds.

Seam Weld

A *seam weld* is like a spot weld, except that the weld is actually continuous from start to finish.

The welding symbol is modified slightly to indicate a seam weld, Figure 19-75. Figure 19-76 indicates how the seam weld symbol is applied to the reference line.

Welding Template

In order to simplify and speed up the drawing time for welding symbols, welding templates can be used. The welding template standardizes the size of each welding symbol and provides a quick, ready reference for welding symbols, Figure 19-77.

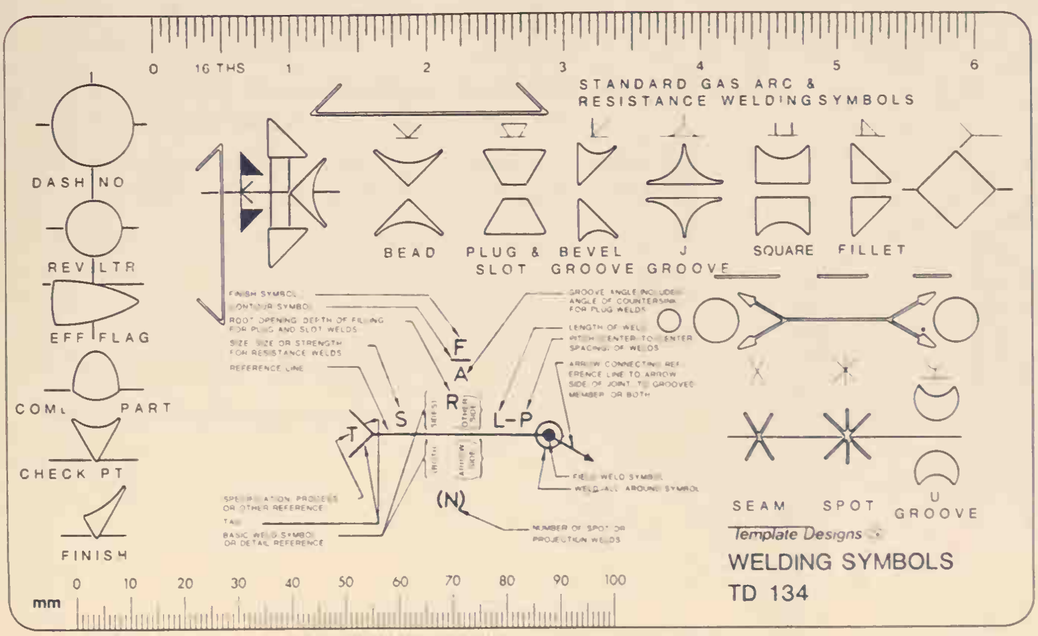


Figure 19-77 Welding template

Review

1. What is the difference between a plug weld and a slot weld?
2. Make a sketch of a welding symbol for a fillet weld with legs of .250 and a weld 4.5 long and weld on OPPOSITE side of arrowhead.
3. List six major types of welds.
4. Explain what the *root opening* is.
5. Describe an intermittent weld.
6. What are the two major welding processes and generally, where is each used?
7. List the five basic kinds of welding joints. How are they classified?
8. Describe the basic welding symbol and explain the significance of welding symbols being placed above and below the reference line.
9. Where and why is a flange weld used?
10. What is meant by a process reference and where is it located on the welding symbol?
11. What is the advantage of using a projection weld over a spot weld?
12. Explain in full the difference between a back weld and a backing weld. How is the melt-through designated to these symbols?
13. List the seven types of groove welds.
14. How is a field weld indicated on the welding symbol?
15. How is a weld that is to be continuously around an object indicated on the welding symbol?

Chapter Nineteen Problems

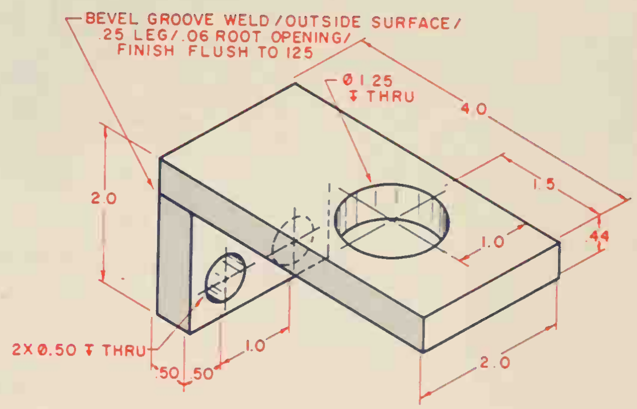
The following problems are intended to give the beginning drafter practice in studying the many factors involved in dimensioning and calling-off welding processes. The student will sharpen skills in centering the views within the work area, line weight, dimensioning, and speed.

The steps to follow in laying out the following problems are:

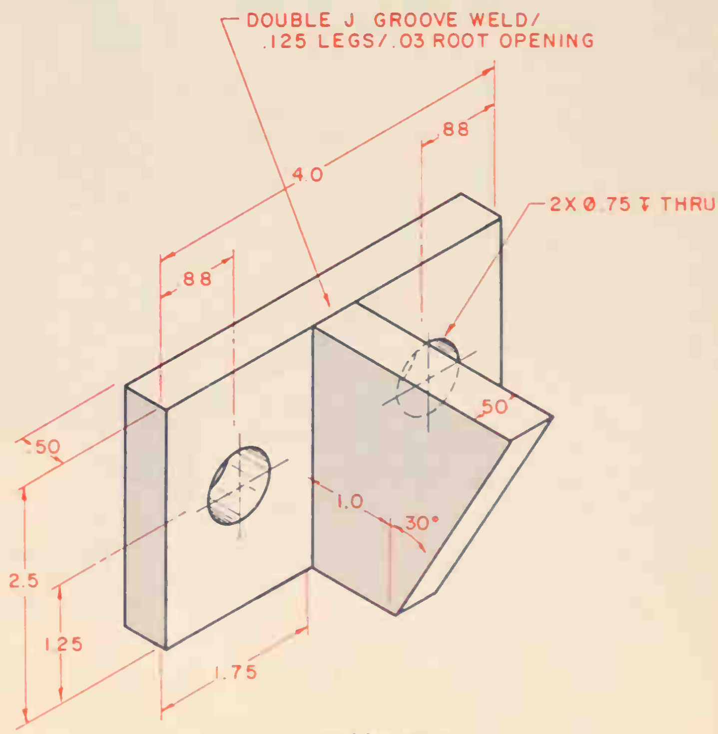
1. Study the problem carefully.
2. Choose the view with the most detail as the front view.
3. Make a sketch of the required views.
4. Add required dimensions to the above sketch per latest drafting standards.
5. Add welding symbols as required to the sketch per the latest welding standards.
6. Lightly lay out all required views and check that they are centered within the work area.
7. Check that all dimensions are added using the latest drafting standards.
8. Darken in all views using correct line thickness and add all dimensioning using light guidelines.
9. Recheck all work, and, if correct, neatly fill out the title block using light guidelines and neat lettering.
10. Recheck that all required welding symbols are added correctly.

Problems 19-1 through 19-11

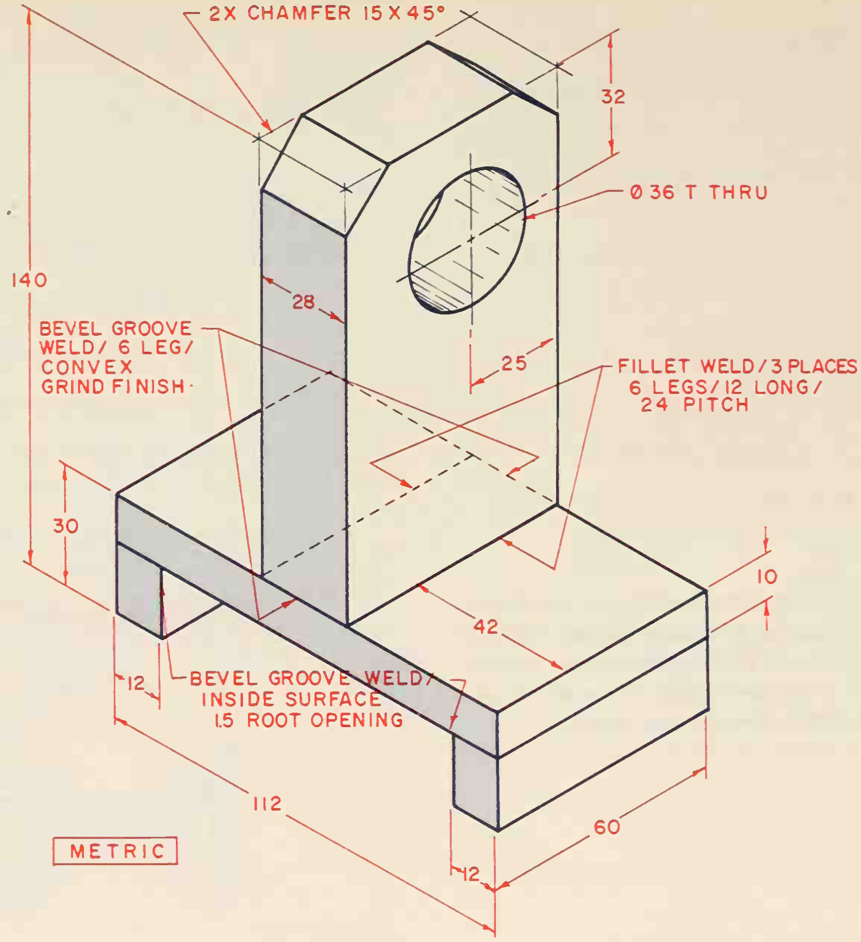
Follow the listed steps, using the latest drafting standards.



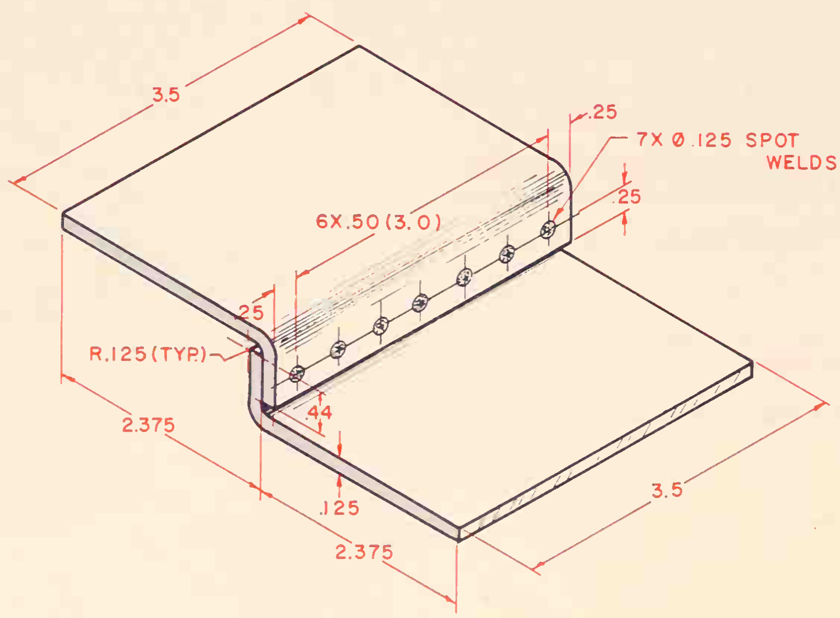
Problem 19-1



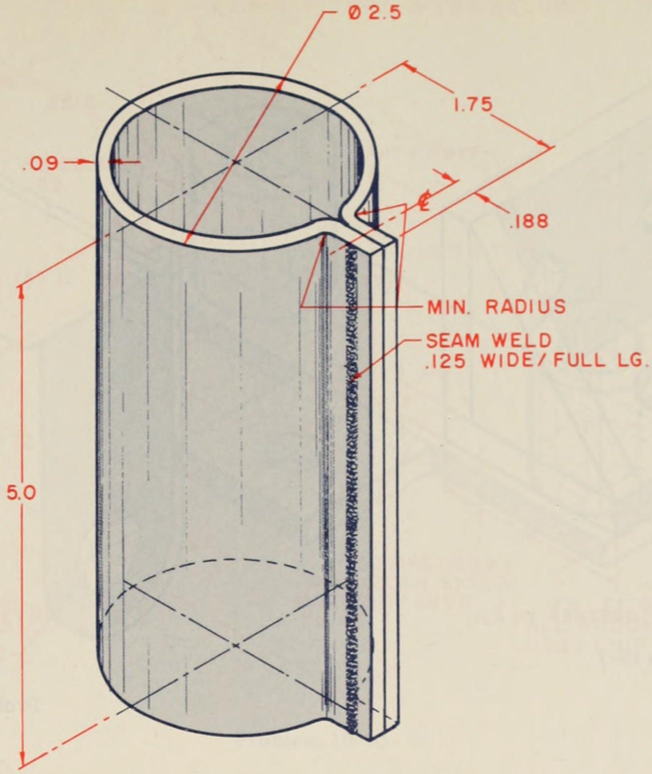
Problem 19-2



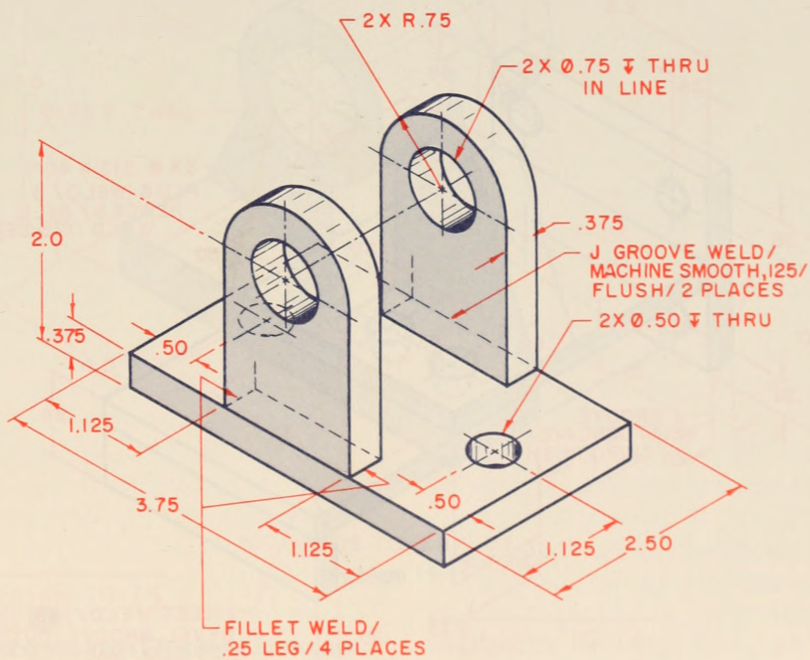
Problem 19-3



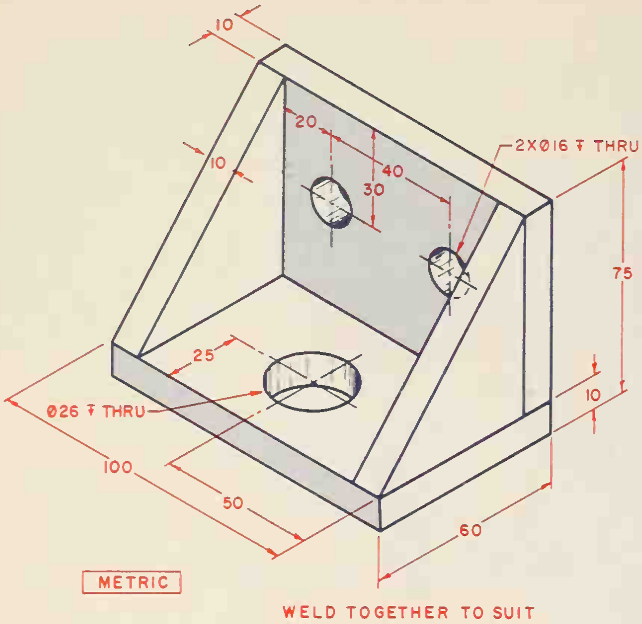
Problem 19-4



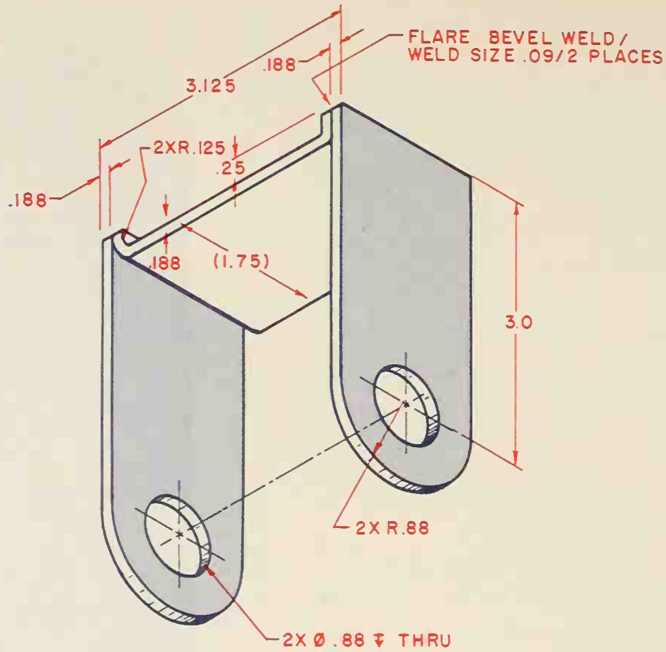
Problem 19-5



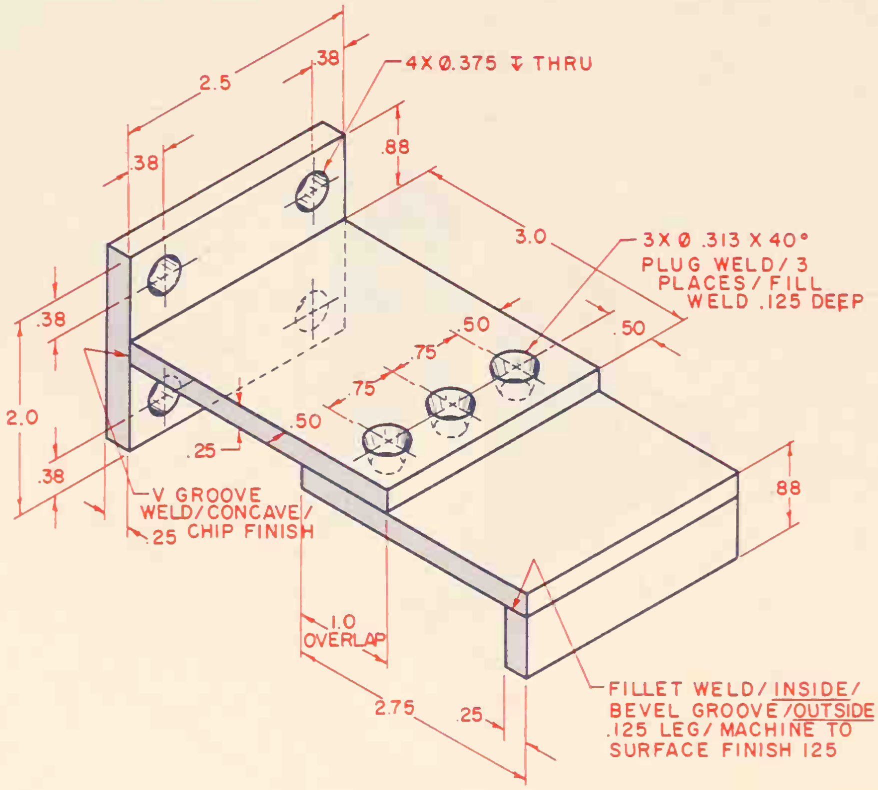
Problem 19-6



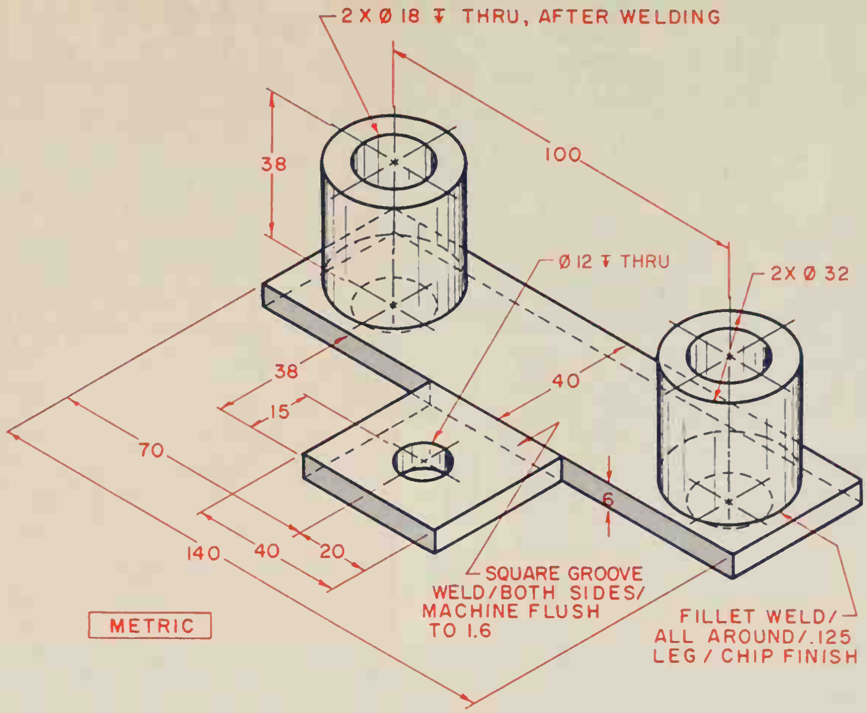
Problem 19-7



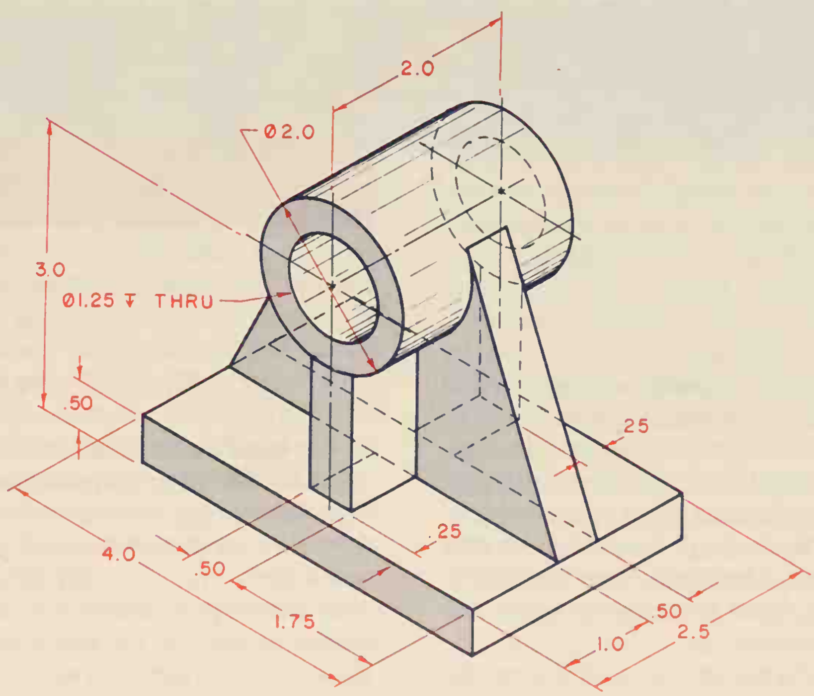
Problem 19-8



Problem 19-9



Problem 19-10



Problem 19-11

Problems 19-12 through 19-15

Convert the following problems from Chapter 4 from casting drawings to weldment drawings:

Problem 19-12

Refer back to Problem 4-27.

Problem 19-13

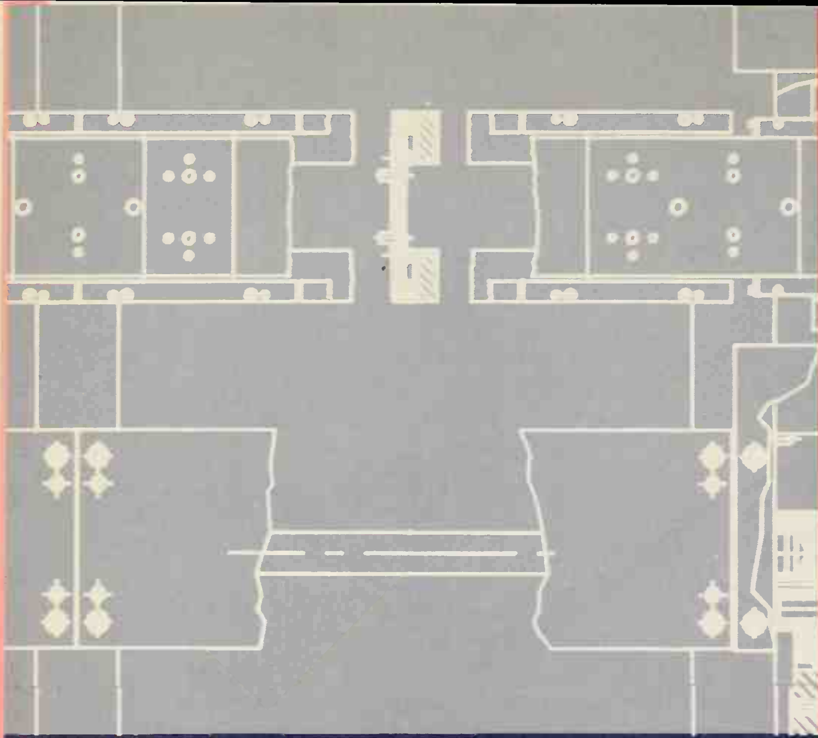
Refer back to Problem 4-28.

Problem 19-14

Refer back to Problem 4-36.

Problem 19-15

Refer back to Problem 4-37.



CHAPTER 20

This chapter describes the methods used to make cast products. Covered are the basic parts of a casting mold, forging die, and stamping die; the processes used to forge and stamp metals; the process and tools used to extrude metals; machine tools and the processes they perform; workholding devices; and processes used to heat treat steels.

SHOP PROCESSES

The ultimate purpose of any engineering drawing is to provide the information necessary to make or fabricate an object. To achieve this purpose an engineering drawing must completely describe and detail the desired object. The drawing must show the specific size and geometric shape of the object as well as furnishing the related information concerning the material specifications, finish requirements, and any special treatments required.

To properly construct an engineering drawing, the designer must be thoroughly familiar with the methods used by the shop to transform the drawn image into the actual object specified in the drawing. By knowing the basic processes used to manufacture an object, the designer can design the object with the manufacturing processes in mind. This will not only make manufacture easier but will many times reduce the cost of a manufactured product. Therefore, the purpose of this chapter is to acquaint the new designer with the basic processes used to fabricate objects, as well as the capabilities and limitations of the machine tools used to machine these objects to their final form.

Shop Processes

The term *shop processes* refers to the basic methods used by the shop to make the object described in the engineering drawing. The specific processes used to make the object depend on the object itself. In some cases the part may be cast, while other parts may be forged, extruded, or stamped. In many instances the part, once fabricated into its basic form, must also be machined to maintain a specific degree of accuracy or to produce a feature not possible with other manufacturing processes.

When the shop receives the engineering drawing, in the form of a part print, it is first reviewed to ensure all pertinent data and information necessary to make the object are contained in the drawing. During this review, the shop personnel will consider several factors necessary to determine how the part must be made. These factors include: the type and condition of the material used to make the object, the overall size and shape of the part, the types of operations required, the required accuracy of the part, and number of parts to be made.

The type and condition of the material used to make the part are important considerations. Some parts may be made from solid bar stock while other parts must be extruded, cast, forged, or stamped. In most cases, parts made from bar stock require the least lead time. The *lead time* is the interval from the time the shop receives the drawing until production begins. Most shops maintain a sufficient supply of bar stock to begin production as soon as the drawing is received. However, when a part must be extruded, cast, forged, or stamped a longer lead time is required to make the necessary molds or dies to fabricate the object.

The size and shape of the object must be considered to determine if the object is within the capabilities of the shop to make. In addition, the size and shape may also determine the size of the machine tools required as well as the datum, or reference, surfaces used to locate the part during manufacture.

The types of operations required determine the types of equipment and machine tools needed to make the part. If, for example, the part requires holes, a drill press, vertical milling machine, or other machine tool may be used. The next consideration, the required accuracy of the part, also determines how the operations are performed. A hole with a required accuracy of .002'' (0.05 mm), for example, would require reaming, while a hole with a required accuracy of .020'' (0.5 mm) could be drilled.

The number of parts to be made will frequently determine if the part should be cast, forged, extruded, or machined from solid stock. Likewise, the number of parts will also determine if any special workholders are to be made. Larger production runs will normally justify more sophisticated tools and processes since the cost can be spread over a larger number of parts. Smaller production runs normally demand the parts be made at the lowest possible cost with little or no investment in special molds, dies, or workholders.

While each of these factors has been separated for the purpose of this discussion, in practice each is considered as part of the other. These factors are so closely related in production that they frequently overlap and one cannot be considered without the others.

The primary processes used to fabricate manufactured products are casting, forging, extruding, stamping, and machining. To use these processes to their best advantage, the designer must be familiar with the strengths and weaknesses of each process as well as the fundamental aspects of each process.

Casting

Casting is basically a process of pouring molten metal into a mold that contains the desired shape in the form of a cavity. The principal types of casting used in manufacturing today are sand casting, investment casting, centrifugal casting, and die casting.

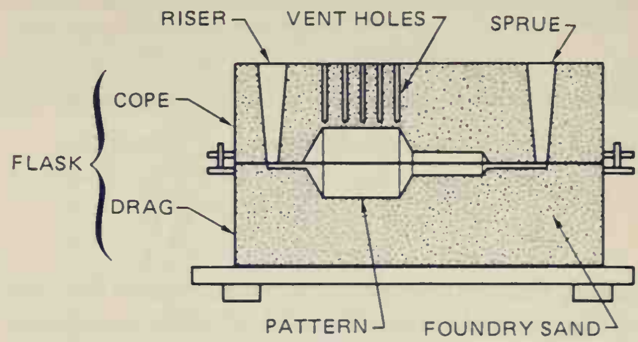


Figure 20-1 Components of a sand casting mold (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

Sand Casting

Sand casting is the most common type of casting method. The major components of the molds used to make sand castings are shown in Figure 20-1 and include the *flask*, *pattern*, and *green sand*. The flask is a two-part box, or frame, used to contain the sand. The top half of the flask is called the *cope* and the bottom half is called the *drag*. Occasionally, a third section may be installed between the cope and drag. This section is called a *cheek*, and is used where a deep or complex shape must be cast. In sand casting the mold is prepared by ramming the green sand around a model of a part, called the *pattern*. The model is then removed to form the cavity for the molten metal. The plane of division between the cope and drag is called the *parting line*. In many castings, the parting line occurs at the approximate middle of the part. The parting line can be seen on most casting by a ragged line which is usually ground off.

The molten metal enters the mold through the *sprue hole* and is directed to the cavity by one or more *gates*. The sprue hole is formed by installing a sprue peg in the cope. This peg is then removed after the final ramming of the cope. The *riser* is used to vent the mold and to allow gases to escape. The riser also acts as a small reservoir to keep the cavity full as the metal begins to shrink during the cooling process.

Once the cope and drag are rammed and the pattern is removed, a solid part could be poured in the mold. However, in some cases a hollow part, or one which has large holes, must be poured. To reduce the amount of material needed to fill the cavity and to reduce the time necessary to machine the part a *sand core* may be installed in the cavity. When sand cores are intended to be installed in a cavity, *core prints* must also be provided to locate and anchor the sand cores during the casting process. Core prints are normally a simple extension of the pattern.

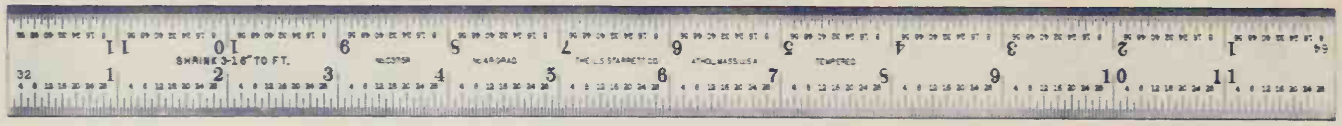


Figure 20-2 Shrink rule (*Courtesy* L.S. *Starrett Co.*)

Making Patterns. When patterns are made for casting two important factors must always be considered. The first is the draft. *Draft* is the slope or taper of the sides of a pattern which permits it to be removed from the cope and drag without disturbing the cavity. The draft also permits the cast part to be removed easily from some molds. The amount of draft necessary will normally depend on the part being cast, but will normally be about one degree.

The second consideration is shrinkage. When metals are cast a certain amount of *shrinkage* occurs as the metal cools. The specific amount of shrinkage depends on the metal being cast. Steel, for example, shrinks at a rate of approximately three-sixteenths of an inch per foot, while cast iron shrinks about one-eighth of an inch per foot. To allow for this shrinkage and to make sure the final part is the correct size the pattern must be made slightly larger than the final size of the desired part.

When making a pattern, the pattern maker will normally use a shrink rule to compensate for the shrinkage. A *shrink rule*, Figure 20-2, is a standard steel rule which has the graduations marked for a specific amount of shrinkage. A shrink rule used for cast iron has an extra one-eighth inch added to each foot, while a shrink rule for steel has an additional three-sixteenths added.

In most instances, when a pattern must be made, the pattern maker will receive the engineering drawing which contains all the final sizes of the part. The pattern maker will then make all the necessary calculations needed to make the oversized pattern. But, occasionally, the pattern maker will be given a drawing with all the calculations already made to produce the pattern. In either case, the patterns must be made to suit the material being cast.

Investment Casting

Investment casting produces parts with great detail and accuracy, while at the same time allowing very thin cross sections to be cast. In this process, the pattern is made by casting wax in the desired form. The pattern is then placed in a sand mold and the mold is fired to melt out the wax pattern. This process is also referred to as *lost wax casting*. The molten metal is then fed into the mold to produce the cast part.

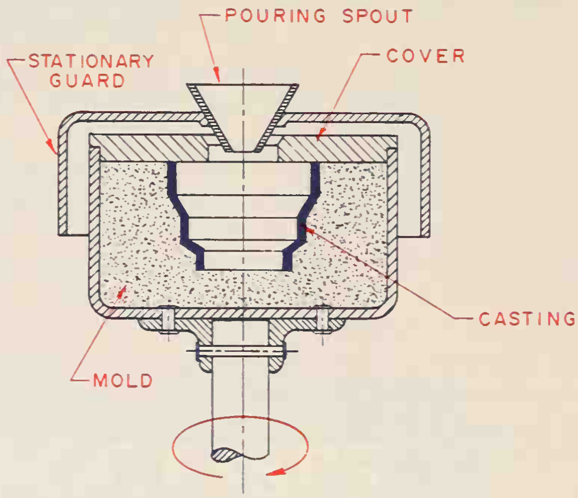


Figure 20-3 Centrifugal casting

Centrifugal Casting

Centrifugal casting, Figure 20-3, is a process of pouring a measured amount of molten metal into a rotating mold. This process can be used for a single mold or multiple molds. The centrifugal force created by the rotation forces the molten metal to fill the cavity. This same centrifugal force, along with the measured amount of material, also controls the wall thickness of the cast part and results in a less porous cast surface than is possible with sand casting. The molds used for this purpose are usually permanent molds made from metal rather than sand. These molds are used repeatedly and produce highly accurate parts requiring very little machining. However, due to their cost, permanent molds are normally used only for high-volume production.

Die Casting

Die casting, Figure 20-4, is a process where molten metal is forced into metal dies under pressure. This process is very well suited for such materials as zinc alloys, aluminum alloys, copper alloys, and magnesium alloys. Parts produced by die casting are superior in appearance and accuracy and require little or no machining to final size.

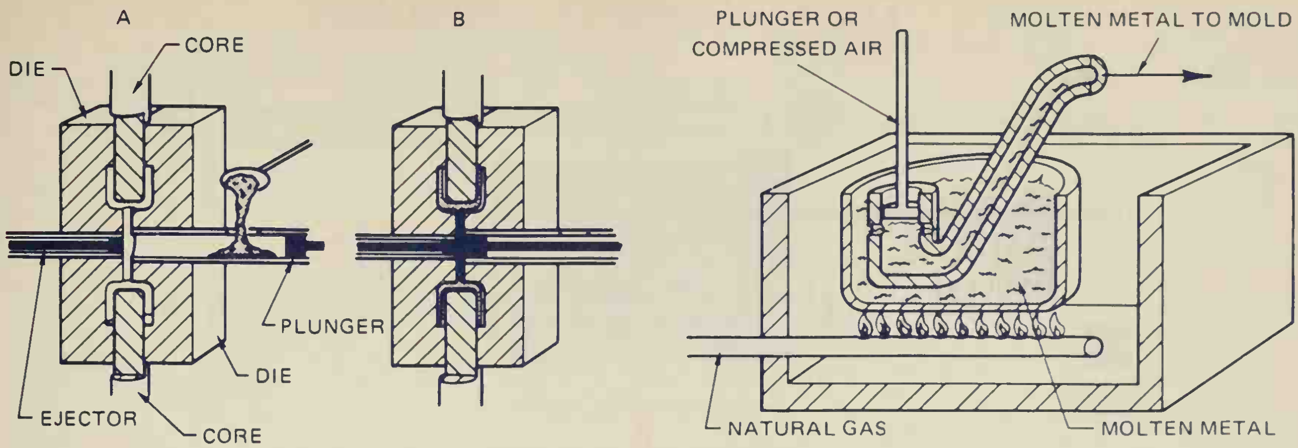


Figure 20-4 Die casting (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

Powder Metallurgy

Powder metallurgy, Figure 20-5, while not an actual casting process, does have some similarities to casting. In the *powder metallurgy* process, metal particles, or powder, are blended and mixed to achieve the desired composition. The powder is then forced into a die of the desired form under pressure from 15,000 to 100,000 pounds per square inch. The resulting heat fuses the powder into a solid piece which can be machined.

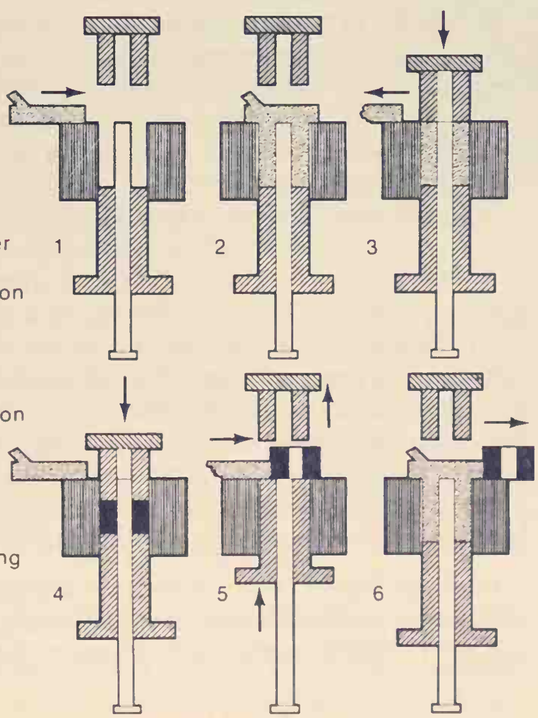


Figure 20-5 Producing parts with powder metallurgy (*Courtesy Metal Powder Industry Foundation*)

Forging

Forging is the process of forming metals under pressure using a variety of different processes. The most common forms of forging are drop forging and press forging. Other variations of forging include rolling and upsetting.

Drop Forging

Drop forging is the process of forming a heated metal bar, or billet, in dies. In practice, the heated metal is placed on a lower portion of a forging die and struck repeatedly with the upper die portion. This forces the metal into the shape of the cavity of the dies. The pressure required to form the metal is provided by a drop hammer.

Most drop forge dies contain at least four different stations, or dies, to complete the part, Figure 20-6. The first station is called the *fuller*. This station is used to rough-form the part to fit the other cavities. The second station, when used, is called the *breakdown*, or *bender*. This station forms the part into any special contours required by the next station, the roughing impression. The roughing impression rough-forms the part to the desired form. The final station is called the *finishing impression* and is used to finish the part to the desired shape and size. Additional stations, such as a trimmer to remove the fins and a cutoff to sever the forged part from the bar, may also be included on the die if they are necessary.

Press Forging

Press forging is a single-step process in which the heated metal bar or billet is forced into a single die and is completed in a single press stroke. The press normally used for press forging is hydraulic.

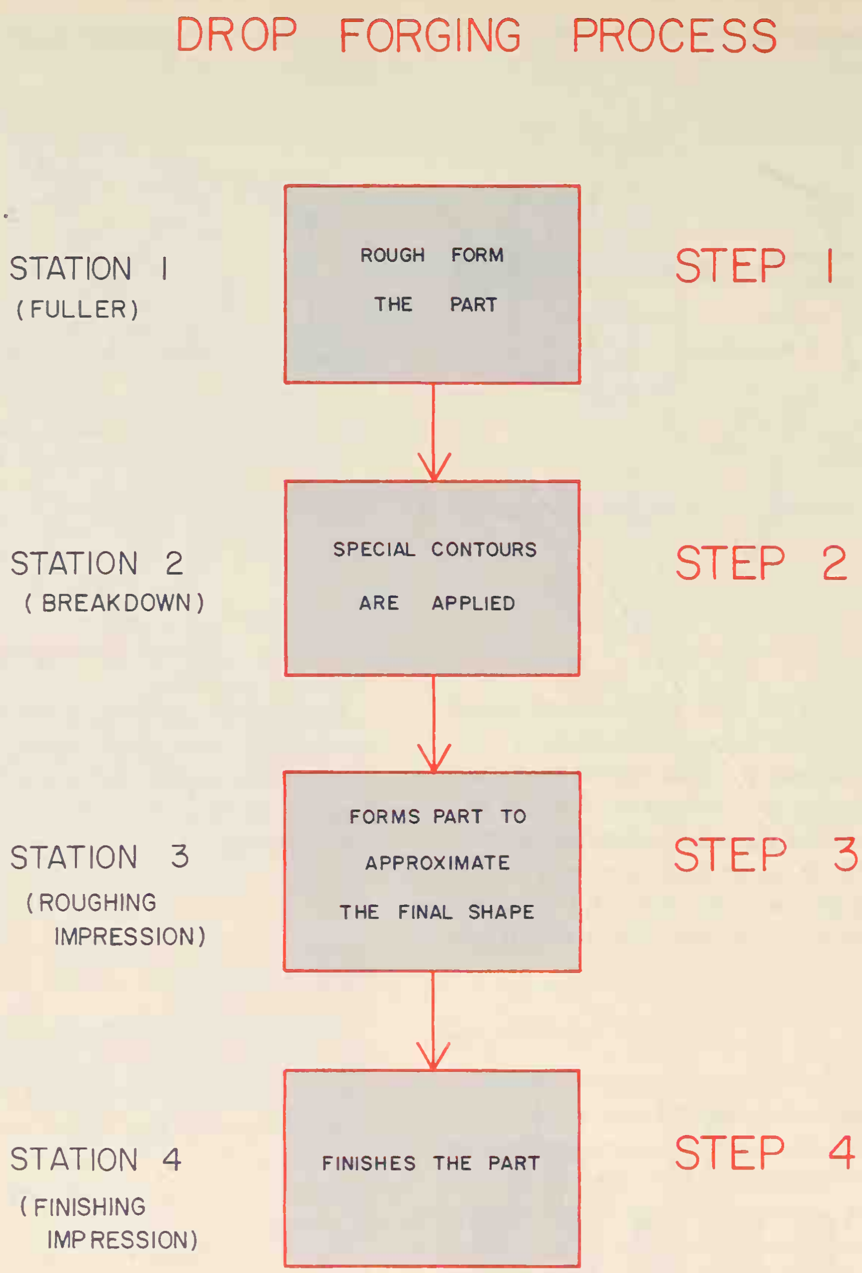


Figure 20-6 Drop forging process

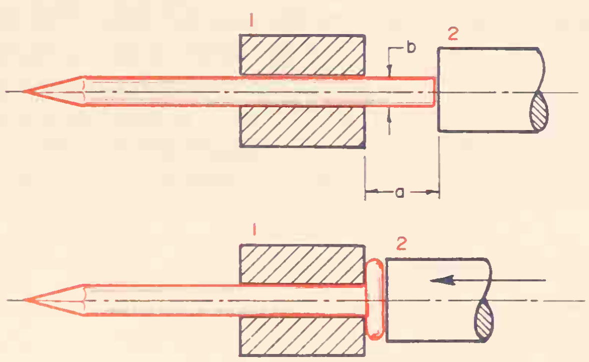


Figure 20-7 Upsetting

Rolling

Rolling is a process where the heated metal bar is formed by passing through rollers having the desired form impressed on their surfaces. Rolling is frequently used to flatten and thin out thick sections.

Upsetting

Upsetting, Figure 20-7, is a process used to enlarge selected sections of a metal part. Bolt heads, for example, are normally produced by an upsetting process.

Extruding

Extruding is a process of forcing metal through a die of a desired form and cross section. The bars

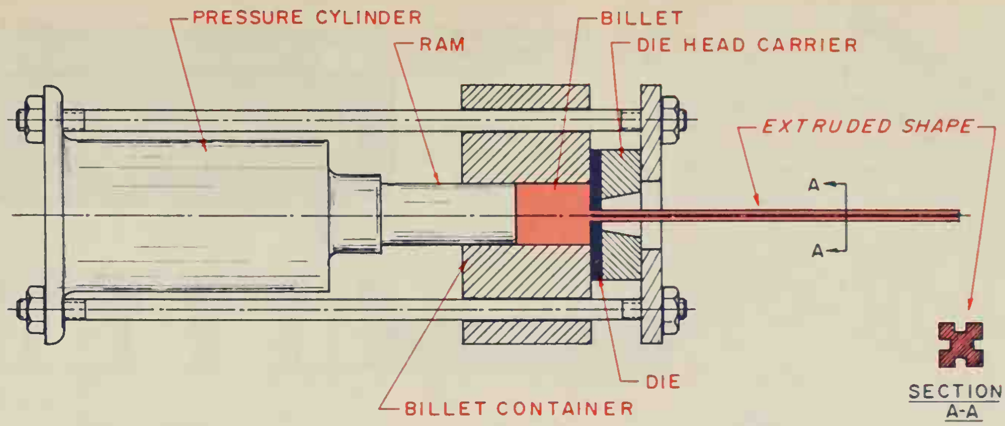


Figure 20-8 Extruding

produced are then cut to the required lengths. Typical examples of extruded parts include parts for aluminum windows and doors. Extrusions provide a near final shape, as shown in Figure 20-8 and, in many cases, only need to be cut off and machined slightly to complete a finished part.

Stamping

Stamping is a process of using dies to cut or form metal sheets or strips into a desired form. The main tool used for metal stamping is a die. The term *die* has a double meaning. It can be used to describe the entire assembled tool or the lower cutting part of the tool. The exact meaning of the term can usually be determined from the context of its use. The principal parts of a die are shown in Figure 20-9. The upper die shoe is used to mount the punch. The die is mounted on the lower die shoe. The guide pins and guide pin bushings are used to maintain the alignment between the punch and die. The stripper is designed to strip the stock material from the punch after the cutting stroke of the die.

When more than one operation takes place on a part during a single stroke, blanking and punching for example, the operation is said to be *compound*. However, when several operations take place sequentially in a die the die is called a *progressive die*.

The principal stamping operations normally performed are shearing, cutting off, parting, blanking, punching, piercing, perforating, trimming, slitting, shaving, bending, forming, drawing, coining, and embossing.

Operations that Produce Blanks

The operations that produce blanks are shearing, cutting off, parting, and blanking, Figure 20-10. *Shearing* is a cutting action performed along a straight line. *Cutting off* is a cutting operation which is performed on a part to produce an edge other than a straight edge. In many cases, cutting off is used to finish the edges of a part. Like shearing, cutting off does not produce any scrap. *Parting*, on the other hand, is also an operation used to finish the edges of a part, but, unlike the other operations, parting does produce scrap.

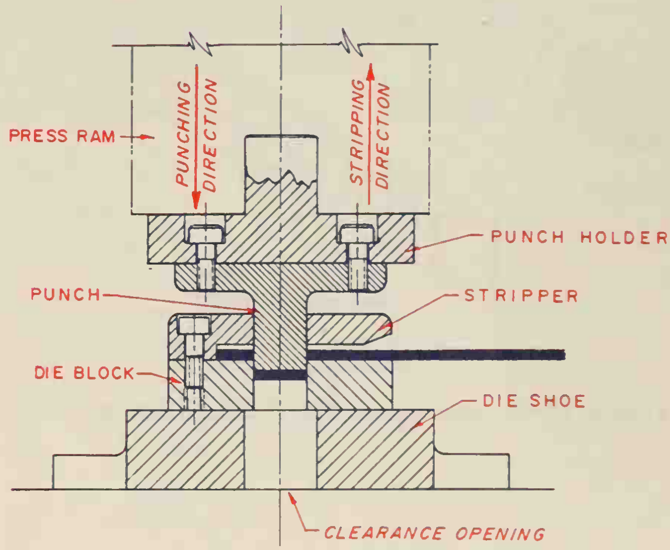


Figure 20-9 Metal stamping die

Blanking is an operation that produces a part cut completely by the punch and die. In blanking operations, the piece that falls through the die is the desired part. The scrap is the skeleton left on the stock strip.

Operations that Produce Holes

The operations that produce holes are punching, piercing, and perforating. *Punching* is an operation that cuts a hole in a metal sheet or strip, Figure 20-11A. In punching, the piece that falls through the die is scrap, and the area on the strip is the desired part. Punching is normally performed on parts that are to be blanked to provide holes for bolts, screws, or similar parts.

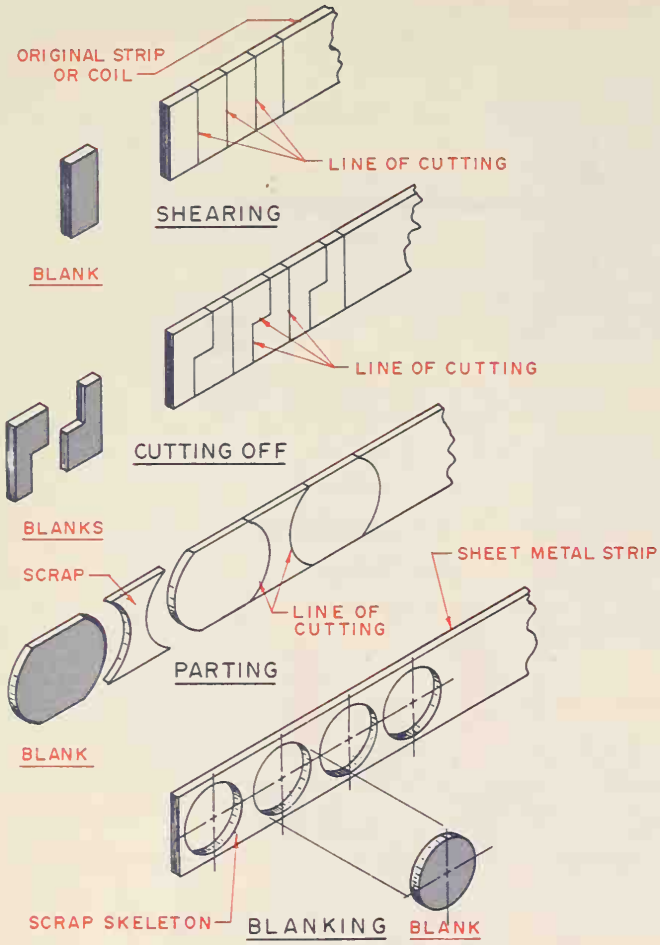


Figure 20-10 Operations that produce blanks

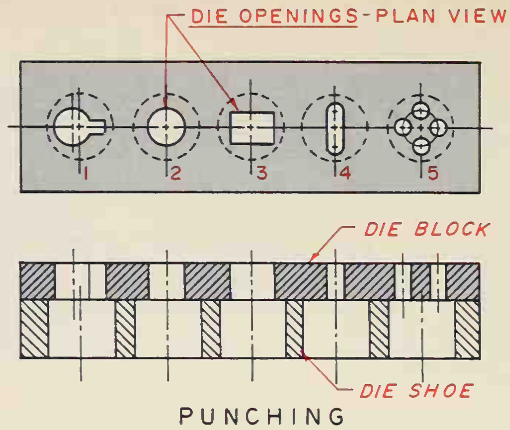


Figure 20-11A Punching operation to produce holes

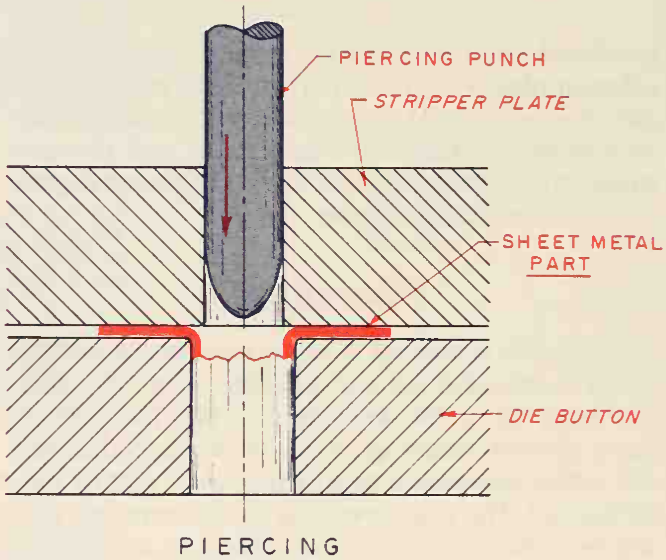


Figure 20-11B Piercing operation to produce holes

Piercing is an operation similar to punching, except that in piercing no scrap is produced, Figure 20-11B. A pierced hole is sometimes used to increase the thickness of metal around a hole for tapping threads in a stamped part. *Perforating* is simply a punching operation performed on sheets to produce either a uniform hole pattern or a decorative form in the sheet.

Operations that Control Size

The operations used to control size are trimming, slitting, and shaving, Figures 20-12A and 20-12B. *Trimming* is an operation performed on formed or drawn parts to remove the ragged edge of the blank. *Slitting* is performed on large sheets to produce thin stock strips. Slitting may be performed by rollers or by straight blades. *Shaving* is an operation performed on a blanked part to produce an exact dimensional size or to square a blanked edge. Shaving produces a part with a close dimensional size, and a cut edge which is almost perpendicular to the top and bottom surfaces of the blanked part.

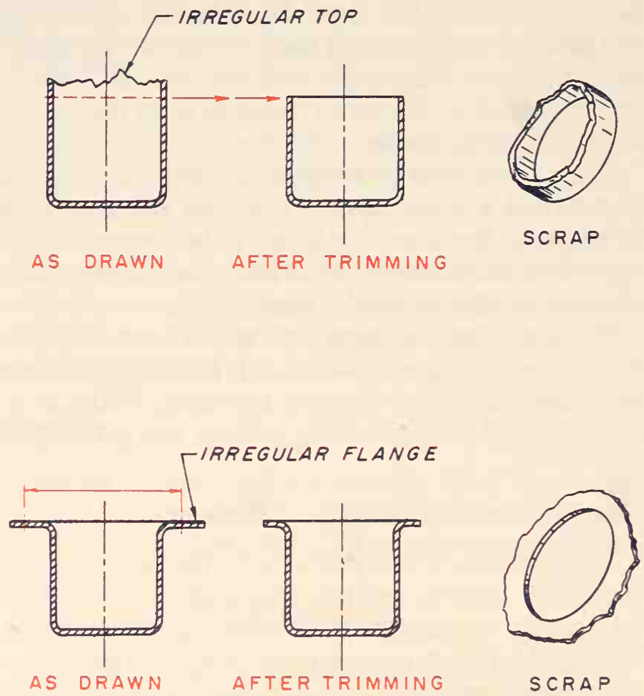


Figure 20-12A Operation that controls size – Trimming

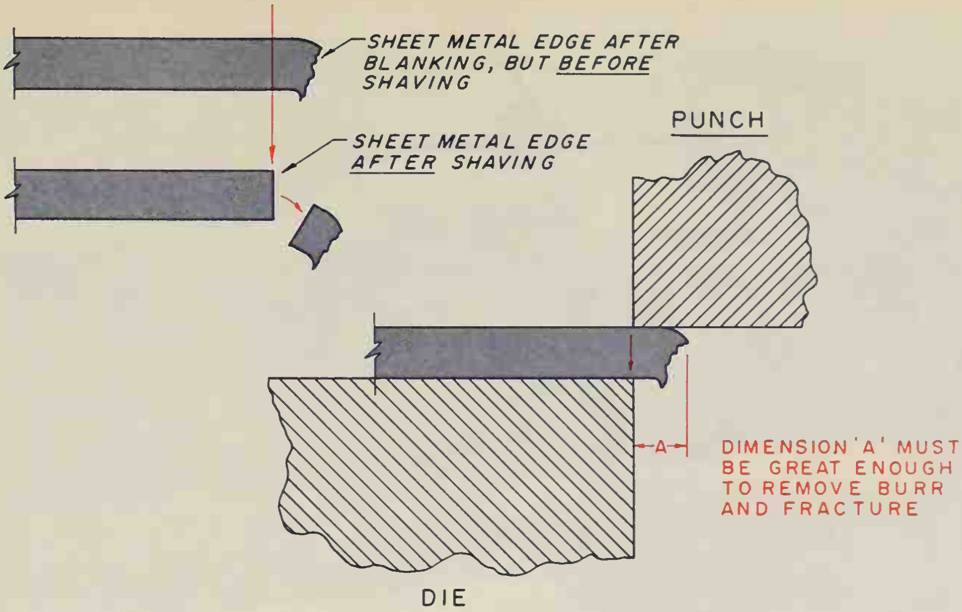
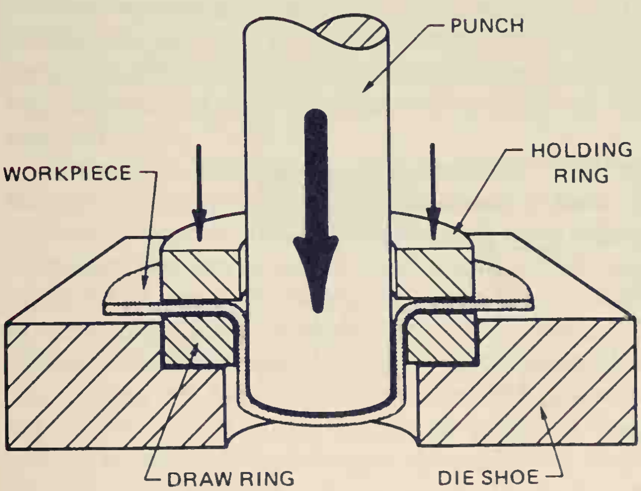


Figure 20-12B Operation that controls size — Shaving



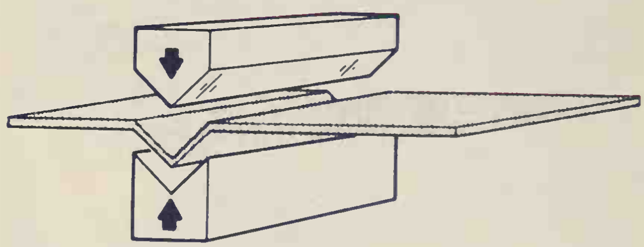


Figure 20-13 Operations that bend or form parts (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

Operations that Bend or Form Parts

The operations used to bend or form parts are bending, forming, and drawing, Figure 20-13. *Bending* is an operation in which a metal part is simply bent to a desired angle. *Forming*, on the other hand, is an operation in which a part is bent or formed into a complex shape. Forming is also a catchall word frequently used to describe any bending operation that does not fall into one of the other categories. *Drawing* is a process of stretching and forming a metal sheet into a shape similar to a cup or top hat.

Machining

Machining is the process of removing metal with machine tools and cutters to achieve a desired form or feature. The principal types of machine tools used to perform these operations are lathes, milling machines, drill presses, saws, and grinders. Other machines that are variations of the basic machines used in the machine shop include shapers and planers, boring mills, broaching machines, and numerically controlled machines. The specific type of machine used to perform a particular machining operation is determined by the type of operation and the degree of accuracy required.

Lathes

A lathe, Figure 20-14, is one of the most commonly used and versatile machine tools in the shop. Typically, a *lathe* performs such operations as straight and

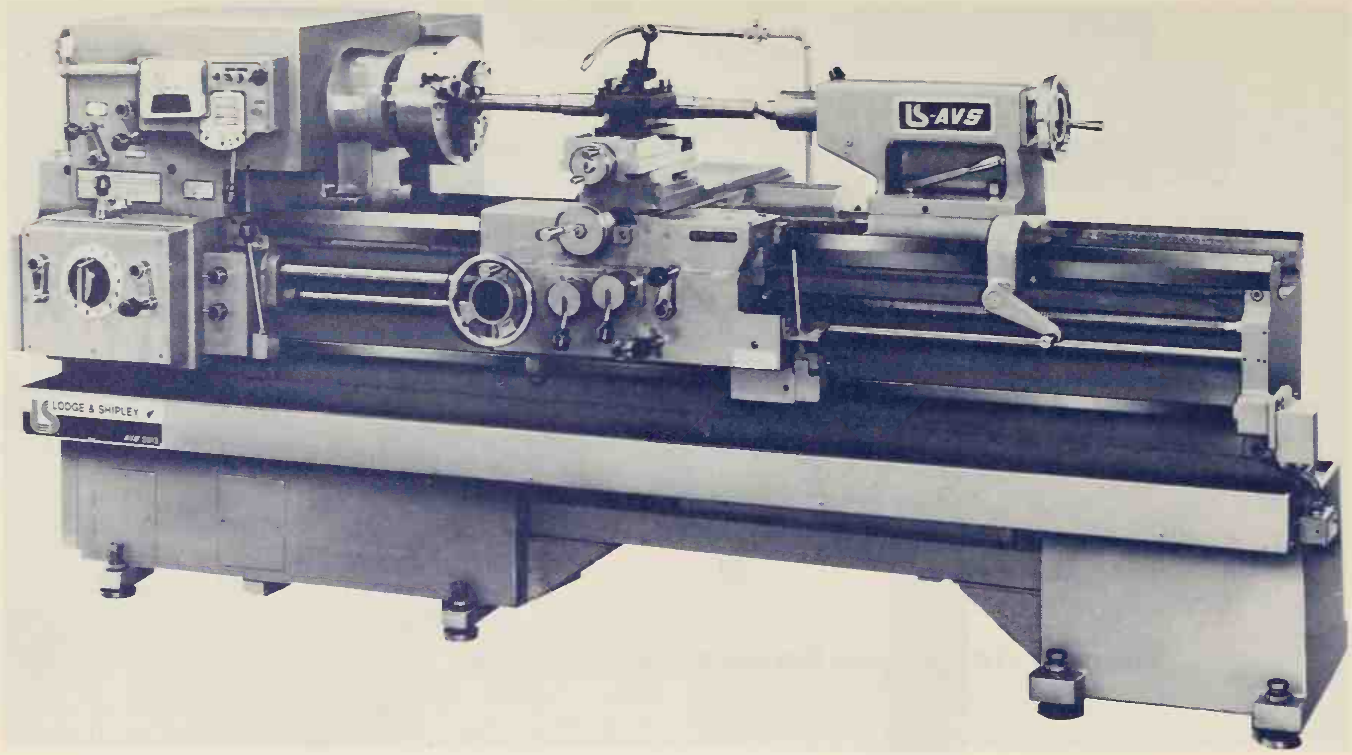


Figure 20-14 Lathe (*Courtesy Lodge & Shipley Co.*)

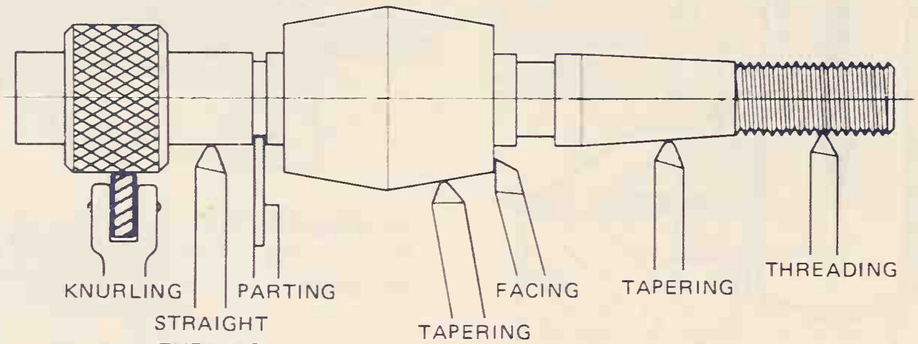


Figure 20-15 Basic lathe operations (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

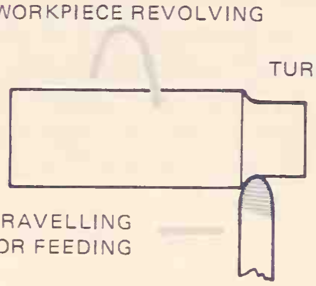


Figure 20-16 Lathe setup for straight turning (From *Turning Technology*, S.F. Krar and J.W. Oswald. Delmar Publishers Inc.)

taper turning, facing, straight and taper boring, drilling, reaming, tapping, threading, and knurling, Figure 20-15.

In operation, the workpiece is held in the headstock and supported by the tailstock. The cutting tool is mounted in the tool post and is traversed past the rotating workpiece to machine the desired form, Figure 20-16. The most common method used to hold parts in a lathe is with a chuck. A *chuck* is a device much like a vise, having movable jaws that grip and hold the workpiece. The most popular type of chuck is the three-jaw chuck, but there are also two-jaw, four-jaw, and six-jaw chucks as well. Other types of devices used to hold and drive a workpiece in a lathe include collets, face plates, drive plates, and lathe dogs.

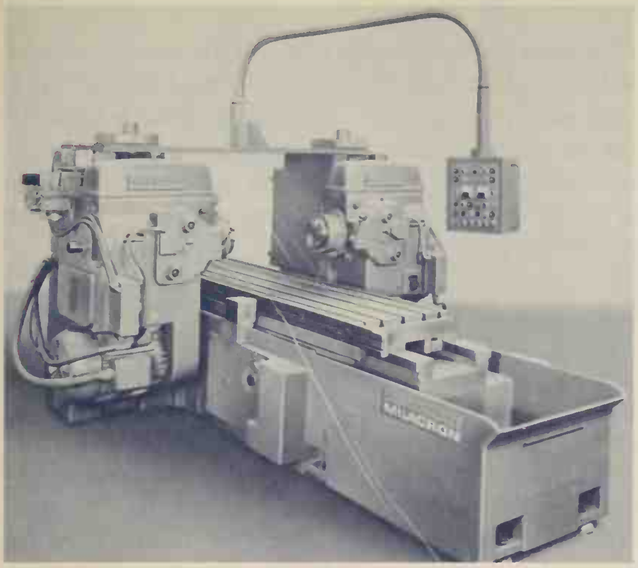


Figure 20-17 Milling machines (*Courtesy Cincinnati Milacron*)

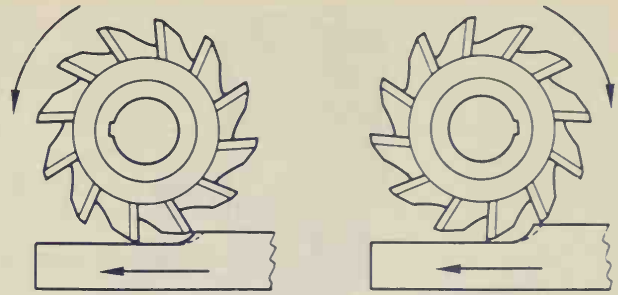


Figure 20-18 Basic milling machine operations (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

Milling Machines

Milling machines are used to machine workpieces by feeding the part into a rotating cutter. The two basic variations of the milling machine are the vertical milling machine and the horizontal milling machine, Figure 20-17.

In operation, the milling cutter is mounted in either the spindle or arbor, and the workpiece is held on the machine table. The most commonly used device to mount the workpiece for milling is the milling machine vise, but the workpiece may also be held directly on the machine table or in other workholding devices. The operations most frequently performed on a milling machine include plain milling, face milling, end milling, straddle milling, gang milling, form milling, keyseat milling, and gear cutting, Figure 20-18. Figures 20-19A and 20-19B show two types of cutters commonly used for milling operations.

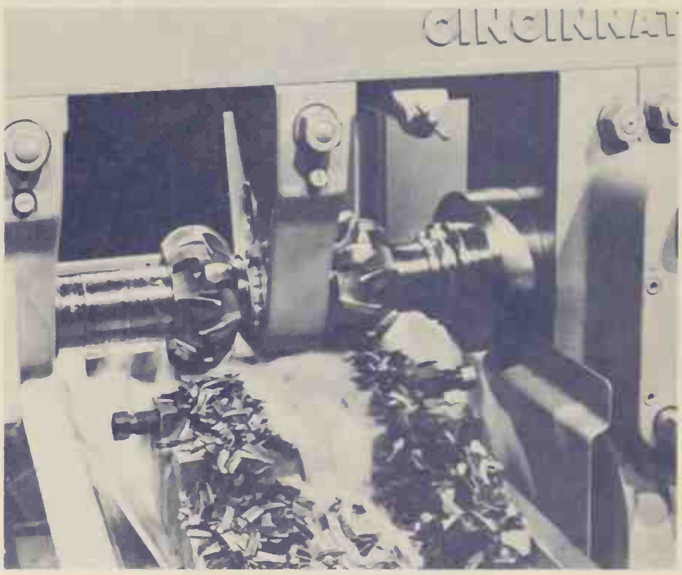


Figure 20-19A Standard milling cutter (*Courtesy Cincinnati Milacron*)

Drill Presses

A *drill press*, Figure 20-20, is a machine that is used mainly for producing holes. The principal types of drill presses used in the shop are the radial drill press and the sensitive drill press.

The operations normally performed on drill presses include drilling, reaming, tapping, chamfering, spotfacing, counterboring, countersinking, reverse countersinking, and reverse spotfacing, Figure 20-21.

When using a drill press, the workpiece is normally held in a vise or clamped directly to the machine table. The drill, or other cutting tool, is mounted in the machine spindle and is fed into the workpiece either by hand or with a mechanical feed unit.

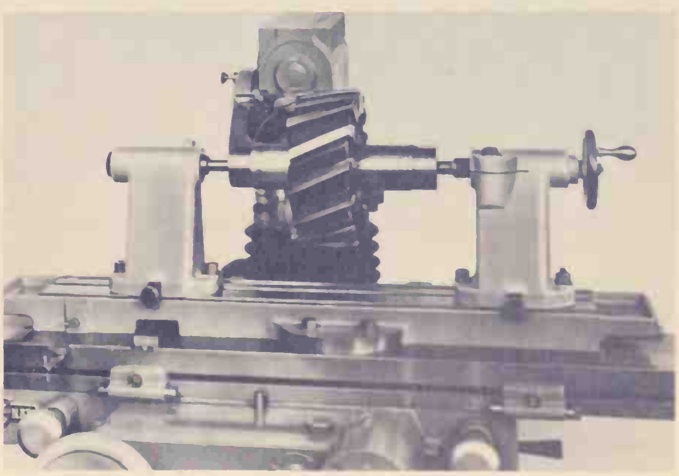


Figure 20-19B Standard milling cutter (*Courtesy Cincinnati Milacron*)

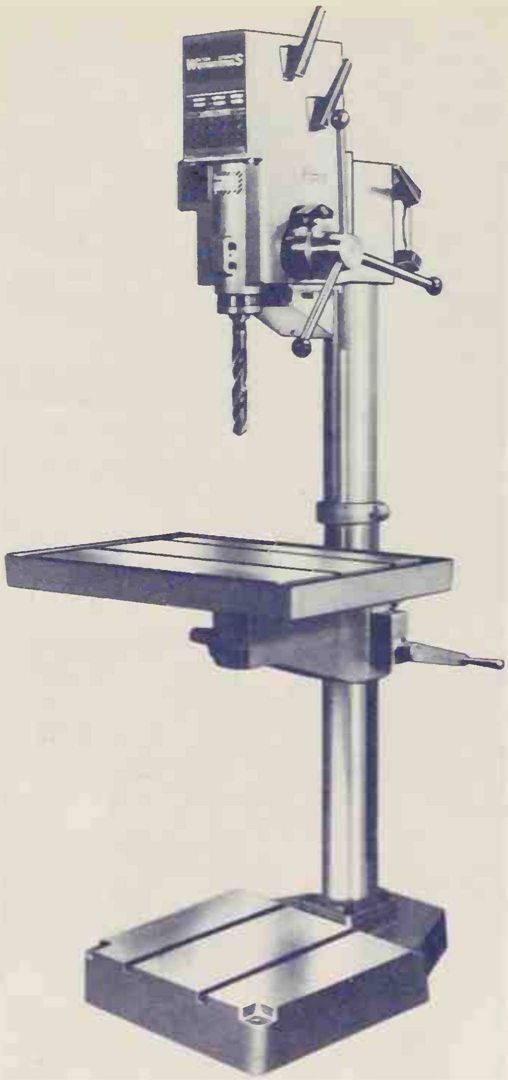


Figure 20-20 Drill press (*Courtesy Wilton Corporation*)

Power Saws

The *power saws* used most often in the machine shop are the contour band machine or band saw and the cutoff saw, Figure 20-22. The *contour band machine* or *band saw* is used primarily for sawing intricate or detailed shapes; the *cutoff saw* is used to cut rough bar stock to lengths suitable for machining in other machine tools.

Precision Grinders

Precision grinders are available in several styles and types to suit their many and varied applications. The principal types of precision grinders used in the machine shop are the surface grinder and the cylindrical grinder, among others.

The *surface grinder*, Figure 20-23, is mainly used to produce flat, angular or special contours on flat workpieces. The most popular variation of this machine consists of a grinding wheel mounted on a horizontal spindle, and a reciprocating table that traverses back and forth under the grinding wheel. One other variation of the surface grinder frequently found in the machine shop uses a vertical spindle and a round, rotating table, Figure 20-24. The workpiece is generally mounted and held on a magnetic chuck during the grinding operation on both styles of surface grinders.

Cylindrical grinders are used to precisely grind cylindrical or conical workpieces. When grinding, the workpiece is mounted either between centers or in a precision chuck, much like a lathe. The grinding wheel is mounted behind the workpiece on a horizontal spindle. The table of the grinder traverses the workpiece past the grinding wheel in a reciprocating motion, while the workpiece rotates at a preset speed.

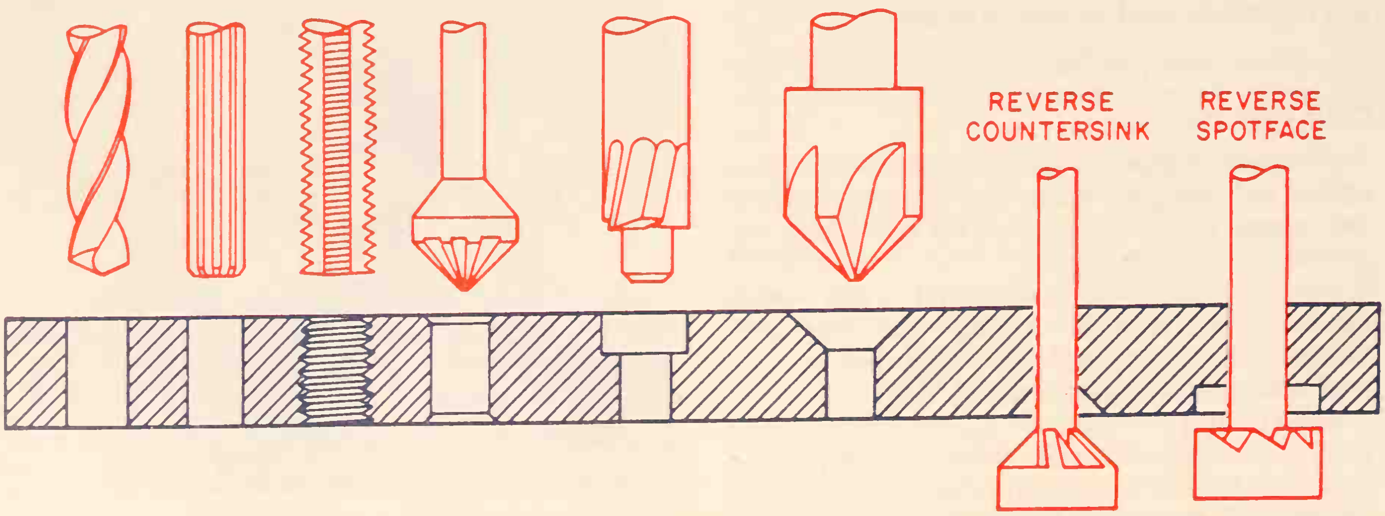


Figure 20-21 Basic drill press operations

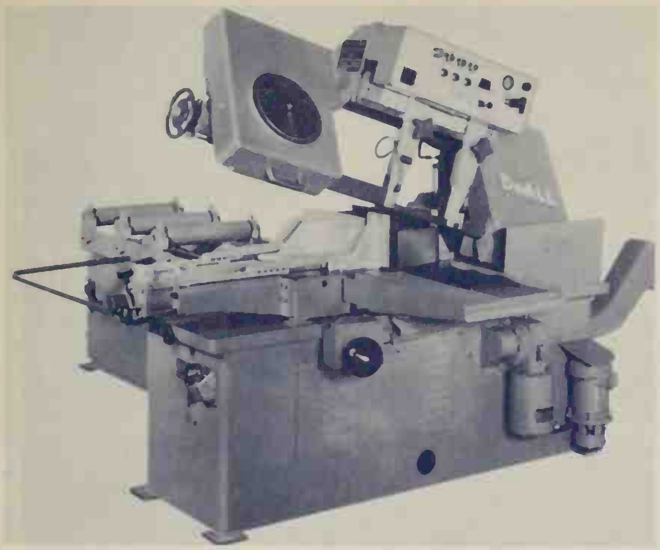


Figure 20-22 Power saw (*Courtesy* DoALL *Co.*)

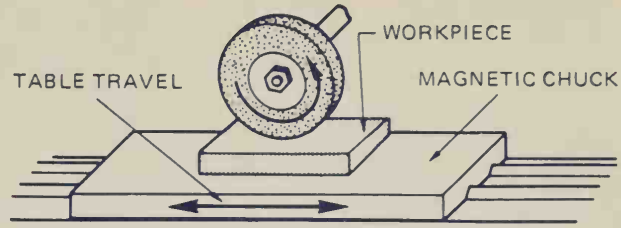


Figure 20-23 Surface grinder (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

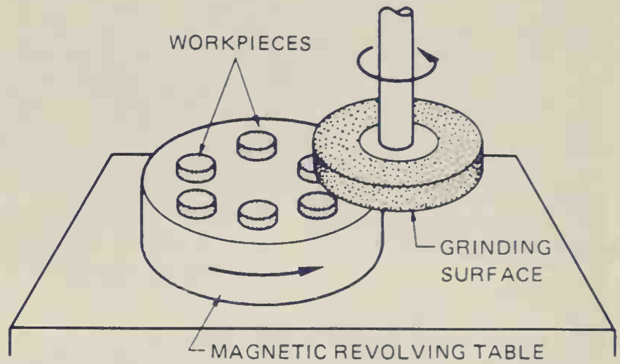


Figure 20-24 Vertical spindle – rotating table surface grinder (From *Materials Processing*, B.R. Thode. Delmar Publishers Inc.)

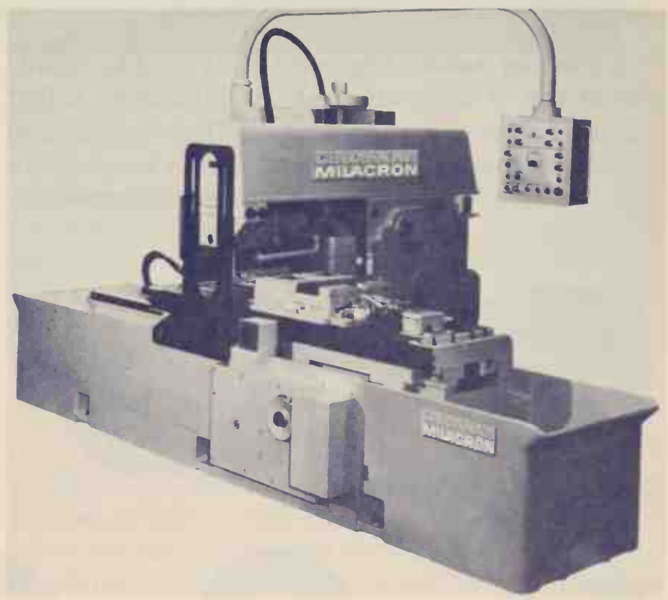


Figure 20-25 Boring mill (*Courtesy* Cincinnati *Milacron*)

Shapers and Planers

Shapers and *planers* are machine tools that use single-point cutting tools to perform their cutting operations. The shaper uses a reciprocating ram to drive the cutter. The cutting tool on this machine tool is mounted on the end of the ram in a unit called the *clapper box*. The clapper box can be positioned vertically or at an angle, depending on the work to be performed. The depth of cut is adjusted by lowering the vertical slide of the clapper box or by raising the position of the table. The workpiece is mounted on the table or vise and is fed past the reciprocating cutter by the table feed. The length and position of the stroke are regulated by the position of the ram and are easily adjusted to suit the size of the workpiece.

Planers operate in a manner similar to the shaper. The major differences between these two machines are their size and method of cutting. The planer is normally much larger than the shaper and the work, rather than the cutter, moves on the planer. In operation, the workpiece is mounted on the table of the planer and the table reciprocates under the stationary tool. As the table reciprocates, the tool is moved across the workpiece by the feed unit. The depth of cut is determined by the height of the tool from the table and is adjusted by lowering or raising the cross beam. The length and position of the cut are determined by the position of the table.

These processes are seldom used today.

Boring Mills

A *boring mill*, Figure 20-25, is a machine tool normally used to machine large workpieces. The two common variations of these machines are horizontal and vertical. The distinction between the two is determined by the position of the spindle. *Horizontal boring mills* perform a wide variety of different machining tasks normally associated with a milling machine but on a much larger scale. *Vertical boring mills* are commonly used to turn, bore, and face large parts in much the same way as a lathe. Another variation of the horizontal boring mill sometimes found in the machine

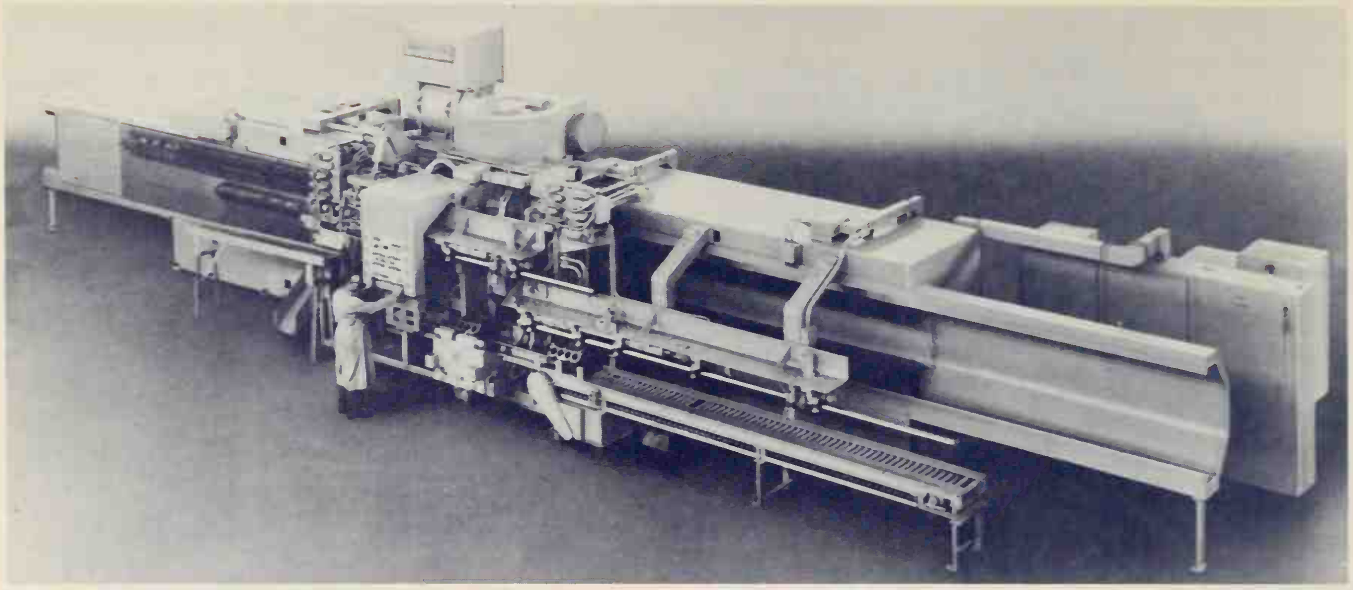


Figure 20-26 Broaching machine (*Courtesy Cincinnati Milacron*)

shop is the *vertical turret lathe*. This machine serves the same basic function as the vertical boring mill but, rather than using a single tool, a vertical turret lathe uses a turret arrangement to mount and position the cutting tools.

Broaching Machines

A *broaching machine*, Figure 20-26, is used to modify the shape of a workpiece by pulling tools called *broaches* across or through the part. Both internal and external forms can be broached. *Internal broaching* can produce holes with a wide variety of different forms, Figure 20-27. *External broaching* is typically used to produce some gear teeth, plier jaws, and other similar details.

Another type of internal broaching operation is broached in an *arbor press* using a push-type, rather than a pull-type broach. This type of broaching is often used in the top to produce keyways or other simple shapes.

Numerically Controlled Machines

Numerically controlled machine tools represent one of the newer innovations in machine tool design in wide

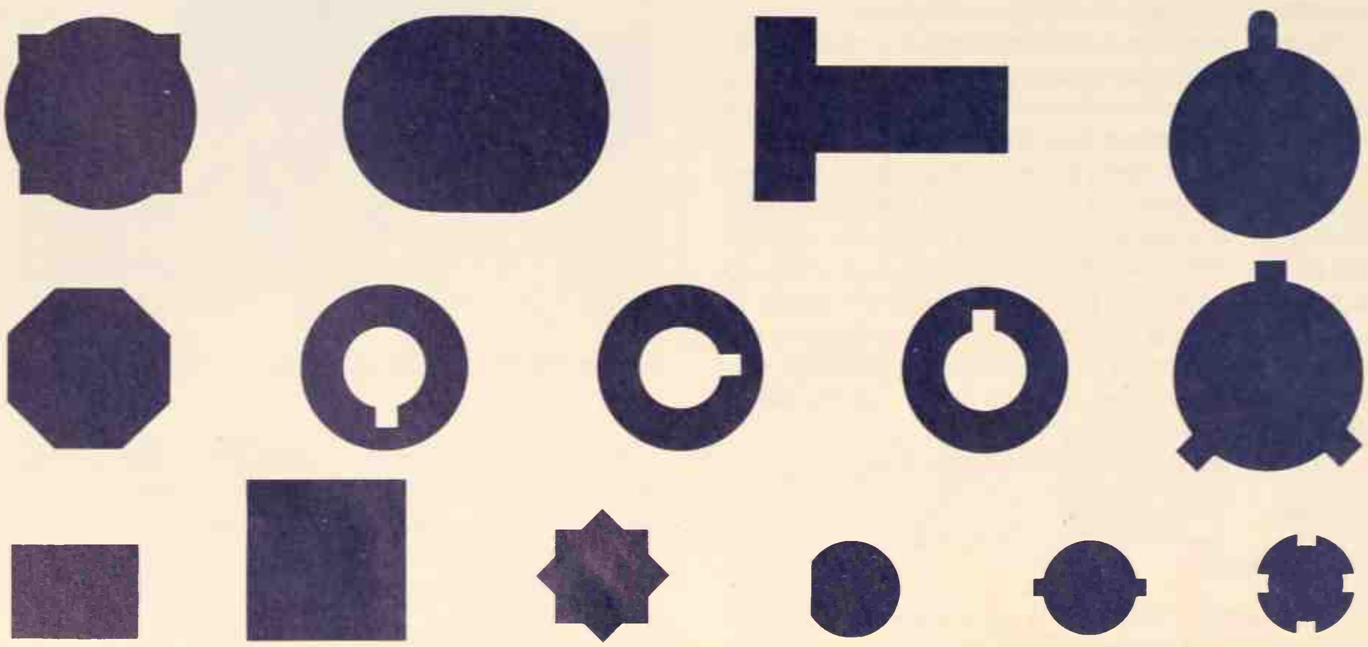


Figure 20-27 Typical internal broached shapes (*Courtesy The DuMont Corporation*)

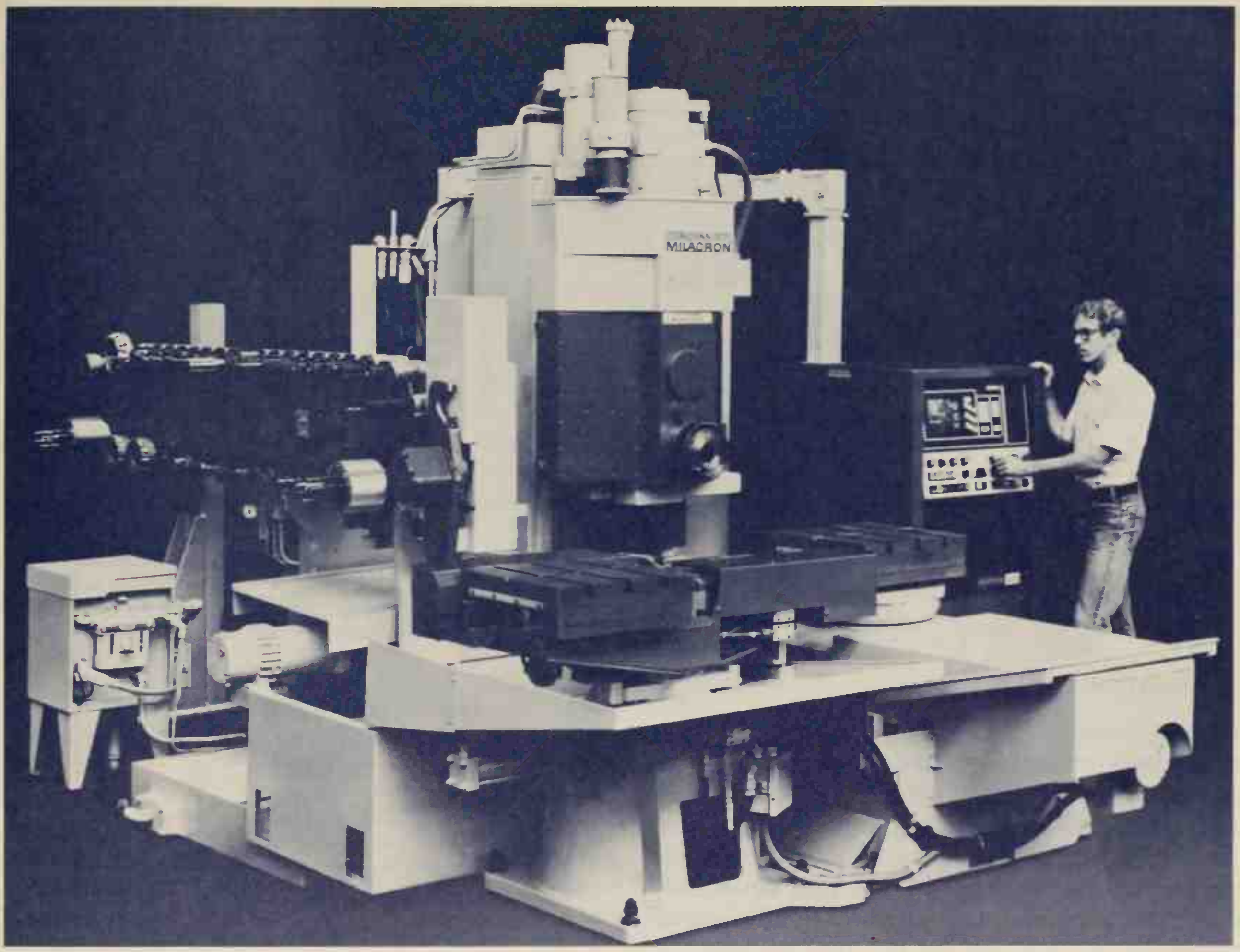


Figure 20-28 Machining center (*Courtesy Cincinnati Milacron*)

use today. These machine tools are operated by either punched tapes or by computers, and virtually eliminate the errors caused by human operators.

The two basic variations of these machines in use today are the point-to-point and the continuous path machines. The principal difference between the two is in the movements of the tool with reference to the workpiece. *Point-to-point* machines operate on a series of preprogrammed coordinates to locate the position of the tool. When the tool finishes at one point, it automatically goes to the next point by the shortest route. This type of control is very useful for drilling machines, but machines such as milling machines require greater control of the tool movement. So, *continuous path* controls are used to control the movement of the tool throughout the cutting cycle. For example, if a circle or radius were to be milled, the operator or programmer would need only to program a few points along the arc. The computer would compute the remaining points and guide the cutting tool throughout the complete cycle.

These controls are frequently used for a wide range of different machine tools, from drill presses and milling machines to lathes and grinders. Due to the advent of these controls, a whole new form of machine tool has evolved: the machining center, Figure 20-28. These machines can take a rough, unmachined part and completely machine the whole part without removing it from the machine or changing a setup.

Special Workholding Devices

Special workholding devices are frequently used to produce parts in high-volume production runs. The major categories of special workholding devices commonly used in the shop are jigs and fixtures. The primary function of *jigs* and *fixtures* is to transfer the required accuracy and precision from the operator to the tool. This permits duplicate parts to be produced within the specified limits of size without error. Both jigs and fixtures hold, support and locate the workpiece: the principal difference between these tools is the method used to control the relationship of the tool to the workpiece. *Jigs* guide the cutting tool through a hardened drill bushing during the cutting cycle. *Fixtures*, on the other hand, reference the cutting tool by means of a set block, Figure 20-29.

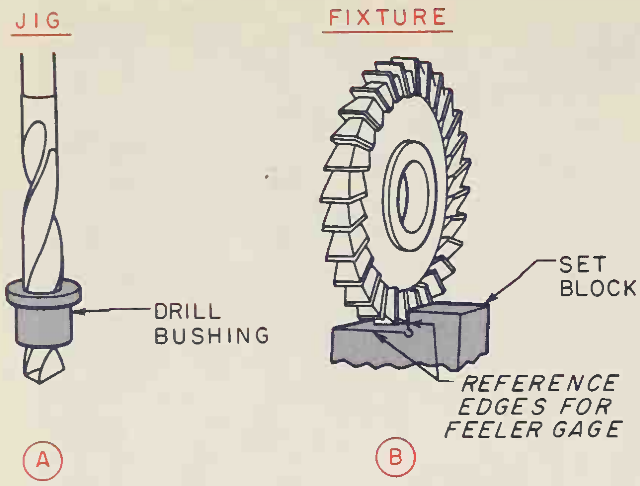


Figure 20-29 Referencing the tool to the workpiece

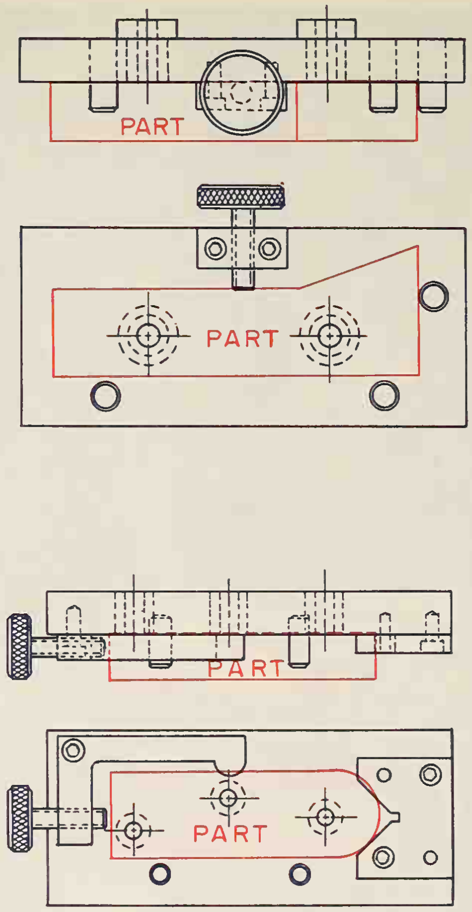


Figure 20-30 Plate jig

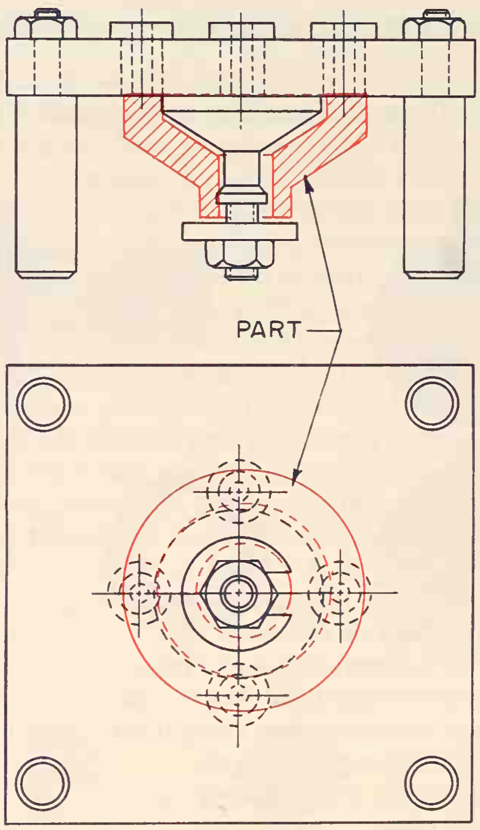


Figure 20-31A Table jig

Classification of Jigs

Jigs are normally classified by the type of operation they perform and their basic construction. Typically, jigs are used to drill, ream, tap, countersink, chamfer, counterbore, and spotface. Jigs are also divided into two general construction categories: open and closed. *Open jigs* are jigs that cover only one side of the part, and are used for relatively simple operations. *Closed jigs* are jigs that enclose the part on more than one side, and are intended to machine the part on several sides without removing the part from the jig.

The most common types of jigs include plate jigs, angle plate jigs, box jigs, and indexing jigs. While there are several other distinct styles of jigs, these represent the most common forms.

Plate jigs, Figure 20-30, are the most common form of jig. These jigs consist of a simple plate which contains the required drill bushings, locators, and clamping elements. Typical variations of the basic plate jig include the *table jig*, Figure 20-31A, and the *sandwich jig*, Figure 20-31B. Another and even simpler version of the plate jig is the *template jig*, Figure 20-32. These jigs are used where accuracy and not speed is the prime consideration. Template jigs may or may not have drill bushings, and do not normally have a clamping device. This form of jig is frequently used for light machining or for layout work.

An *angle plate jig*, Figure 20-33, is a modified form of a plate jig in which the surface to be machined is perpendicular to the locating surface. This type of jig is often used to machine pulleys, gears, hubs or similar parts. Another variation of this type of jig is the *modified angle plate jig*. These jigs are used to machine parts at angles other than 90°.

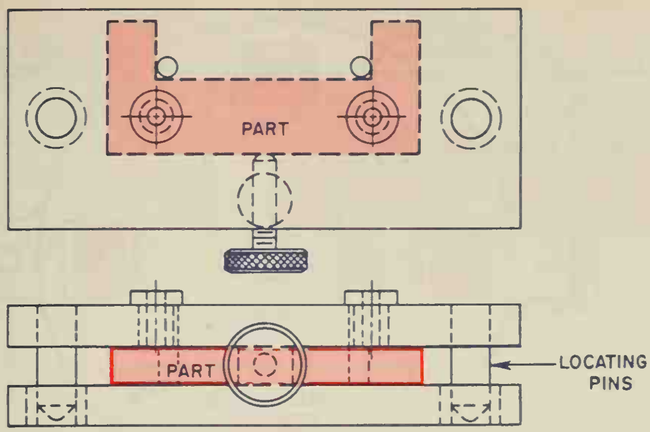


Figure 20-31B Sandwich jig

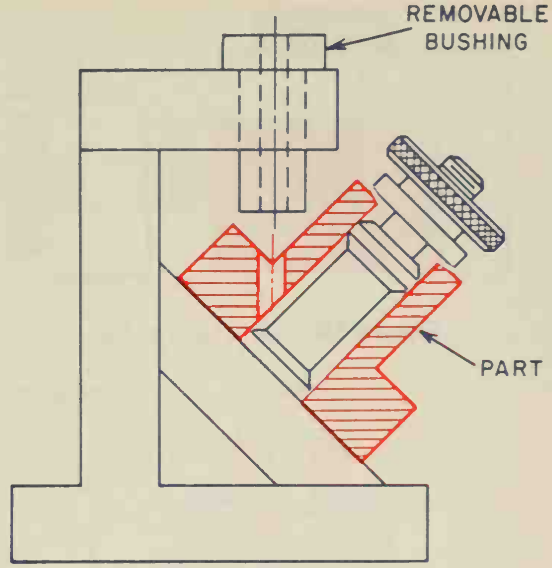


Figure 20-33 Angle plate jig

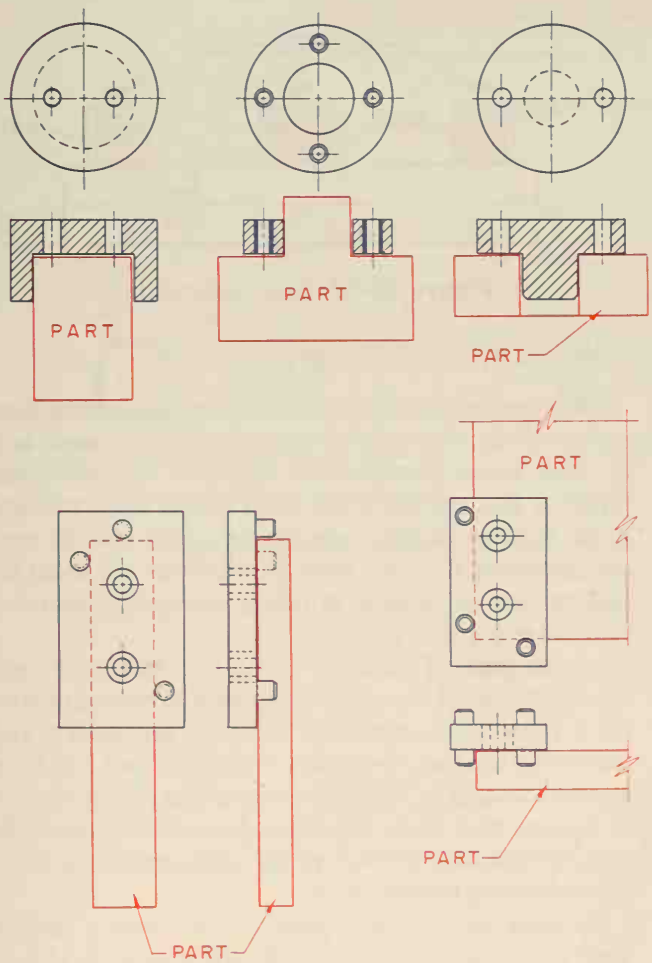


Figure 20-32 Template jigs

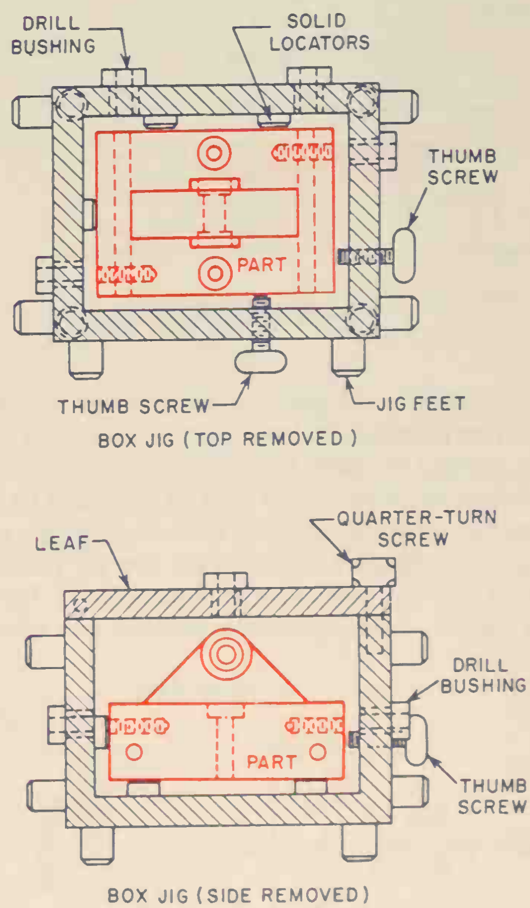


Figure 20-34 Box jig

A *box jig*, Figure 20-34, is designed to be used for parts that require machining on several sides. With these jigs, the part is mounted in the jig and clamped with a leaf or door. Other variations of the basic box jig include the *channel jig*, Figure 20-35A, and the *leaf jig*, Figure 20-35B. These jigs are similar in design to the box jig but they machine the part on only two or three sides, rather than all six sides.

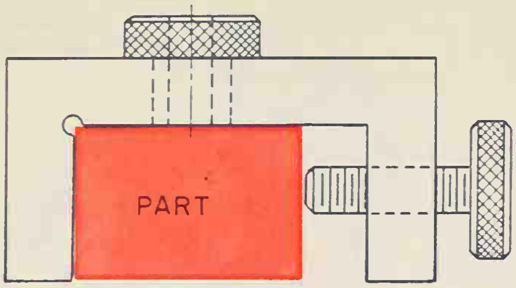


Figure 20-35A Channel jig

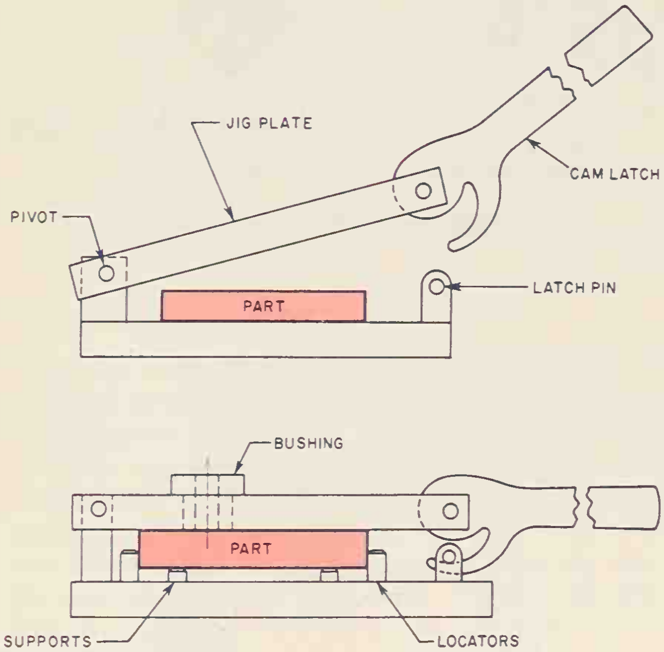


Figure 20-35B Leaf jig

An *indexing jig*, Figure 20-36, is used primarily to machine parts which have machined details at intervals around the part. Drilling four holes 90° apart is a typical example of the type of work this jig is best suited to perform. Another type of jig which uses an indexing arrangement to locate the jig, rather than the part, is the *multistation jig*, Figure 20-37. These jigs are used to machine several parts at one time.

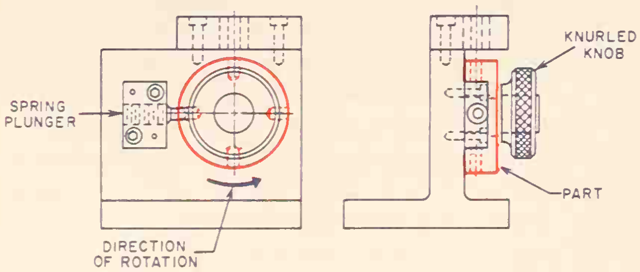


Figure 20-36 Indexing jig

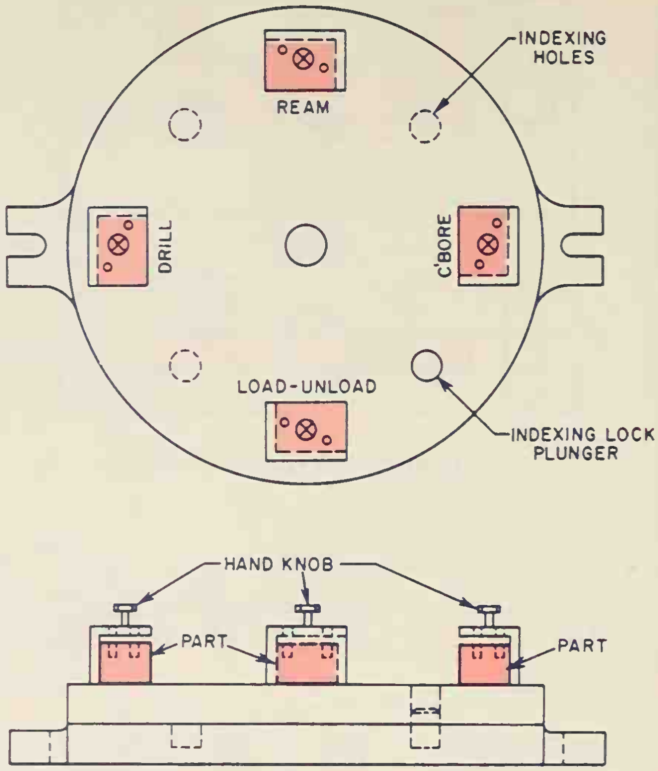


Figure 20-37 Multistation jig

Classification of Fixtures

Fixtures are classified by the type of machine they are used on, the type of operation performed, and by their basic construction features. The principal types of fixtures normally used in the shop include plate fixtures, angle plate fixtures, vise jaw fixtures, and indexing fixtures. Typically, fixtures are used for milling, turning, sawing, grinding, inspecting, and several other varied operations.

A *plate fixture*, Figure 20-38, is the most common type of fixture. Like plate jigs, plate fixtures are simply a plate containing the locators, set blocks, and clamping devices necessary to locate and hold the workpiece and to reference the cutter. While similar in design to a plate jig, plate fixtures are normally made much heavier than plate jigs to resist the additional cutting forces.

An *angle plate fixture*, Figure 20-39A, and a *modified angle plate fixture*, Figure 20-39B, are simple modifications of the basic plate fixture design. These fixtures are used when the reference surface is at an angle to the surface to be machined.

A *vise jaw fixture*, Figure 20-40, is a useful modification to the standard milling machine vise. With this type of fixture, the standard jaws of a milling machine vise are replaced with specially shaped jaws to suit the part to be machined. The result is an accurate fixture which can be made at a minimal cost. Since the clamping device is contained within the vise, this fixture is very cost effective. Likewise, one vise can

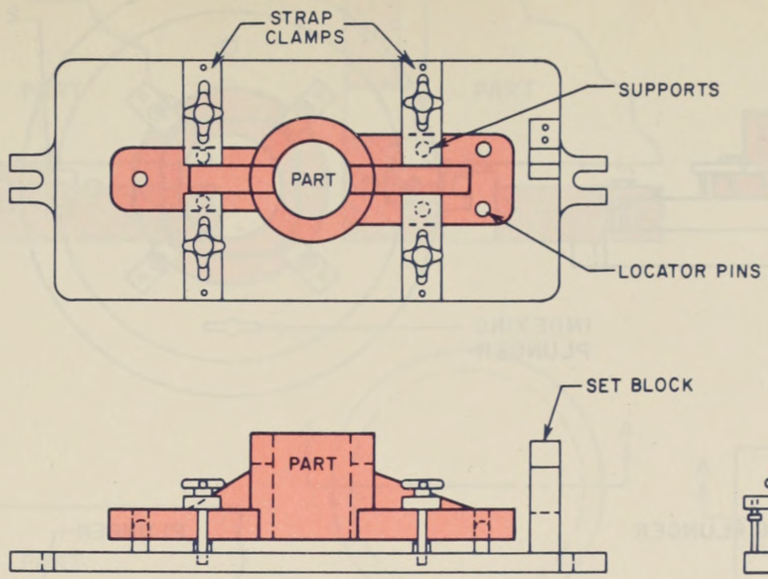


Figure 20-38 Plate fixture

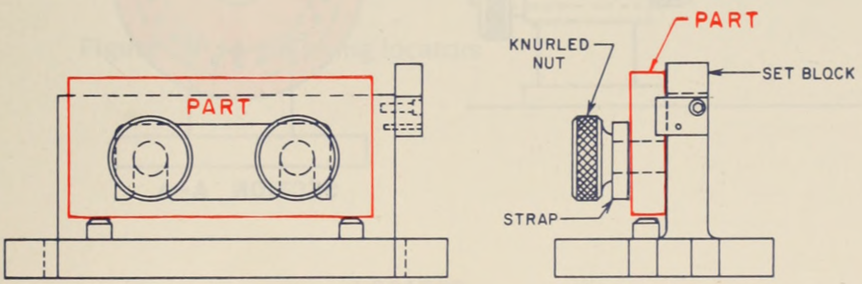


Figure 20-39A Angle plate fixture

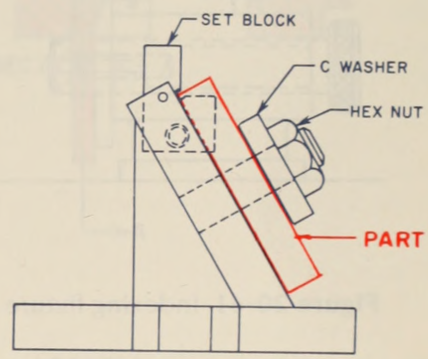


Figure 20-39B Modified angle plate fixture

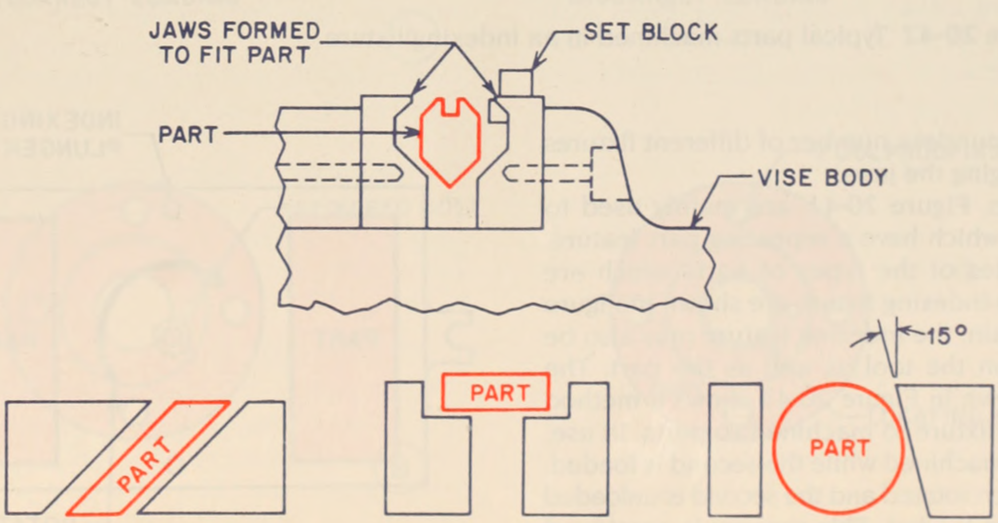
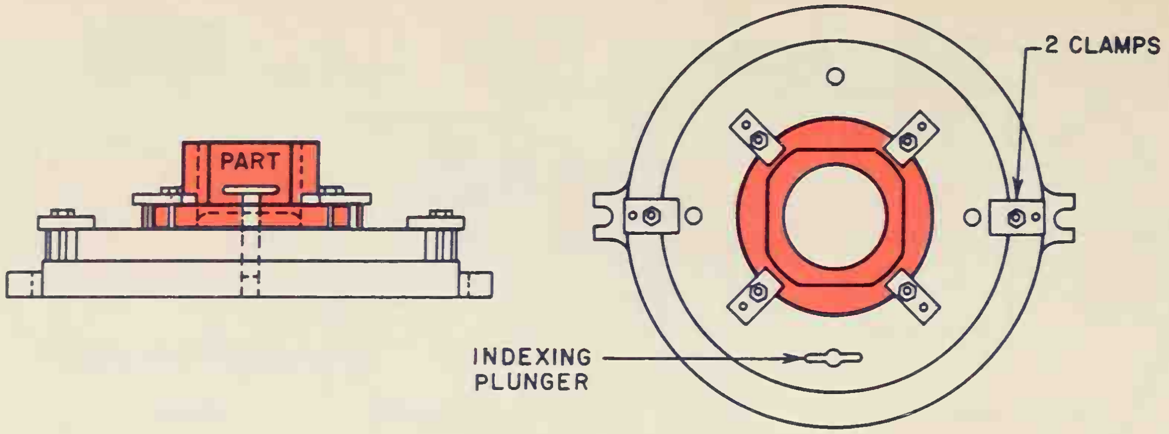


Figure 20-40 Vise jaw fixture



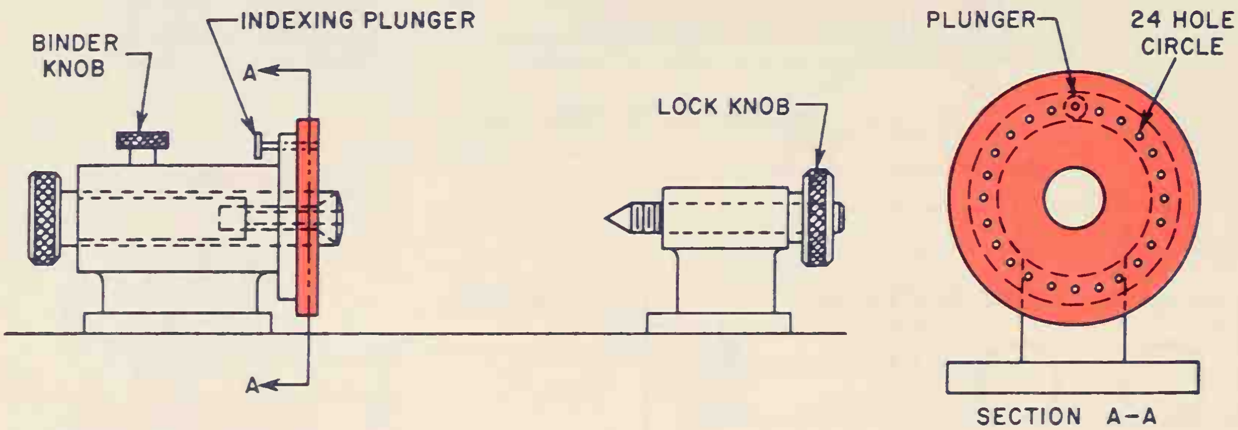


Figure 20-41 Indexing fixture

Figure 20-42 Typical parts machined in an indexing fixture

be used for a countless number of different fixtures by simply changing the jaws.

Indexing fixtures, Figure 20-41, are mainly used to machine parts which have a repeating part feature. Typical examples of the types of parts which are machined in an indexing fixture are shown in Figure 20-42. Here again, the indexing feature may also be used to position the tool as well as the part. The *duplex fixture* shown in Figure 20-43 shows a method of indexing the fixture to machine two parts. In use, the first part is machined while the second is loaded. The fixture is then rotated and the second is unloaded and a fresh part loaded. This process is continued throughout the production run.

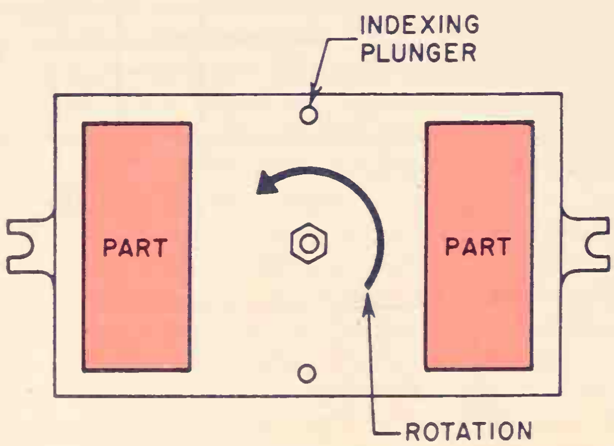


Figure 20-43 Duplex fixture

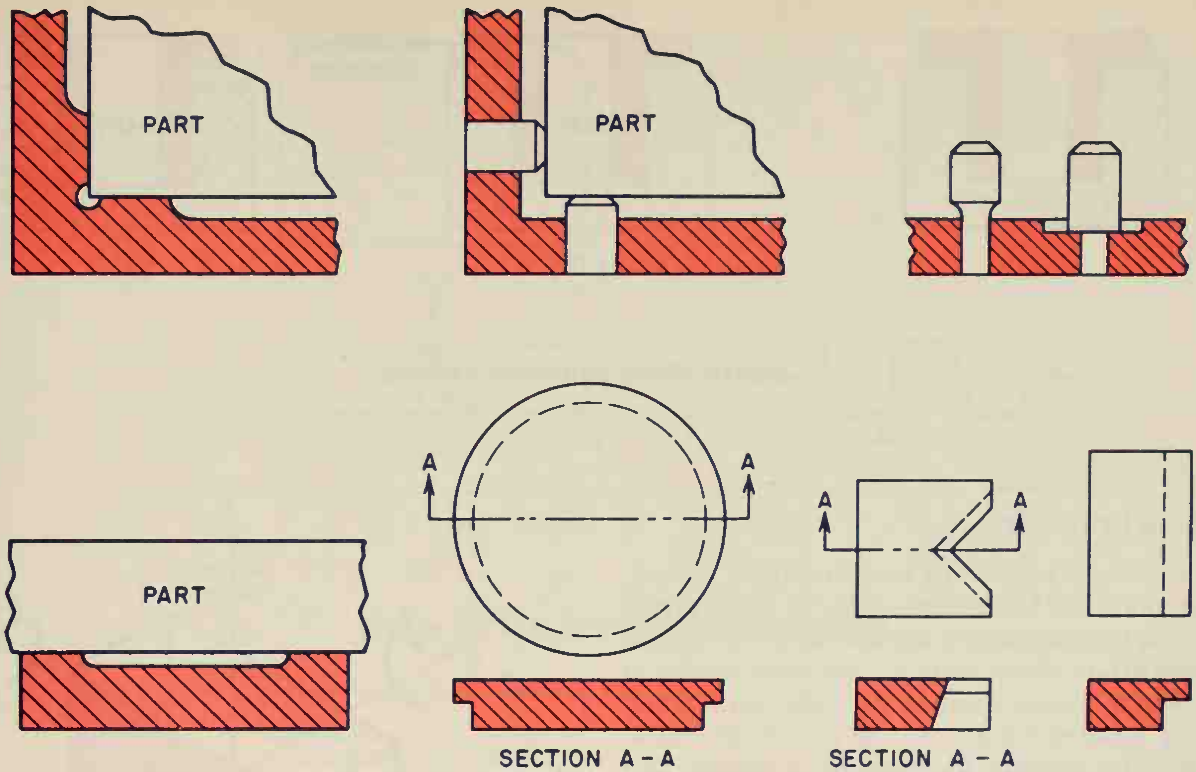


Figure 20-44 Relieving locators

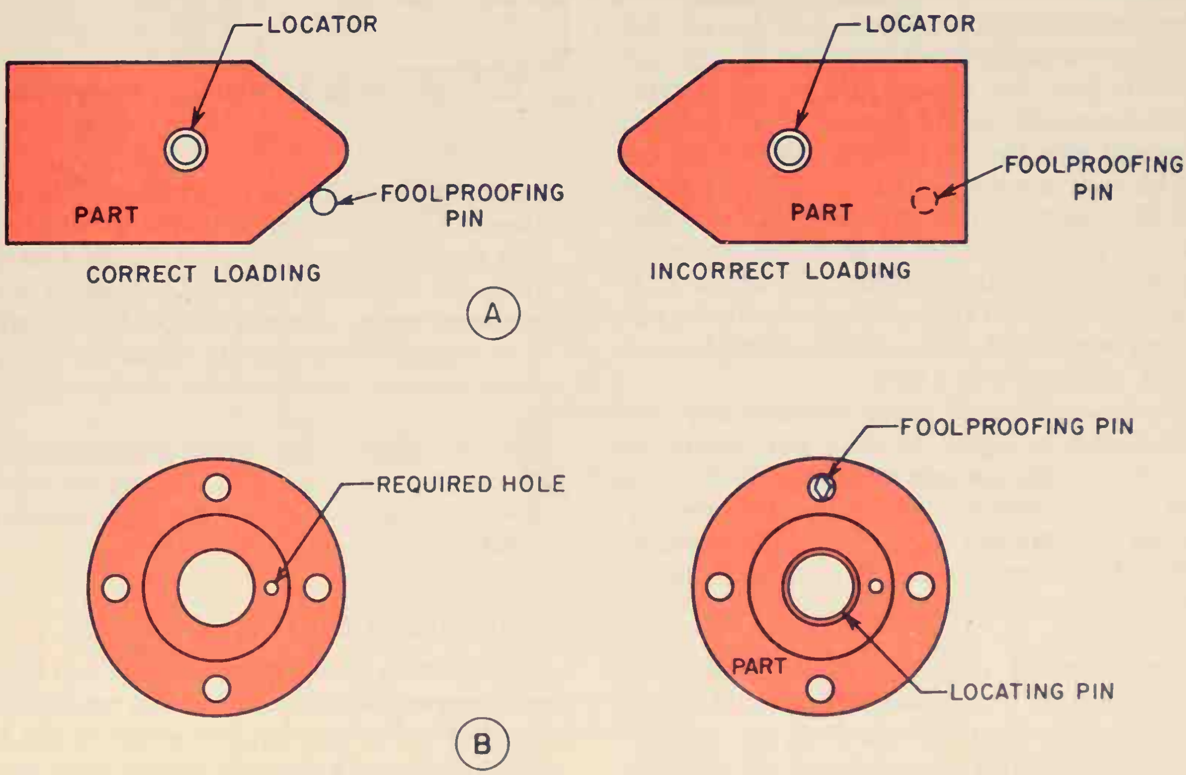


Figure 20-45 Foolproofing a workholder

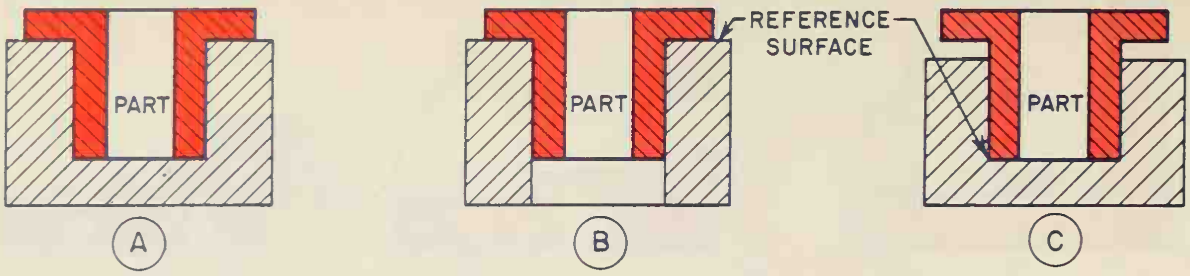


Figure 20-46 Duplicate locating

Locating Principles

To properly machine any part in a jig or fixture, the part must first be located correctly. The first rule of locating is repeatability. *Repeatability* is the feature of a jig or fixture which permits parts to be loaded in the tool in the same position part after part. When selecting locators for a part, the prime considerations must be position, foolproofing, tolerance, and elimination of duplicate or redundant locators.

Locators must be *positioned* as far apart as practical, and should contact the workpiece on a reliable surface to ensure repeatability. The locators must also be designed to minimize the effect of chips or dirt. Figure 20-44 shows a few methods generally used to relieve locators to prevent interference from chips.

Foolproofing is simply a method used to prevent the part from being loaded incorrectly. A simple pin, Figure 20-45, is normally enough to ensure proper loading of every part. The *tolerance* of a locator is determined by the specific size of the part to be machined. As a general rule, the tolerance of jigs and fixtures should be approximately 30% to 50% of the part tolerance. For example, if a hole were to be located within .010'' (0.25 mm) from an edge, the locators in the jig or fixture should be positioned within .003'' to .005'' (0.08 mm to 0.13 mm) to make sure the part is properly positioned. An overly tight tolerance only adds cost, not quality, to a tool.

Finally, locators should never duplicate any location. As shown in Figure 20-46, a part should be located on only one surface. Locating a part on two parallel surfaces only serves to reduce the effectiveness of the location, and could improperly locate the part. First determine the reference surface, and use only that surface for locating.

Restricting Movement. Every part is free to move in a limitless number of directions if left unrestricted. But, for the purpose of jig and fixture design, the number of directions in which a part can move has been limited to twelve: six axial and six radial, Figure 20-47. The methods used to restrict these twelve movements normally depend on the part itself, but the examples in Figures 20-48A and 20-48B show two methods that are frequently used. In the first example, three-pin base restricts five directions of movement. In the second example, a five-pin base restricts eight directions of movement. In Figure 20-48C, a six-pin base restricts nine directions of movement.

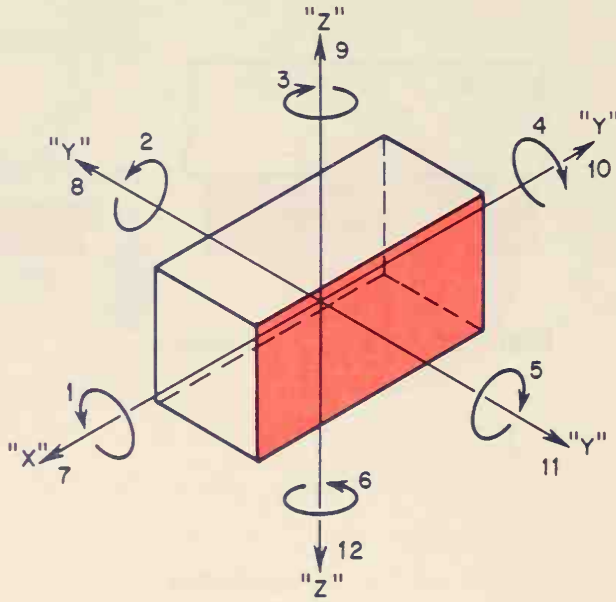


Figure 20-47 Planes of movement

Types of Locators. Locators are commercially available in many styles and types. Figures 20-49A through 20-49F show several of the most common types of locators.

Clamping Principles

In addition to locators, most jigs and fixtures use some type of clamping device to restrict the directions of movement not contained by the locators. When designing a clamping arrangement, several factors should be considered. These include position of the clamps, clamping forces, and tool forces.

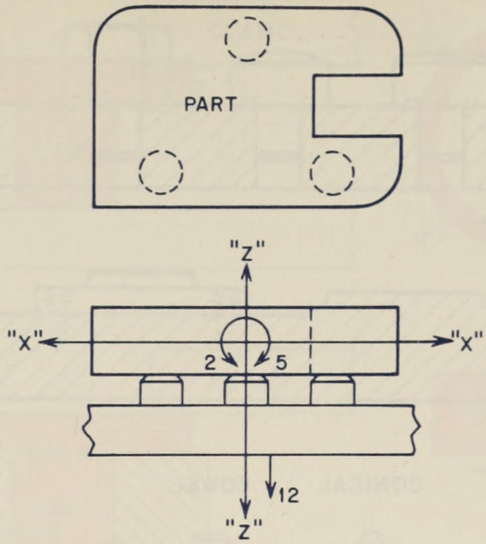


Figure 20-48A Restricting part movement

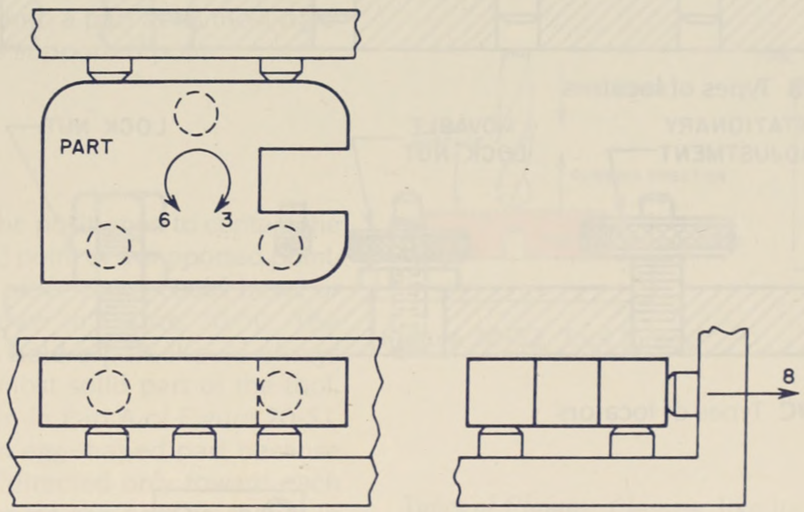


Figure 20-48B Restricting part movement

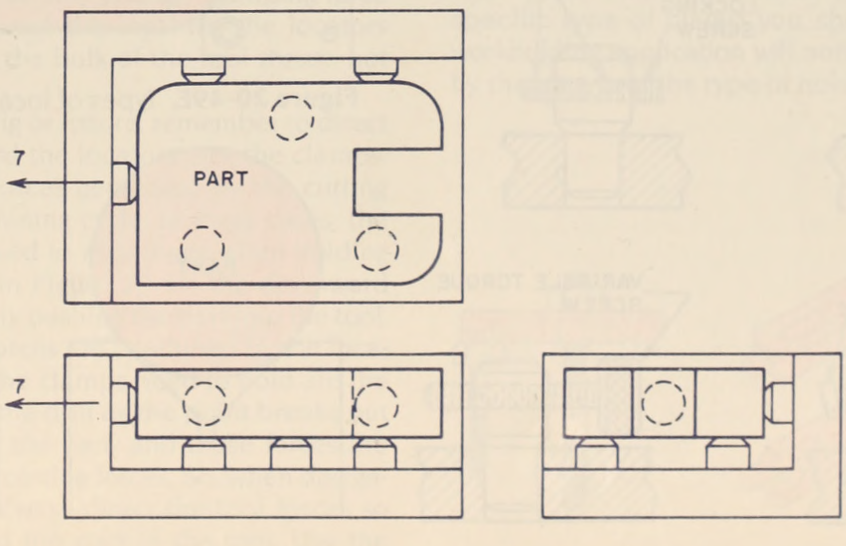


Figure 20-48C Restricting part movement

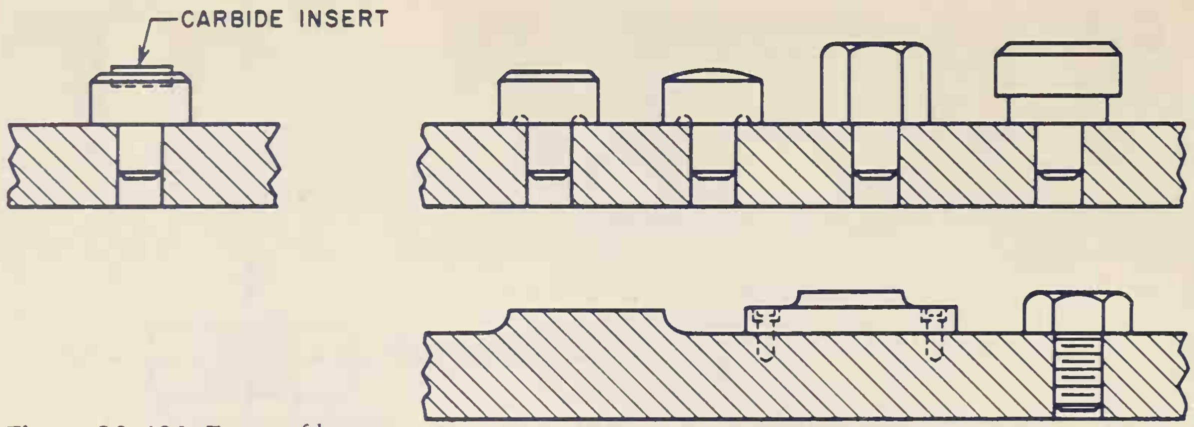


Figure 20-49A Types of locators

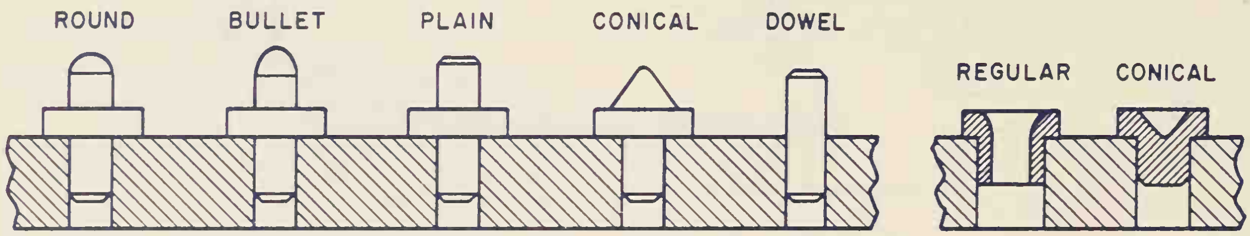


Figure 20-49B Types of locators

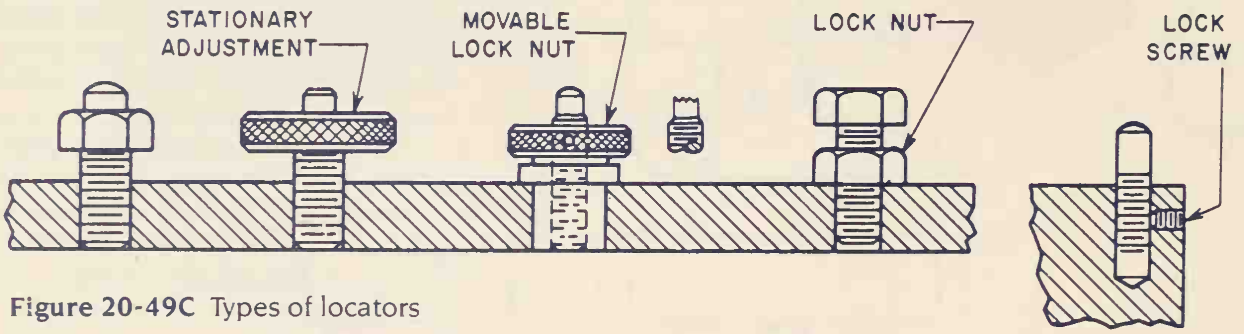


Figure 20-49C Types of locators

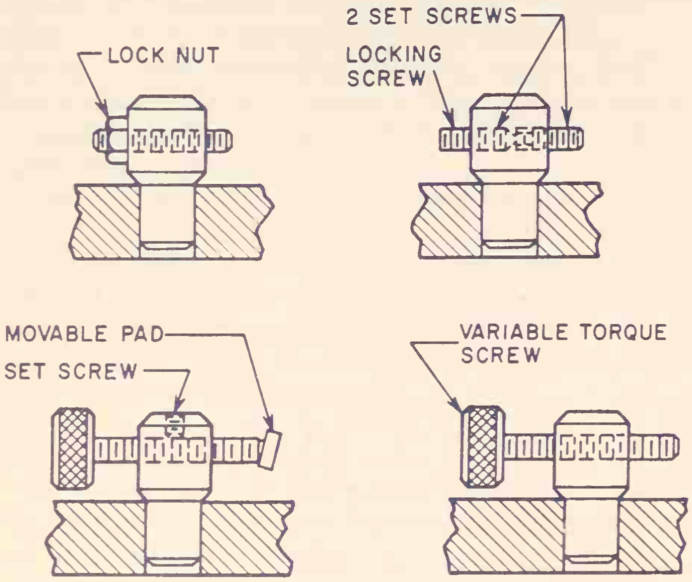


Figure 20-49D Types of locators

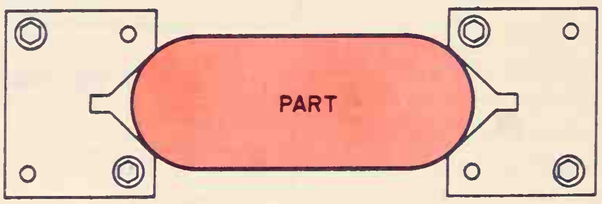


Figure 20-49E Types of locators

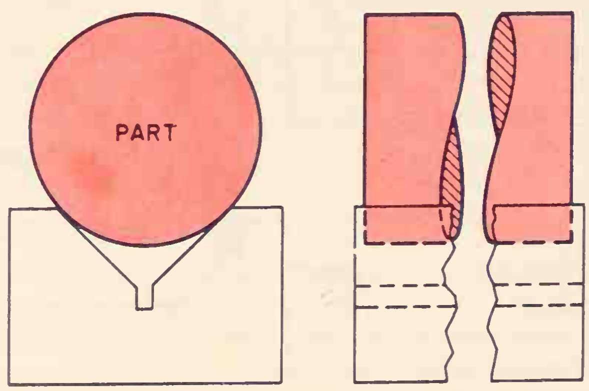


Figure 20-49F Types of locators

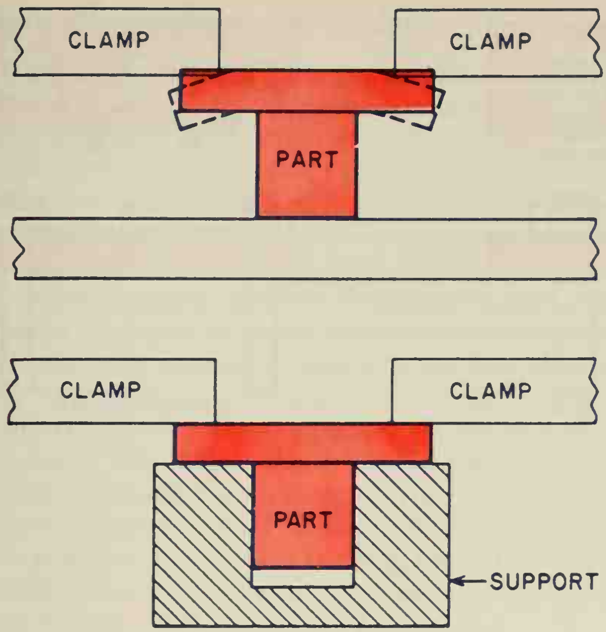


Figure 20-50 Always clamp a part at its most rigid point or a supported point

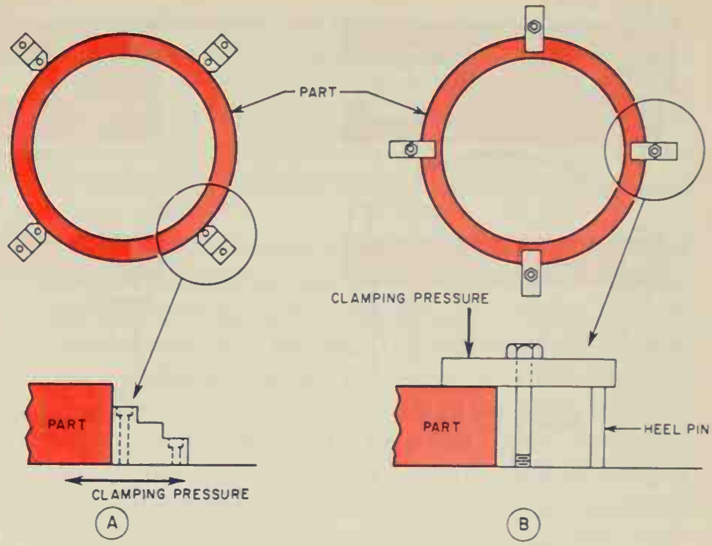


Figure 20-51 Clamping forces

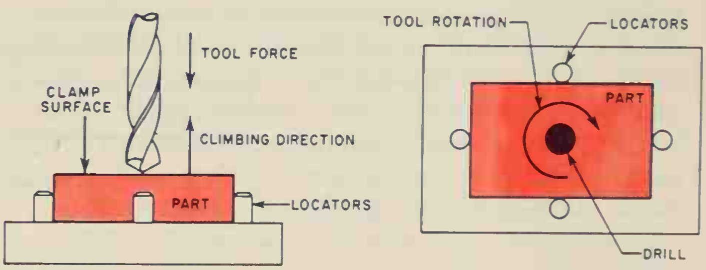


Figure 20-52 Tool forces

Clamps should always be positioned to contact the part at either its most rigid point or a supported point. Clamping a part at any other point could bend or distort the part, as shown in Figure 20-50. The clamping forces used to hold a part should always be directed toward the most solid part of the tool. Clamping a part as shown in Part A of Figure 20-51, will normally result in an egg-shaped part because the clamping forces are directed only toward each other. However, by clamping the part as shown in Part B of Figure 20-51, the part is not only held securely, but the chance of distortion is greatly reduced. As a rule, use only enough clamping force to hold the part against the locators. the locators should always resist the bulk of the tool thrust, not the clamps.

When designing a jig or fixture, remember to direct the tool forces toward the locators, not the clamps. *Tool forces* are those forces generated by the cutting tool during the machining cycle. In most cases, the tool forces can be used to advantage when holding any part. As shown in Figure 20-52, the downward tool forces are actually pushing the part into the tool. The rotational tool forces are contained by the locators. The only force the clamps need to hold are the forces generated by the drill as the point breaks out the opposite side of the part, and these forces are only a fraction of the cutting forces. So, when designing a jig or fixture, always direct the tool forces so that they act to hold the part in the tool. Use the clamps only to hold the part against the locators.

Types of Clamps. Clamps, like locators, are commercially available in many styles and types. Figures 20-53A through 20-53D show some of the more common types of clamps used for jigs and fixtures. The specific type of clamp you should select for any workholding application will normally be determined by the part, and the type of holding force desired.

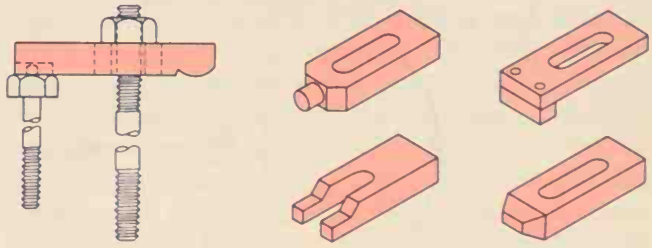


Figure 20-53A Types of clamps

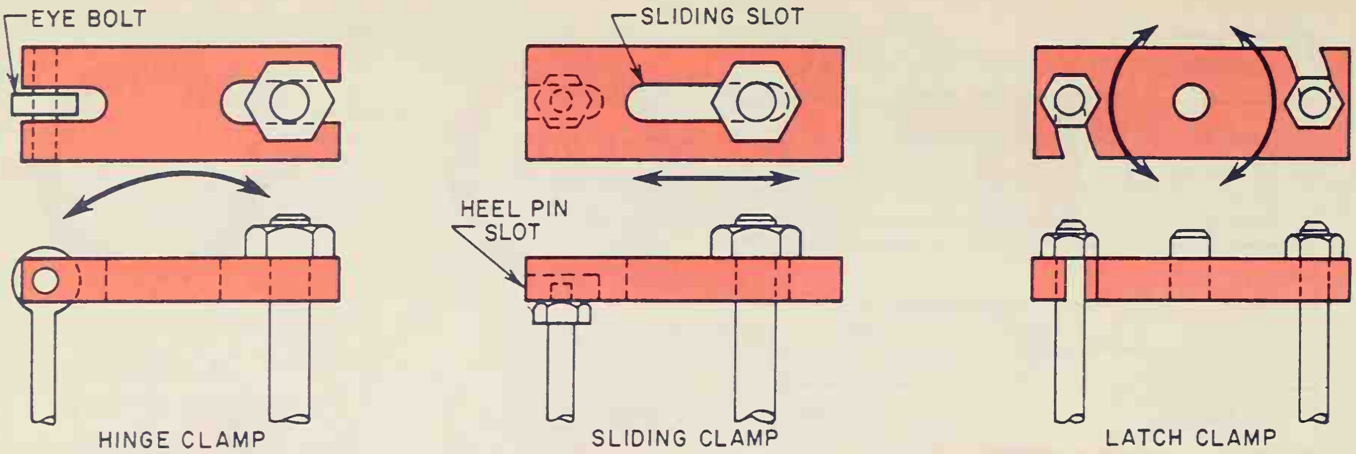


Figure 20-53B Types of clamps

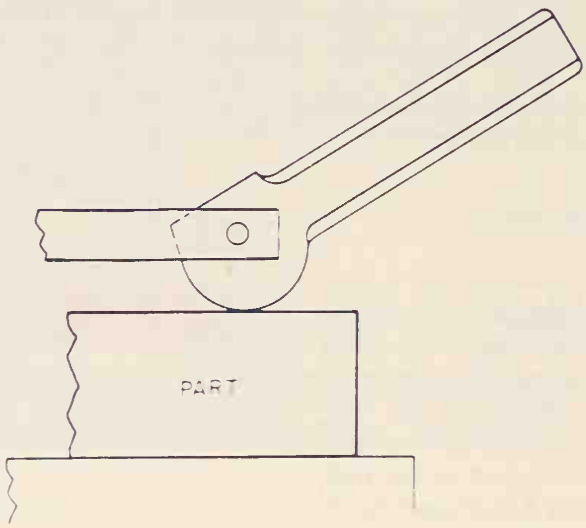


Figure 20-53C Types of clamps

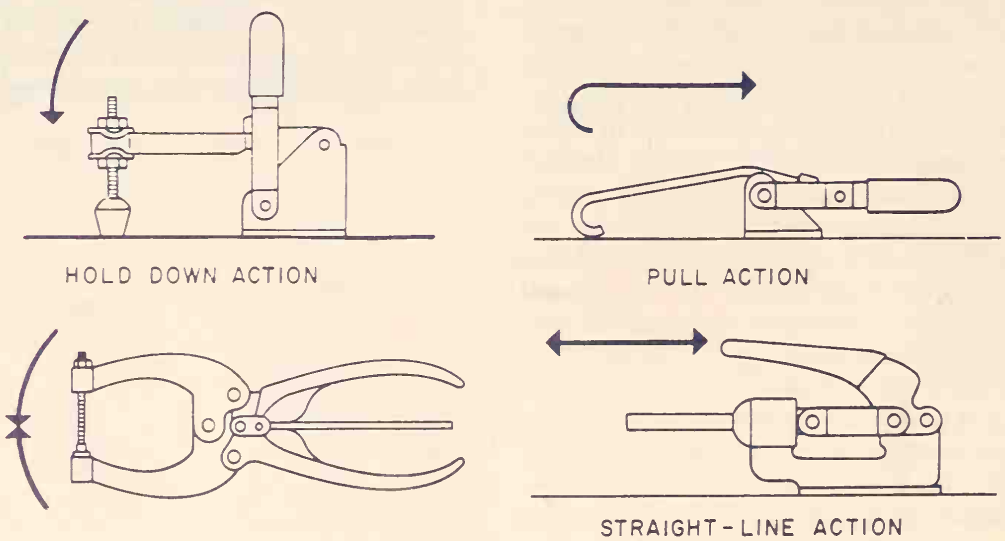


Figure 20-53D Types of clamps

Basic Construction Principles

When designing any jig or fixture, the first consideration is normally the tool body. Tool bodies are generally made in any of three ways: cast, welded or built-up, Figure 20-54. *Cast tool* bodies are generally the most expensive, and require the longest lead time to make. They do, however, offer such advantages as good material distribution, good stability, and good vibration-damping qualities. *Welded tool* bodies offer a faster lead time, but must be machined frequently to remove any distortion caused by the heat of welding. The most popular and common type of tool body in use today is the built-up. *Built-up* tool bodies are made from pieces of preformed stock, such as precision-ground flat stock, ground rod or plain cold-rolled sections which are pinned and bolted together. The principle advantages of using this type of construction are fast lead time, minimal machining, and easy modification.

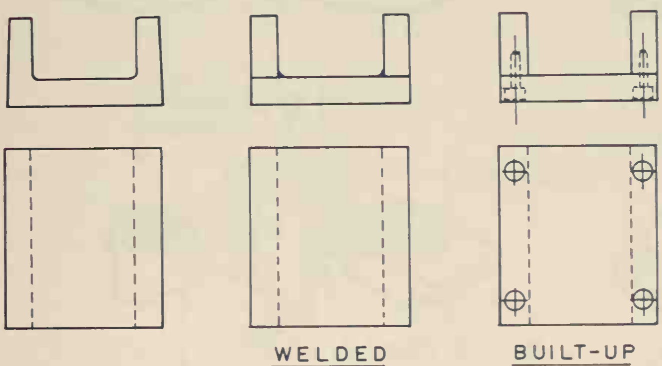


Figure 20-54 Tool bodies

Drill Bushings. *Drill bushings* are used to position and guide the cutting tools used in jigs. The three basic types of drill bushing used for jigs are press fit bushings, renewable bushings, and liner bushings.

Press-fit bushings, Figure 20-55, as their name implies, are pressed directly into the jig plate. These bushings are useful for short-run jigs or in applications where the bushings are not likely to be replaced frequently. The two principle types of press fit bushings are the head type and headless type.

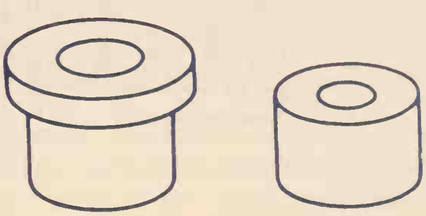


Figure 20-55 Press-fit drill bushings

Renewable bushings are used in high-volume applications or where the bushings must be changed to suit different cutting tools used in the same hole. The two types of renewable bushings that are commercially available are the slip-renewable type, Figure 20-56, Part A, and the fixed-renewable type, Figure 20-56, Part B.

Slip-renewable bushings, Figure 20-56, Part C, are used where the bushing must be changed quickly. Typical applications include holes which must be drilled, countersunk, and tapped. The bushings are held in place with a lock screw and need only to be turned counterclockwise and lifted out of the hole. The next bushing is inserted in the hole and turned clockwise to lock it in place.

Fixed-renewable bushings are used for applications where the bushings do not need to be changed often, but when they are changed more often than press fit bushings. High-volume production is a typical example where fixed renewable bushings are often used.

Liner bushings, Figure 20-56, Part D, are used in conjunction with renewable bushings and provide a hardened, wear-resistant mount for renewable bushings. Liner bushings are actually press-fit bushings with a large-diameter hole. Like press-fit bushings, liner bushings are available in both a head type and a headless style. The clamps normally used to hold the fixed-renewable bushing in the jig plate are shown in Figure 20-56, Part E. The screw is used to mount slip-renewable bushings, whereas the other three styles are used to secure the fixed-renewable bushings.

Several other variations of these basic bushing styles include special purpose bushings, serrated and knurled bushings, and oil-groove bushings. Oil-groove bushings are shown in Figure 20-57.

Mounting Drill Bushings. When installing a drill bushing in the jig plate, the specific size of the jig plate and spacing from the part are important factors the designer must consider. As shown in Figure 20-58A, the jig plate should be between one to two times the tool diameter. If a thinner jig plate must be used, a head-type bushing can be used to achieve the added thickness needed to support the cutting tool. The space between the jig plate and the workpiece should be one to one and one half the tool diameter for drilling, Figure 20-58B, and one quarter to one half the tool diameter for reaming, Figure 20-58C.

In those cases where both drilling and reaming operations are to be performed in the same hole, an arrangement similar to the one shown in Figure 20-58D may be used. Here the jig plate is properly positioned for drilling, and the bushing used for reaming is made longer to achieve the desired distance for reaming. When special shapes or contours must be drilled, the ends of the bushings can be modified to suit the contour and maintain the proper support for the cutting tool, Figures 20-58E and 20-58F.

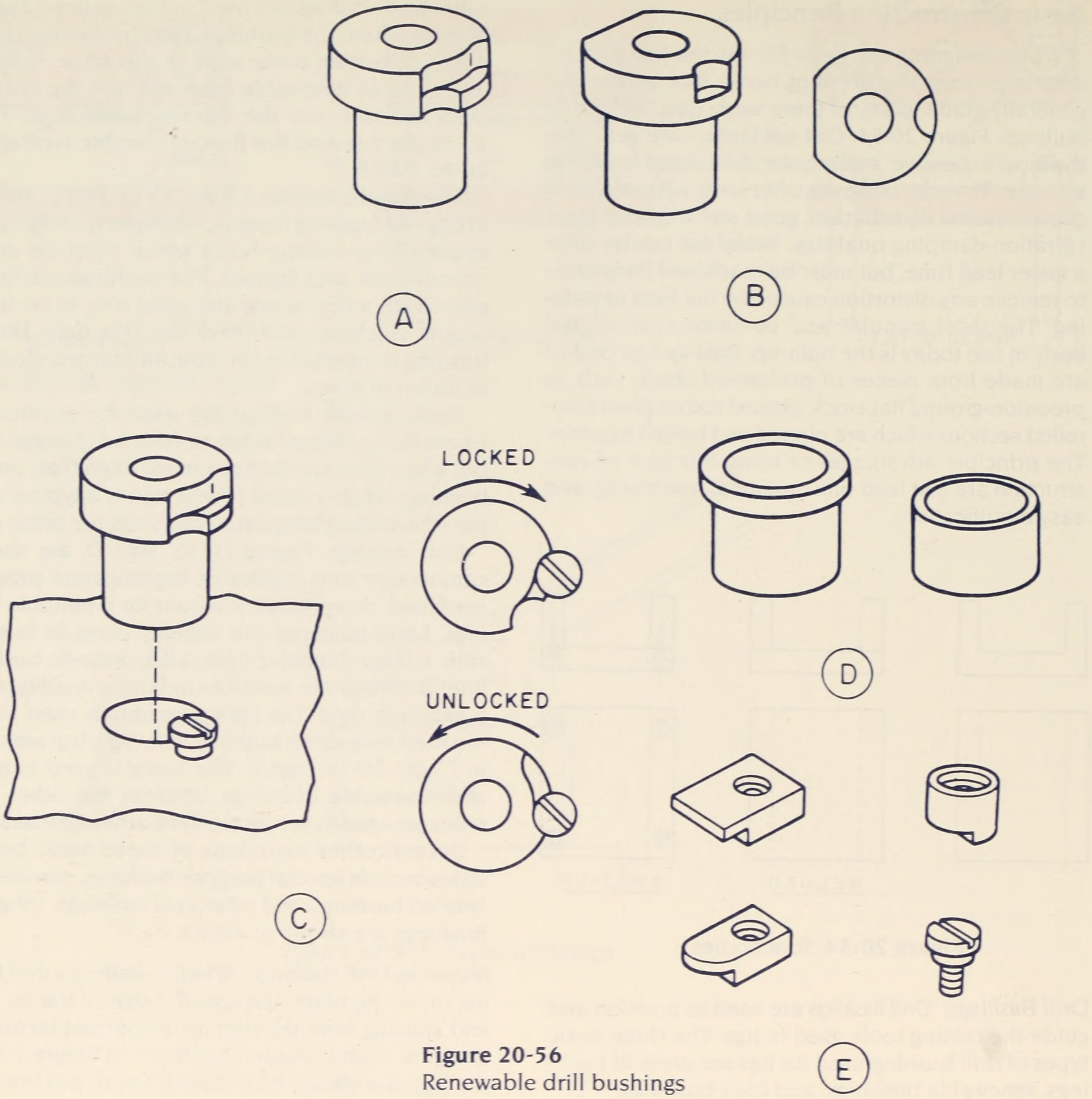


Figure 20-56
Renewable drill bushings

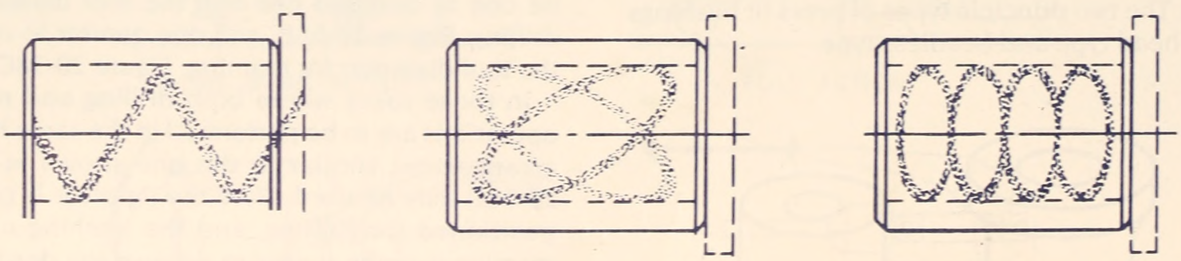


Figure 20-57 Oil-groove bushings

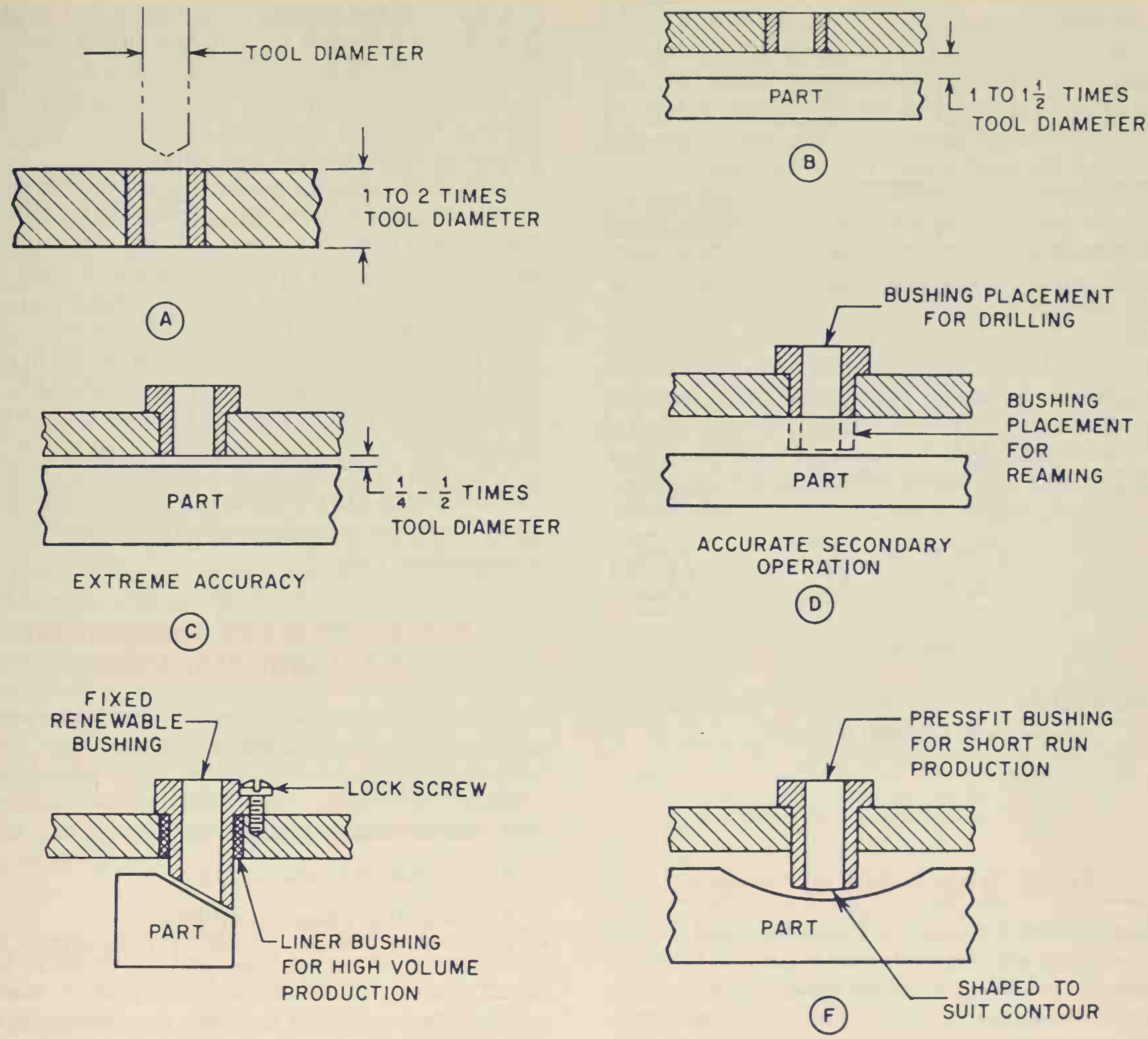


Figure 20-58 Mounting drill bushings

Set Blocks. Set blocks are used along with thickness gages to properly position the cutting tool with a fixture. The specific design of the set block is determined by the part and shape to be machined. The basic set block designs shown in Figure 20-59 are typical of the styles found on many fixtures.

Fastening Devices. The most common fastening devices used with jigs and fixtures are dowel pins and socket-head cap screws. Other fasteners sometimes used with these tools include the nuts and washers shown in Figure 20-60.

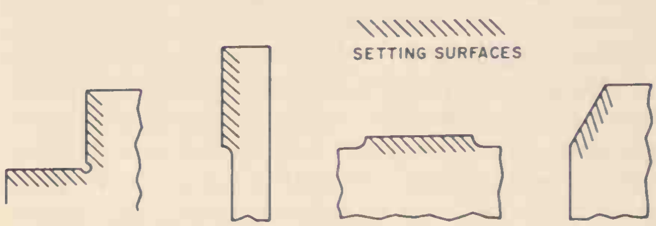


Figure 20-59 Set blocks

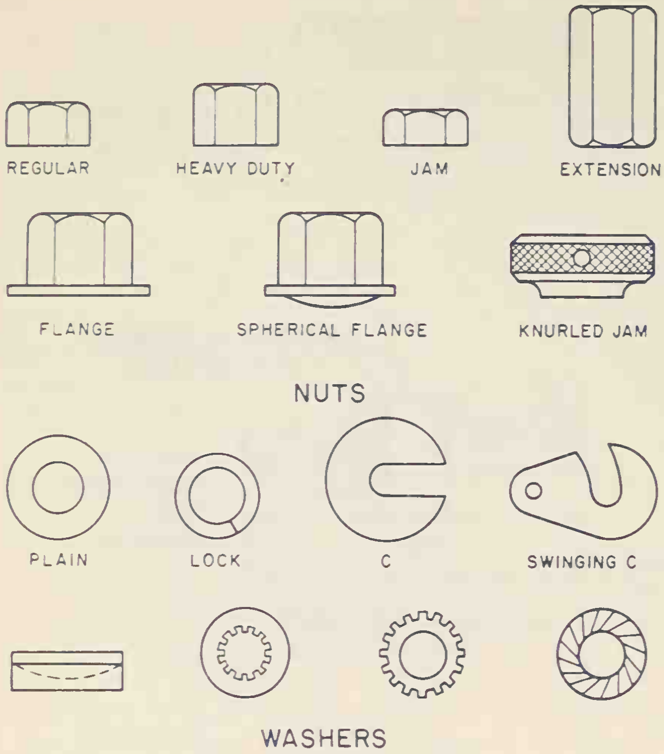


Figure 20-60 Nuts and washers frequently used with jigs and fixtures

Heat Treatment of Steels

Heat treatment is a series of processes used to alter or modify the existing properties in a metal to obtain a specific condition required for a workpiece. The specific properties normally changed by heat treatment include hardness, toughness, brittleness, malleability, ductility, wear resistance, tensile strength, and yield strength. The five standard heat treating operations normally performed on steel parts are hardening, tempering, annealing, normalizing, and case hardening.

Hardening is the process of heating a metal to a predetermined temperature, allowing the part to soak until throughly heated, and cooling rapidly in a cooling material called a *quench*. The most common quench media are air, oil, water, and a water and salt mixture called brine. Hardening is mainly used to increase the hardness, wear resistance, toughness, tensile strength, and yield strength of a workpiece.

Tempering is the process of heating a hardened workpiece to a temperature below the hardening temperature, allowing the part to soak for a specific time period, and cooling. Tempering is mainly used to reduce the hardness so the toughness is increased and brittleness is decreased. Almost every hardened part is tempered to control the amount of hardness in the finished part.

Annealing is the process of heating a part, soaking it until it is throughly heated, and slowly cooling it by turning off the furnace. Annealing is mainly used to completely remove all hardness in a metal. Frequently, hardened parts are annealed to be remachined or modified and then rehardened.

Normalizing is the process used to remove the effects of machining or cold-working metals. In this process, the metal is heated, allowed to soak, and cooled in still air. This process produces a uniform grain size, and eliminates almost all stresses in the metal.

Case hardening is the process of hardening the outside surface of a part to a reselected depth. In most case-hardening operations, carbon is added to the surface of the part by packing the part in a carbonous material, and then heating it so that the carbon is transferred into the surface of the part. Once the carbon is added to the surface of the part, the part is then hardened to produce a hardened shell around a normalized core.

Automation and Integration (CAM and CIM/FMS)

There have been four phases in the development of shop and manufacturing processes:

1. Manual phase
2. Mechanization phase
3. Automation phase (CAM)
4. Integration phase (CIM/FMS)

Of course, there has been and continues to be a good deal of overlap among these phases. Manual manufacturing did not suddenly stop when the age of mechanization began, nor did mechanized manufacturing stop when the automation phase began. Correspondingly, the beginning of the integration phase did not bring automated manufacturing to a sudden stop.

It takes many years for a given stage in the development of shop and manufacturing processes to phase out completely. For example, by the year 1900, mechanized manufacturing had replaced manual manufacturing as the dominant approach. However, manual manufacturing was still widely practiced at that time. By the year 2000, automated manufacturing will be the dominant approach; nevertheless, mechanized manufacturing will still be widely practiced, and even manual manufacturing will still be practiced in very isolated cases.

At present, we are seeing the introduction of the integration phase, which will eventually dominate but not completely replace—at least not for a long time—the other three approaches.

The manual phase preceded the Industrial Revolution. During these early times, manufactured products were produced by hand, using a variety of manual tools. The Industrial Revolution ushered in the mechanization phase. The fundamental component of this phase was the machine. Early machines were steam powered, while later machines, of course, were dependent on electricity. In this phase, machines such as mills, drills, saws, and lathes did the work, but people provided the control.

The automation phase has changed the way machines are controlled. It has also lessened the amount of human involvement in manufacturing. With the automation approach, manufacturing machines are controlled by computer. This has come to be known as CAM or computer-aided manufacturing. CAM machines are operated automatically according to computer programs. People still write the programs, set up the machines, monitor operations, and unload machines.

With CAM, individual operations such as milling, drilling, turning, and cutting are automated, but they still operate independently of each other. The most advanced manufacturing approach to date—computer-integrated manufacturing or CIM—solves this problem by linking automated manufacturing processes with other processes such as materials handling, warehousing, contracts and bids, scheduling, and design. CIM represents a major step toward the wholly automated factory. These two concepts—CAM and its eventual successor CIM—deserve special attention.

Computer-Aided Manufacturing (CAM)

Through CAM, such manufacturing processes as machining and materials handling can be automated. CAM encompasses any manufacturing process that is automated through the use of the computer, but the best-known examples of CAM are computer numerical control (CNC) of machine tools and robotics.

Computer Numerical Control (CNC)

Numerical control is a method of controlling machine tools by using coded programs. These programs consist of numbers, letters, and special characters that define the path of the machine tool in accomplishing specific tasks. When the job changes, the program must be rewritten to accommodate the change. The programmability feature is the key to the growth of NC. Machine tools that are programmable are more flexible than their nonprogrammable counterparts.

NC is a broad term that encompasses the traditional approach to NC as well as the more modern outgrowths of computer numerical control (CNC) and direct numerical control (DNC).

The first NC machines used punched cards as the programming medium. Later, punched tape was substituted, which was an improvement over manual control but did have some disadvantages. Paper tape was easy to damage and difficult to correct or edit.

Mylar tape, as a less fragile medium, began to replace paper tape. This solved the problem of frequent damage but did not make punched tape any easier to edit. Such problems, coupled with advances in microelectronic technology, led to the use of computers as the means for programming machine tools. Computers solved the damage and editing problems, and this gave birth to both CNC and DNC. CNC involves using a computer in writing, storing, and editing NC programs. DNC involves using a computer as the controller for one or more NC machines, Figure 20-61. A more advanced form of DNC is called "distributive numerical control," Figure 20-62.

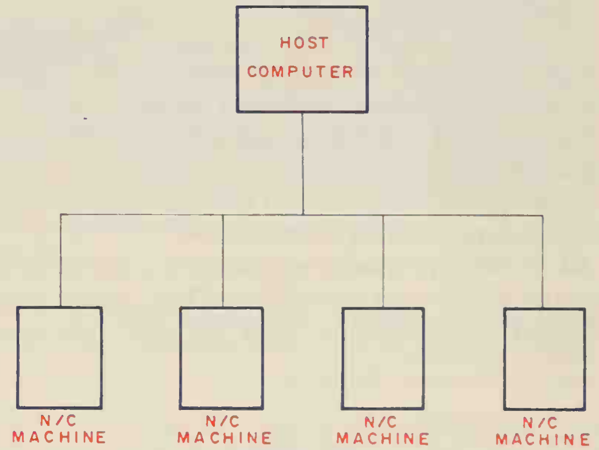


Figure 20-61 Direct numerical control (*Adapted from Computer Numerical Control, by Warren S. Seames. Copyright 1986 by Delmar Publishers Inc.*)

In this concept there is a host coupler and several intermediate computers which are tied to NC machines, robots, and other NC manufacturing devices. The main host computer is the central repository for all programs for all jobs. Specific programs for specific jobs are "dumped" from the host computer to the intermediate computers. This cuts down on the amount of time required to get the programmed instructions from the computer to the machine tool. CNC machines are available for most machining processes, including cleaning and finishing, inspection and quality control, pressing and forming, and material removal.

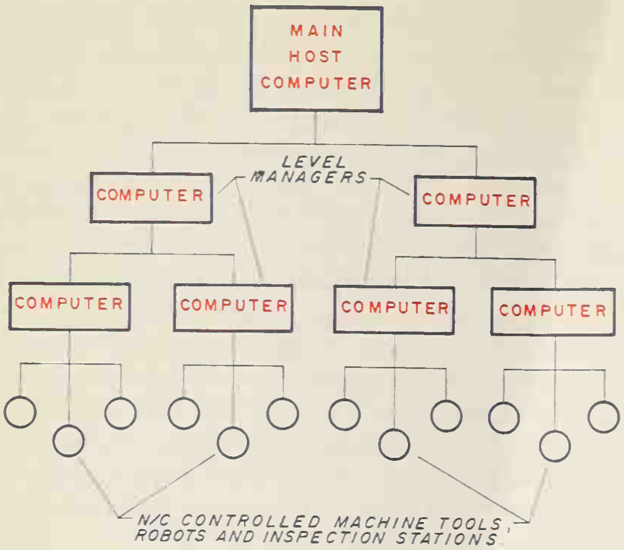


Figure 20-62 Distributive numerical control (*Adapted from Computer Numerical Control, by Warren S. Seames. Copyright 1986 by Delmar Publishers Inc.*)

Figure 20-63 is a Bridgeport Series II CNC Interact 520 bed-type vertical machining center.

Figure 20-64 is a Bridgeport Interact I CNC milling machine.

Figure 20-65 is a Cincinnati Milacron 2EF Cinternal multi-surface grinding machine.

All of the CNC machines shown in Figures 20-63 through 20-65 have controllers. There are as many different controllers as there are CNC machines.

Figure 20-63 Series II CNC INTERACT (*Courtesy of Bridgeport Machines, Division of Textron, Inc.*)

Figure 20-64 INTERACT I CNC milling machine (*Courtesy of Bridgeport Machines, Division of Textron, Inc.*)

Regardless of the type of controller, there must be some means of storing and inputting programs which instruct the machines. These means are called input media.

The most frequently used types of input media are punched tape and magnetic tape. Punched tape may be either the paper or mylar (plastic) variety. Mylar is more widely used because it is less prone to damage.

With earlier CNC machines a tape punch was used to put holes in a tape that was fed through it. The holes represented the program code. The punched tape was run through a tape reader that sensed the holes and fed the code into the controller. A problem with this type of input media is that it is easy to make an error when punching the tape and difficult to correct it.

An improvement to this early, cumbersome method of input is to interface a tape punch directly with a microcomputer. The code is typed via the microcomputer's keyboard. As the code is entered, it is stored so that it can be checked for accuracy and edited. Once correct, it is fed to the tape punch, and the tape is prepared. This solves the error correction problem.

Magnetic tape is now more popular than punched tape. With this type of medium the program code

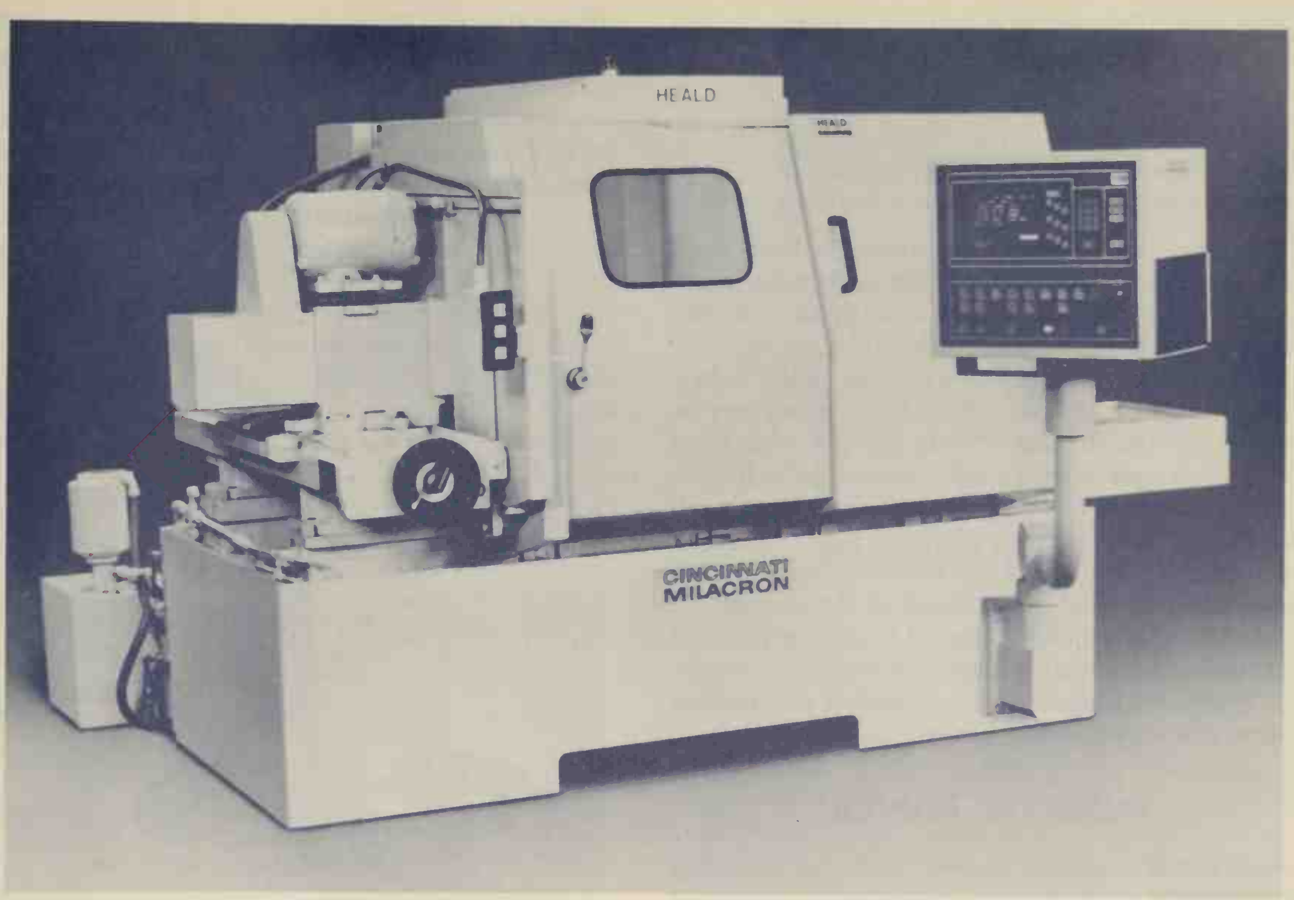


Figure 20-65 CINTERNAL grinding machine (*Courtesy of* Cincinnati Milacron, Inc.)

is affixed to the tape as magnetic spots rather than as holes punched through it. Because this type of medium is becoming so popular, standards for format and coding have been developed by the Electronics Industries Association.

CNC is the most modern and most technologically advanced method of controlling manufacturing machines. However, it is not the best control method in every case. Like any technological development, CNC has its advantages and disadvantages. There are times when the traditional manual approach is better. CNC is indicated when one or both of the following factors is important:

- Increased productivity
- Decreased labor and production costs

When CNC is indicated, there are advantages and disadvantages with which students of CAD/CAM should be familiar. The advantages include:

1. Better production and quality control
2. Increased productivity, flexibility, accuracy, and uniformity
3. Reduced labor, production, tool, and fixture costs
4. Less parts handling and tool storage

There are other advantages of CNC; however, these are the most important. There are also disadvantages associated with CNC. Those most frequently stated are:

1. High "up-front" costs
2. Higher operating costs
3. Retraining costs
4. Potential personnel problems

The advantages of CNC outweigh the disadvantages. But the list of disadvantages does make the point that it is not always the appropriate choice.

CNC Applications

CNC applications can be viewed at two levels. First, there is the industry level. At this level, all of the various manufacturing industries use CNC machines. These include:

- Aerospace manufacturers
- Electronics manufacturers
- Automobile, truck, and bus manufacturers
- Appliance manufacturers
- Tooling manufacturers
- Locomotive/train manufacturers

The second application level to consider is the machine level. At this level, CNC applications include:

- Cleaning and finishing applications
- Material removal applications
- Presswork and forming applications
- Inspection/quality control applications

Cleaning and finishing machines perform such tasks as washing, degreasing, blasting, lapping, grinding, and deburring. There are currently several CNC cleaning and finishing machines on the market.

Material removal machines include mills, lathes, grinders, drills, and saws. All such machines may be CNC controlled. In fact, this is the machine level application area most strongly associated with CNC.

Presswork and forming machines perform such tasks as pressing, stamping, blanking, punching, bending, and swagging. There are currently several CNC presswork and forming machines on the market.

Inspection and quality control machines perform such tasks as measuring, gaging, testing, and weighing. There are several CNC inspection and quality control machines on the market.

Industrial Robots

As is sometimes the case with new and emerging technological developments, there are a variety of definitions used for the term "robot." Depending on the definition used, the number of robot installations in this country and others will vary widely. There are a variety of single-purpose machines used in manufacturing plants which, to the lay person, would appear to be robots. These machines are hardwired to perform one function. They cannot be reprogrammed to perform a different function. These single-purpose machines do not fit the definition of industrial robots that is coming to be widely accepted. This definition is the one developed by the Robot Institute of America:

> A robot is a reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Notice that the RIA's definition contains the words "reprogrammable" and "multifunctional." It is these two characteristics that separate the true industrial robot from the various single-purpose machines used in modern manufacturing firms. The term "reprogrammable" implies, first, that the robot operates according to a written program, and, second, that this program can be rewritten to accommodate a variety of manufacturing tasks. The term "multifunctional" means that the robot is able, through reprogramming and the use of a variety of end effectors, to perform a number of different manufacturing tasks. Definitions written around these two critical characteristics are becoming the accepted definitions among manufacturing professionals. Figures 20-66 and 20-67 are examples of modern industrial robots that fit this definition.

Figure 20-66 Industrial robot (*Courtesy of* UNIMATION *Incorporated, a Westinghouse Company*)

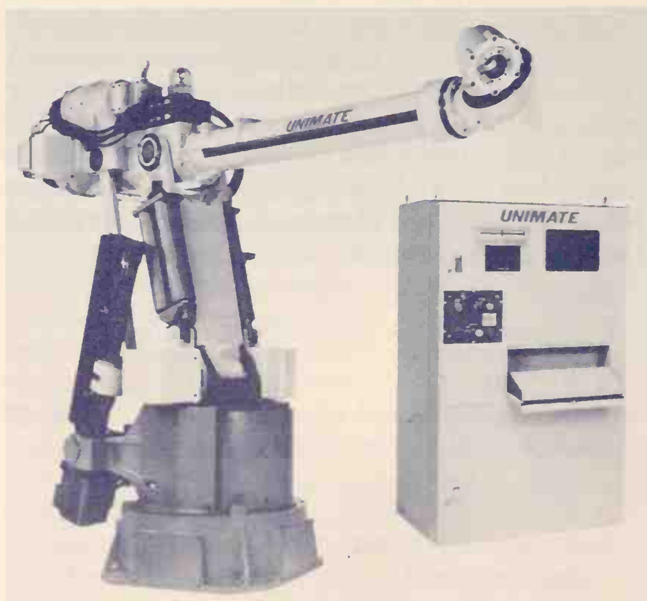


Figure 20-67 Industrial robot (*Courtesy of* UNIMATION *Incorporated, a Westinghouse Company*)

The microprocessor was the enabling device with regard to the wide-scale development and use of industrial robots. But major technological developments do not take place simply because of a new capability. Something must provide the impetus for taking advantage of the new capability. In the case of industrial robots, the impetus was economics.

In the 1970s it became imperative for the U.S. to produce better products at lower costs in order to be competitive with foreign manufacturers. Other factors, such as the need to find better ways of performing dangerous manufacturing tasks, contributed to the development of industrial robots. However, the principle rationale has always been, and is now, improved productivity.

Industrial robots offer a number of benefits that account for the rapid current and projected growth of industrial robot installations.

1. Increased productivity
2. Improved product quality
3. More consistent product quality
4. Reduced scrap and waste
5. Reduced reworking costs
6. Reduced raw goods inventory
7. Direct labor cost savings
8. Savings in related costs, such as lighting, heating, and cooling
9. Savings in safety-related costs
10. Savings from correctly forecasting production schedules

The Robot System

Work in a manufacturing setting is not accomplished by a robot. Rather, it is accomplished by a robot system. A robot system has four major components: the controller, the robot arm or manipulator, the end-of-arm tools, and the power sources, Figure 20-68. These components, coupled with the various other pieces of equipment and tools needed to perform the job for which a robot is programmed, are called the robot's work cell.

Figure 20-69 contains a schematic drawing of the work cell for the Cincinnati Milicron Corporation's T3-726 robot, which is used for TIG welding. Notice that the work cell contains not only the robot system but an index table, an operator's safety shield, and special welding equipment.

The contents of a robot's work cell will vary according to the application of the robot. However, the one constant in a robot's work cell is the robot system.

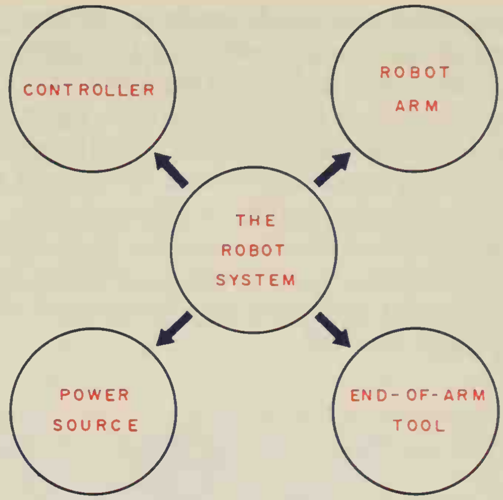


Figure 20-68 The robot system

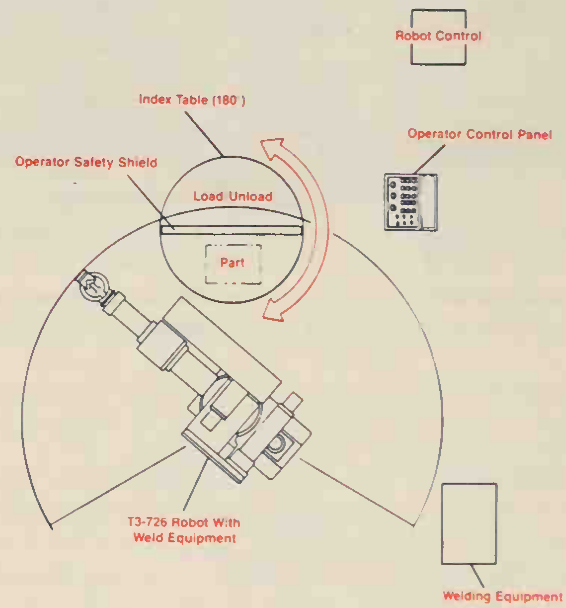


Figure 20-69 Robot work cell (*Courtesy of Cincinnati Milacron*)

The Controller. A robot is a special-purpose device similar to a computer. As such, it has all the normal components of a computer, including the central processing unit—made up of a control section and an arithmetic/logic section—and a variety of input and output devices.

The controller for a robot system does not look like the microcomputer one is used to seeing on a desk. It must be packaged differently so as to be able to withstand the rigors of a manufacturing environment. Typical input/output devices used in conjunction with a robot controller include teach stations, teach pendants, a display terminal, a controller front panel, and a permanent storage device.

Teach terminals, teach pendants, or front panels are used for interacting with the robot system. These devices allow humans to turn the robot on, write programs, and key in commands to the robot system. Display terminals give operators a soft copy output source. The permanent storage device is a special device on which reusable programs can be stored. Figure 20-70 is a photograph of a robot system. In the background you will notice a display terminal with a special keyboard, an input/output module, and a teach pendant.

Figure 20-70 Puma 200 industrial robot (*Courtesy of* UNIMATION *Incorporated, a Westinghouse Company*)

Mechanical Arm. The mechanical arm, or manipulator, is the part of a robot system with which most people are familiar. It is the part that actually performs the principle movements in doing manufacturing-oriented work. Mechanical arms are classified according to the types of motions of which they are capable. The basic categories of motion for mechanical arms are rectangular, cylindrical, and spherical. Figure 20-71 is a drawing of the mechanical arm for the Unimate Puma Series 700 robot.

End-of-Arm Tooling. The human arm by itself can perform no work. It must have a hand, which in turn, grips a tool. The mechanical arm of a robot, like the human arm, can perform no work. It, too, must have a hand, a tool, or a device which combines both functions. On industrial robots, the function of the wrist is performed by the tool plate. The tool plate is a special device to which end-of-arm tools are attached. The tools themselves vary according to the type of tasks the robot will perform. Any special device or tool attached to the tool plate to allow the robot to perform some specialized task is classified as an end-of-arm tool or an end effector.

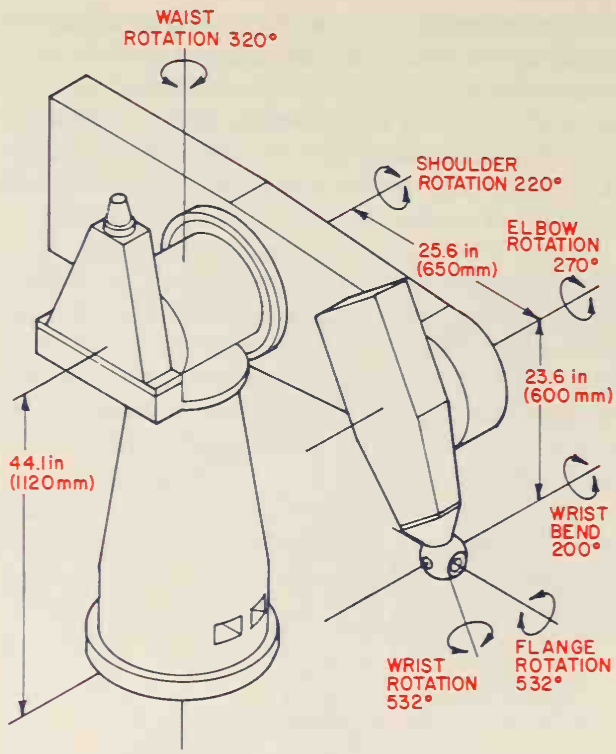


Figure 20-71 Robot mechanical arm (*Courtesy of* UNIMATION *Incorporated, a Westinghouse Company*)

The Power Source. A robot system can be powered by three different types of power. The power sources used in a robot system are electrical, pneumatic, or hydraulic. The controller, of course, is powered by electricity, as is any computer. The mechanical arm and end-of-arm tools may be powered by either pneumatic or hydraulic power. Some robot systems will use all three types of power. For example, a given robot might use electricity to power the controller, hydraulic power to manipulate the arm, and pneumatic power to manipulate the end-of-arm tool. Hydraulic power is fluid based. Pneumatic power comes from compressed gas.

Figure 20-72 shows a widely used industrial robot with a gripper device as an end-of-arm tool. The tool plate is the rectangular plate immediately behind the gripper.

CIM/FMS

Computer-integrated manufacturing is the most modern, most automated form of production. It involves tying different phases of production together into one wholly integrated system. The term "flexible manufacturing system" is sometimes used synonomously with computer-integrated manufacturing system. Actually, however, a flexible manufacturing system is one type of CIM system designed for

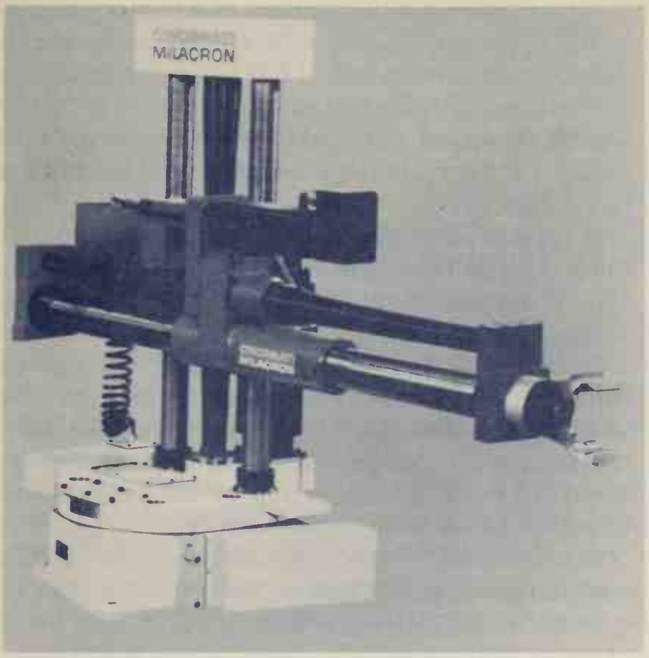


Figure 20-72 End-of-arm gripper (*Courtesy of Cincinnati Milacron, Inc.*)
(Note: Safety equipment may have been removed or opened to clearly illustrate products and must be in place prior to operation.)

medium-range production volumes and moderate flexibility. Other types of CIM systems are special systems and manufacturing cells. There are other terms that have been used to describe the same concept, but CIM and FMS are the two that are most widely used today.

There are a number of different types of computer-integrated manufacturing systems. This is because each system is designed to meet the specific needs of the individual manufacturing setting where it will be used. However, in general, a CIM system is any computerized manufacturing system in which numerically controlled machines are joined together and connected by some form of automated material handling system.

Figure 20-73 shows CNC machining centers linked together in an automated cell. In this system, two CNC machining centers are linked together by a cart-type material handling system. The cart system is further linked to four part load/unload stations to permit untended operation.

In a CIM system such as this, the computer is used in several ways: 1) it is used to control CNC machines; 2) it is used to control the materials handling system; and 3) it is used for monitoring all production tasks accomplished by the system.

Figure 20-74 is a photograph of a flexible manufacturing machine/robot cell. In this CIM system, rough castings are machined and inspected. The system contains two CNC machines, gaging devices, a

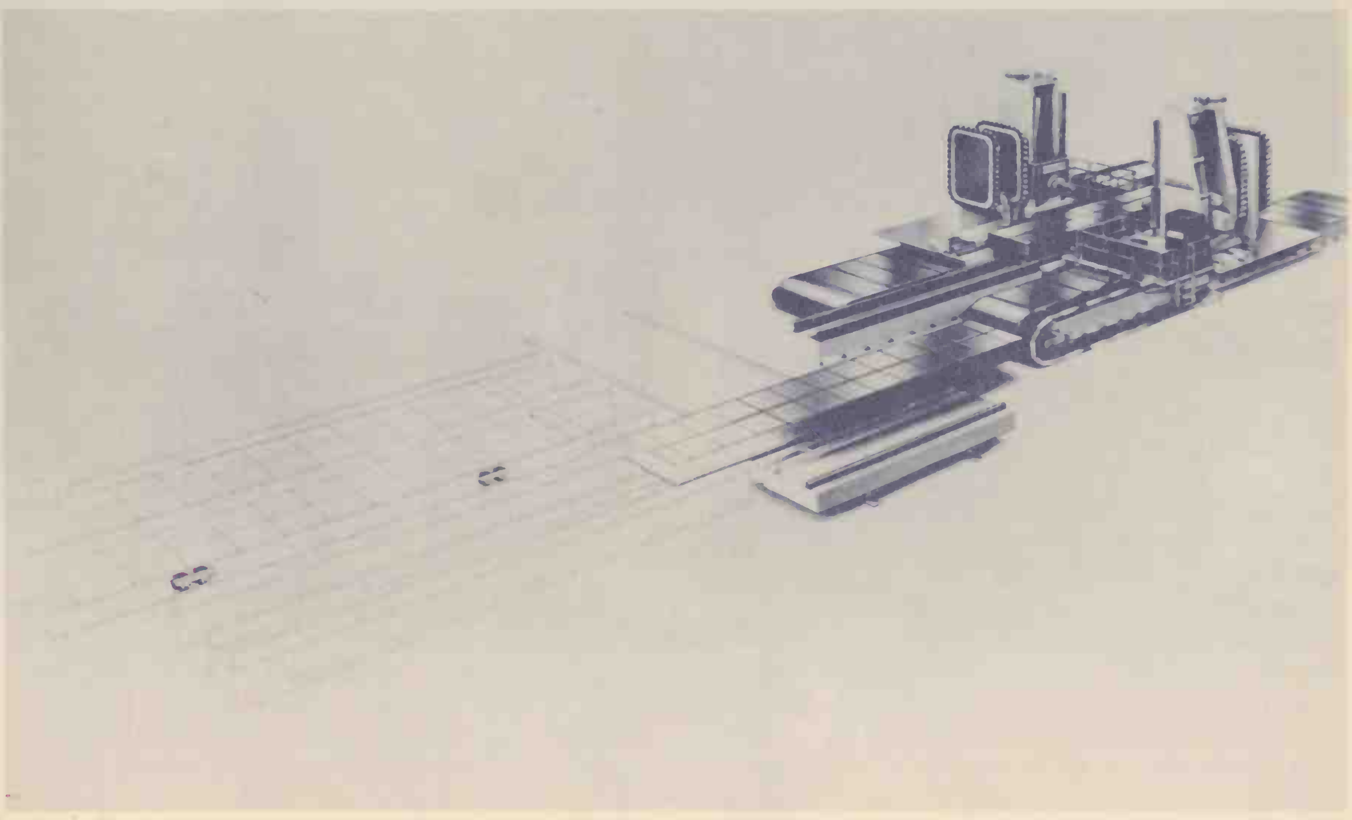


Figure 20-73 Example of a CIM system (*Courtesy of Cincinnati Milacron, Inc.*)

conveyor, and two robots. The rough castings are loaded onto the conveyor by a robot, and finished castings are unloaded by a robot.

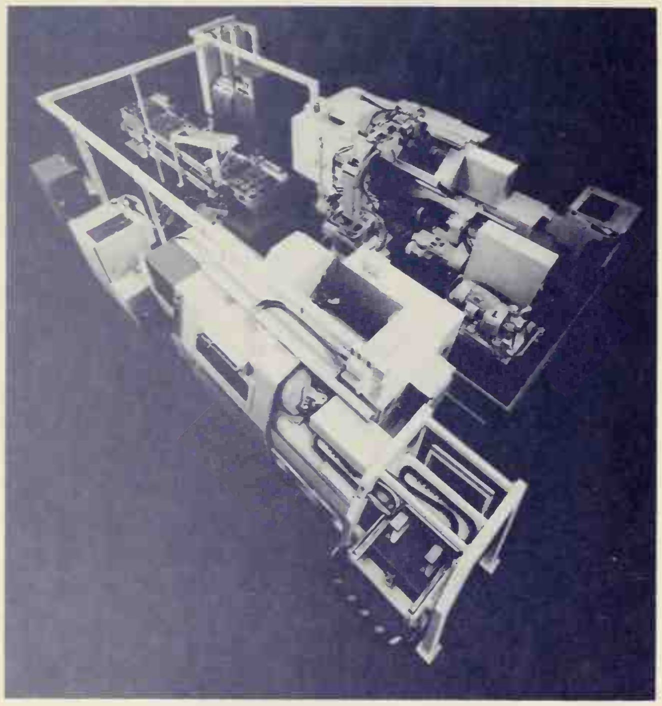


Figure 20-74 FMS (*Courtesy of Cincinnati Milacron, Inc.*)

Figure 20-75 is a photograph of a composite tape laying (CTL) system. The CTL system automatically dispenses tape at speeds of 100 feet per minute. Tape can be automatically laid in 3-inch, 6-inch, or 12-inch widths, debulked, cut, and overlaid ply-on-ply. Such systems are used in the manufacture of aircraft and space products.

In spite of advances in manufacturing automation, there is human involvement with a CIM system. Typically, this involvement falls into six broad categories: 1) loading raw stock and materials onto the system for processing; 2) unloading processed work pieces from the system; 3) changing tools on machines within the system; 4) setting tools on machines within the system; 5) continuous maintenance of the system; and 6) occasional repair of the system when there is a breakdown or malfunction.

Stand-alone CNC machines are used in low-volume manufacturing applications that require a high degree of flexibility in order to produce a wide variety of parts. They represent one extreme on the manufacturing spectrum. At the other extreme are transfer lines. Transfer lines are used in high-volume manufacturing applications where all parts produced are identical. Transfer lines are not flexible; they cannot accommodate variety.

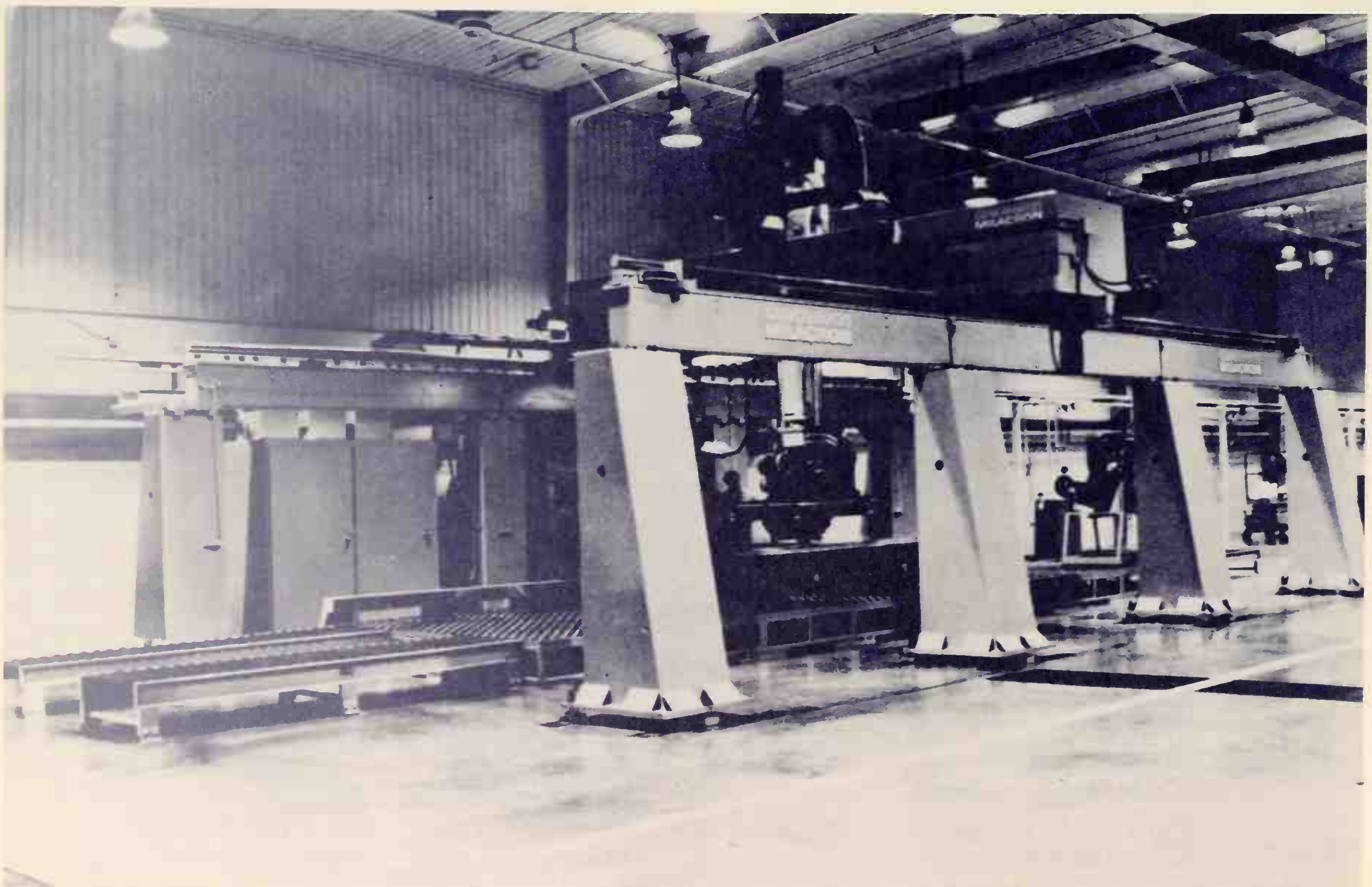


Figure 20-75 CTL system (*Courtesy of Cincinnati Milacron, Inc.*)

Figure 20-76 Volume/flexibility continuum

Transfer lines are a major component of what is sometimes referred to as "Detroit Automation." A transfer line consists of several workstations linked together by materials handling devices that transfer workpieces from station to station.

The first station holds the raw material. The last station is a bin for collecting the finished parts. Each station inbetween performs some type of operation on the parts as they pass through. The transfer of parts from station to station, and the work performed on them, are automatic. Transfer lines are appropriate in situations that involve high-volume production of identical parts.

There has always been a gap between these two extremes, and there has always been a need to fill this gap. The medium-volume, moderate flexibility manufacturing situation has long been a problem in need of a solution. CIM systems are such a solution. CIM fills the void between stand-alone CNC machines and transfer lines, Figure 20-76.

CIM offers a number of advantages that, when taken together, form the rationale for this modern approach to medium-volume, flexible production. The most important of these are:

1. Produces families of parts
2. Accommodates the random introduction of parts
3. Requires less lead-time
4. Allows a closer relationship between parts to be produced and workpieces loaded onto the system
5. Allows better machine utilization
6. Requires less labor

CIM systems reduce the amount of direct and indirect labor costs associated with finished workpieces. This is because CIM systems require less human involvement in producing them. Ten to 12 traditional CNC machines require 10 to 12 operators. A CIM system with 10 to 12 CNC machines might require as few as 4 people. This means less direct labor. Indirect labor costs resulting from such tasks as materials handling are also reduced with CIM. This is because most material handling in CIM systems is automated.

Types of CIM Systems

CIM systems fall between transfer lines and stand-alone CNC machines on a graph of production volume versus part variety flexibility. By applying these same criteria—production volume and part variety—CIM systems can be divided into three categories, Figure 20-77.

1. Special systems
2. Flexible manufacturing systems
3. Manufacturing cells

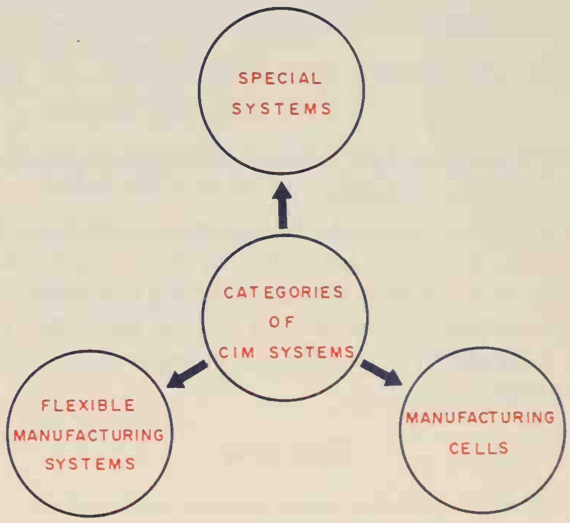


Figure 20-77 Categories of CIM systems

The systems above are listed in order from the least flexible (special systems) to the most flexible (manufacturing cells). Of all CIM systems, those classified as special systems are capable of the most volume production and the least flexibility. Special systems might produce as many as 15,000 parts per year, but they are limited to less than 10 different part types.

Flexible manufacturing systems represent the middle group in CIM systems. An FMS might have a production volume as high as 2,000 parts per year and a capability of handling as many as 200 different

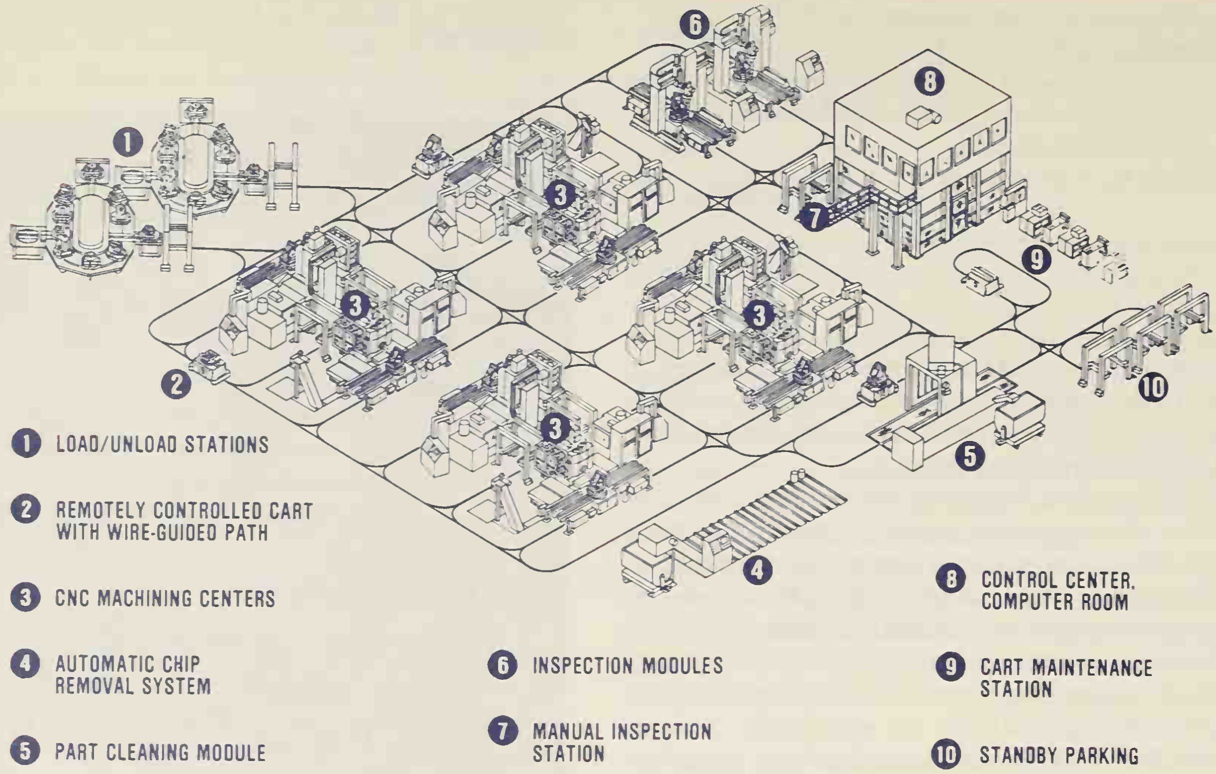


Figure 20-78 CIM system (*Courtesy of Cincinnati Milacron, Inc.*)

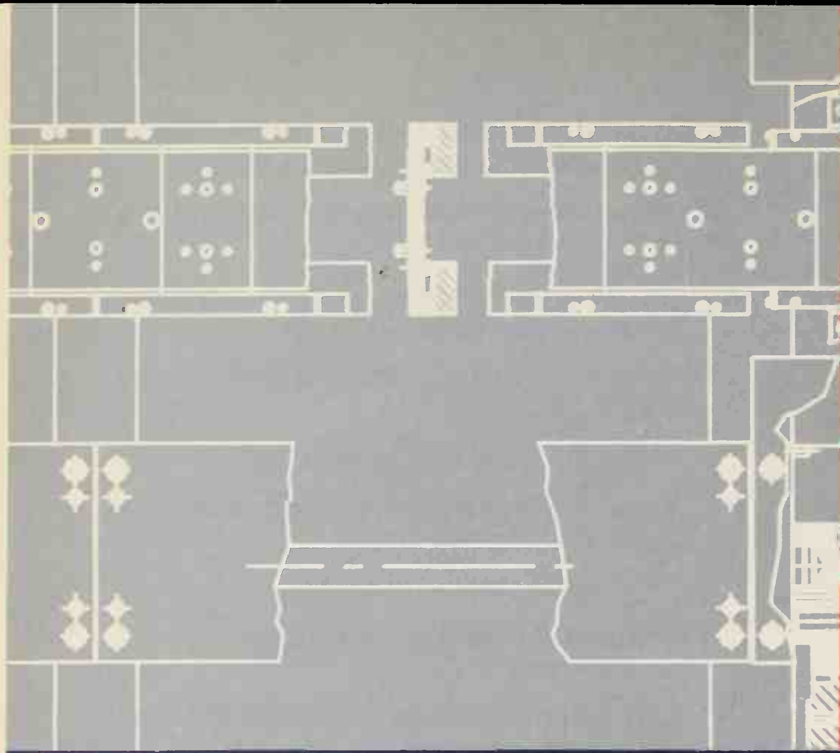
parts. Figure 20-78 is a diagram of a FMS produced by Cincinnati Milacron.

The most flexible of CIM systems are manufacturing cells, which, in turn, are capable of the lowest production volumes. A manufacturing cell might have a production volume as low as 500 parts per year but a capability of handling as many as 500 different part types.

Review

1. List four of the major factors to consider before any part is made in the shop.
2. What is meant by the term *lead time*?
3. List four primary methods used to fabricate manufactured products.
4. What terms are used to describe the top and bottom sections of the flask used for casting?
5. What two important factors must be considered when making a pattern for casting?
6. What is the approximate rate of shrinkage for steel? For cast iron?
7. Which casting process is also referred to as *lost wax casting*?
8. In which casting process is the molten metal forced into metal dies?
9. List three common forging processes.
10. How many stations are normally contained in a drop forge die?
11. Explain the extruding process.
12. What is the principal tool used for metal stamping?
13. List two stamping operations that produce blanks.
14. List two stamping operations that produce holes.
15. What do operations such as slitting, trimming, and shaving control?
16. What is the difference between notching and seminotching?
17. List four operations used to bend or form parts.
18. List four basic types of machine tools used for machining parts.
19. Explain the operation of a lathe.
20. What two variations of the milling machine are the most common?
21. List five operations normally performed on a drill press.

22. What are the two most common variations of saws used in the machine shop?
23. List three forms of precision grinders.
24. How is the cutter on a shaper driven?
25. On most planers, which element moves, the tool or the part?
26. What are the two variations of boring mills?
27. What type of operation is normally used to machine special shapes in holes?
28. What are the two variations of numerically controlled machines?
29. What are the two primary forms of workholding devices?
30. Which workholding device references the tool to the work? Which guides the tool?
31. Which form of workholder for drilling is the most common?
32. Which type of workholder is normally used to mill hexagonal or similar shapes?
33. What is the first rule of locating a part?
34. What is the general guide for the tolerance of workholders?
35. In how many directions is an unrestricted part free to move insofar as workholder design is concerned?
36. What devices are normally used to restrict the movement of a part?
37. List the three factors which must be considered when selecting a clamping device.
38. What is the principal purpose of clamps in a workholding device?
39. What are the three types of tool bodies normally used for workholding devices?
40. What are the three general variations of drill bushings?
41. How thick should the jig plate be?
42. How far should the bushing be from the work for drilling? For reaming?
43. What is the purpose of a set block?
44. What are the principal fasteners used for workholders?
45. List six of the properties of steels modified by heat treatment.
46. What are the five common heat treating operations?
47. Which heat treating operation is used to produce a hardened shell around a tough core?
48. Which heat treating operation is used to soften a hardened part?
49. Which heat treating operation should always follow the hardening process?
50. What effect does normalizing have on a part?



CHAPTER 21

Every type of fluid used by modern society is transported through pipes and piping systems. Water, oil, chemicals, gases, and liquid metals are all transported through piping systems. Pipes are also used in hydraulic and pneumatic devices and systems. The piping systems used to transport fluids must be designed, and the designs communicated by drawings. For this reason, engineering and drafting students should be proficient in the preparation of pipe drawings. The major topics included in this chapter are: types of pipe, types of joints and fittings, types of fixtures and valves, and pipe drawing.

PIPE DRAFTING

Types of Pipe

The wide variety of fluids used by modern society requires a number of different types of pipe. The most widely used of these are:

- Steel pipe
- Cast iron pipe
- Brass and copper pipe
- Copper tubing
- Plastic pipe

Steel Pipe

Steel pipe is well suited for high-pressure and high-temperature applications. It is frequently used in piping systems that transport water, oil, petroleum, and steam. Steel pipe comes in several cross-sectional configurations. The most widely used of these are the standard, extra strong, and double extra strong configurations, Figure 21-1. There are actually ten different cross-sectional configurations for steel pipe.

Steel pipe is specified by a nominal diameter callout. The actual diameter will vary slightly from the nominal. The American National Standard Institute (ANSI) specifies pipe in ten different schedules.

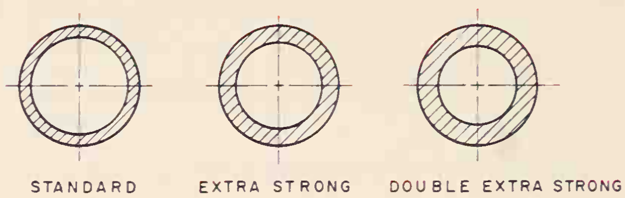


Figure 21-1 Schedule of pipe

Each schedule corresponds to a wall thickness. For example, standard and extra strong pipe are Schedules 40 and 80, respectively. The nominal diameter for pipe up to 12 inches refers to the inside diameter. Callouts are given in inches or millimeters. The nominal diameter for pipe over 12 inches refers to the outside diameter.

Cast Iron Pipe

Cast iron pipe is used most frequently for underground applications—to transport water, gas, and sewage. It is well suited for low-pressure steam connections also.

Brass and Copper Pipe

Brass and copper pipe are used in applications where corrosion will be a problem. Because brass and copper are able to withstand corrosion, the expected lifetime of a piping system in a high-corrosive setting will be longer if brass or copper pipe are used.

Copper Tubing

Copper tubing is used extensively in applications where vibration and misalignment are important factors. It is used in hydraulic and pneumatic applications, such as industrial settings involving robots, and in automotive settings.

Plastic Pipe

Plastic pipe is used extensively in modern piping settings. It is highly resistant to corrosion and chemical degradation. Plastic pipe is flexible and can be easily installed. However, it is not used where heat or pressure are factors. Plastic pipe does not have the chemical makeup to withstand heat or the wall strength to withstand high pressures.

Types of Joints and Fittings

Each kind of pipe explained in the previous section comes in straight length. However, piping systems require turns and branches and changes of size. In every instance where a pipe must change directions or size there is a joint. Joints are accomplished using fittings. There are three broad classifications of fittings.

1. Screwed
2. Welded
3. Flanged

Figure 21-2 illustrates these three types of fittings.

Engineers and drafters need to be able to specify pipe fittings. A given pipe fitting is specified by stating the nominal pipe size, the name of the fitting, and the material out of which the fitting is made. Any fitting that is used to connect different sizes of pipes is referred to as a "reducing fitting." When specifying reducing fittings, you must state the nominal pipe sizes for both the large and small end of the fitting. The large size is stated first. There are enough differences among screwed, welded, and flanged fittings that each must be studied separately.

Screwed Fittings

Screwed fittings are generally used in applications requiring small diameter pipe of 2.5 inches or less. The threaded end of the pipe and the internal threads on the fitting are usually coated with a special lubricant to seal the joint and to ease the connection process. Figures 21-3, 21-4, 21-5, and 21-6 contain information on the most commonly used threaded type fittings. Figure 21-3 contains information on the 90° elbow, 90° street elbow, 45° elbow, 45° street elbow, and 90° reducing elbow. The table accompanying each illustration gives the type sizes with which that particular fitting can be used, the various dimensions in which it is available, and the weight of the fitting itself. Figure 21-4 contains information for blind flange, screwed flange, and flat band cap fittings, as well as bushings. Figure 21-5 contains information on union, coupling, cross, Tee, and reducing Tee fittings. Figure 21-6 contains information on plug, return bend, and lock nut fittings, as well as reducers and nipples.

There are two types of American Standard pipe threads: tapered and straight. Tapered threads are more common. Straight threads are usually used only for special applications. The ANSI Standard for Pipe Threads is ANSI/ASME B1.20.1-1983. Figure 21-7 illustrates the conventions used for drawing pipe threads. Figure 21-8 illustrates the American National Standard taper pipe thread notation methods. Both types of threads have the same number of threads per inch.

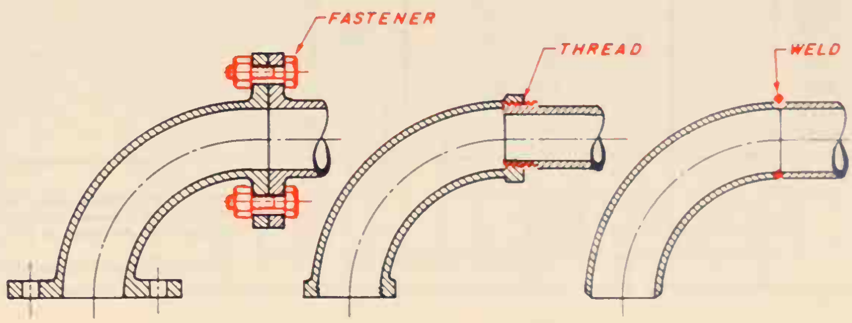
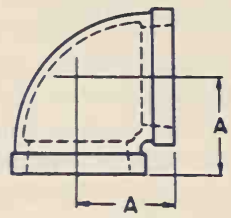


Figure 21-2 Pipe connections

AVAILABLE STYLES AND SIZES

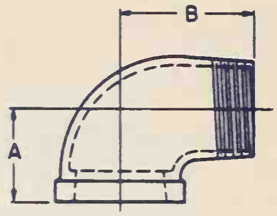
90° ELBOW

REFERENCE	PIPE SIZE, INCHES														
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6
A	11/16	13/16	15/16	1 1/8	1 5/16	1 7/16	1 3/4	1 15/16	2 1/4	2 11/16	3 1/8	3 7/16	3 3/4	4 1/2	5 1/8
Weight	.055	.060	.095	.145	.210	.355	.705	.790	1.180	1.670	2.590	3.250	4.065	6.900	9.800



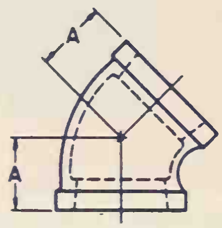
90° STREET ELBOW

REFERENCE	PIPE SIZE, INCHES										
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
A	11/16	13/16	15/16	1 1/8	1 5/16	1 7/16	1 3/4	1 15/16	2 1/4	2 11/16	3 1/8
B	1 1/8	1 5/16	1 7/16	1 5/8	1 7/8	2 1/8	2 1/2	2 11/16	3 3/16	3 13/16	4 1/2
Weight	.025	.045	.085	.140	.180	.205	.495	.750	1.250	1.850	2.900



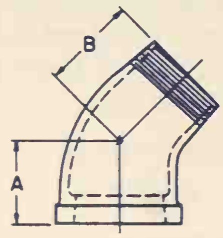
45° ELBOW

REFERENCE	PIPE SIZE, INCHES														
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6
A	11/16	3/4	13/16	7/8	1	1 1/8	1 5/16	1 7/16	1 11/16	1 15/16	2 3/16	2 3/8	2 5/8	3 1/16	3 15/32
Weight	.040	.040	.075	.115	200	.260	.455	.605	.970	1.420	1.925	2.530	3.335	5.650	8.700



45° STREET ELBOW

REFERENCE	PIPE SIZE, INCHES									
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2
A	—	—	—	1 1/16	1 3/16	1 3/8	1 17/32	1 5/16	1 5/8	2 1/16
B	—	—	—	1 3/16	1 3/8	1 17/32	1 23/32	2 1/4	2 3/8	2 1/2
Weight	—	—	—	.140	.180	.205	.495	.700	1.000	1.625



90° REDUCING ELBOW

Size	Weight
1/2" x 1/4"	.115
1/2" x 3/8"	.120
3/4" x 1/2"	.190
1" x 1/2"	.260
1" x 3/4"	.300
1 1/4" x 3/4"	.405
1 1/4" x 1"	.470

Size	Weight
1 1/2" x 1"	.560
1 1/2" x 1 1/4"	.720
2" x 1 1/4"	1.000
2" x 1 1/2"	1.030
2 1/2" x 2"	1.745
3" x 2"	2.205
3" x 2 1/2"	2.315

Size	Weight
4" x 3"	3.065

LATERALS — 1. 45° Y

a. Size Range - 1/2" through 3"

b. Dimensional Standard - F-52618-C (Revision)

NOTE: Any reducing fittings not specifically listed can be produced on a Special Order basis and will be subject to a Special Order charge of 25% of the listed retail price.

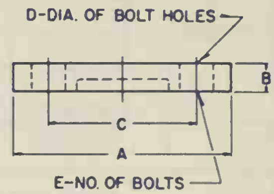
(For additional fittings see Page 8)

Figure 21-3 Pipe fittings (*Courtesy of Latrobe Foundry Machine and Supply Company*)

AVAILABLE STYLES AND SIZES

FLANGE - Blind

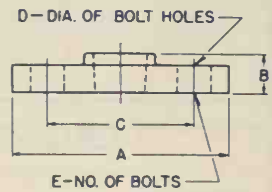
REFERENCE	PIPE SIZE, INCHES										
	½	¾	1	1¼	1½	2	2½	3	3½	4	6
A	3½	3⅞	4¼	4⅝	5	6	7	7½	8½	9	11
B	7/16	7/16	7/16	½	9/16	⅝	11/16	¾	13/16	15/16	1
C	2⅜	2¾	3⅛	3½	3⅞	4¾	5½	6	7	7½	9½
D	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	¾	¾	⅞
E	4	4	4	4	4	4	4	4	8	8	8
Weight	.275	.385	.560	.765	1.015	1.640	2.440	3.075	4.730	5.285	9.250



FLANGE - Screwed

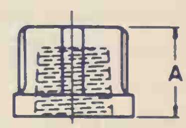
FOR REDUCING, SLIP-ON, FLOOR AND WELDING NECK FLANGES SEE PAGE 8.

REFERENCE	PIPE SIZE, INCHES											
	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6
A	3½	3⅞	4¼	4⅝	5	6	7	7½	8½	9	10	11
B	⅝	⅝	11/16	13/16	⅞	1	1 3/16	1¼	1¼	1 5/16	1 7/16	1 9/16
C	2⅜	2¾	3⅛	3½	3⅞	4¾	5½	6	7	7½	8½	9½
D	⅝	⅝	⅝	⅝	⅝	¾	¾	¾	¾	¾	⅞	⅞
E	4	4	4	4	4	4	4	4	8	8	8	8
Weight	.255	.375	.550	.740	.970	1.530	2.385	2.835	4.250	4.565	5.650	6.850



CAP - Flat Band

REFERENCE	PIPE SIZE, INCHES														
	⅛	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6
A	19/32	25/32	27/32	1 1/16	1 5/32	1¼	1 5/16	1 15/32	1 9/16	2 1/32	2 1/16	2 3/32	2 3/16	2⅜	2⅝
Weight	.015	.025	.050	.075	.100	.150	.290	.350	.450	.760	1.435	1.825	3.080	4.950	6.500



BUSHINGS

Size	Weight
¼" x ⅛"	.010
⅜" x ⅛"	.020
⅜" x ¼"	.015
½" x ⅛"	.045
½" x ¼"	.030
½" x ⅜"	.030
¾" x ¼"	.055
¾" x ⅜"	.050
¾" x ½"	.045
1" x ¼"	.110
1" x ⅜"	.105
1" x ½"	.090

Size	Weight
1" x ¾"	.070
1¼" x ⅜"	.170
1¼" x ½"	.165
1¼" x ¾"	.145
1¼" x 1"	.130
1½" x ½"	.215
1½" x ¾"	.210
1½" x 1"	.205
1½" x 1¼"	.125
2" x ½"	.370
2" x ¾"	.370
2" x 1"	.365

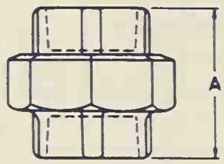
Size	Weight
2" x 1¼"	.325
2" x 1½"	.285
2½" x 1"	.785
2½" x 1¼"	.755
2½" x 1½"	.715
2½" x 2"	.605
3" x 1¼"	1.095
3" x 1½"	1.015
3" x 2"	.895
3" x 2½"	.705
3½" x 2"	1.120
3½" x 2½"	.920

Size	Weight
3½" x 3"	.750
4" x 1½"	1.860
4" x 2"	1.720
4" x 2½"	1.535
4" x 3"	1.255
5" x 2"	2.600
5" x 3"	2.350
5" x 4"	2.000
6" x 3"	3.950
6" x 4"	3.600
6" x 5"	3.250

Figure 21-4 Pipe fittings (*Courtesy of Latrobe Foundry Machine and Supply Company*)

AVAILABLE STYLES AND SIZES

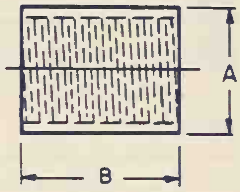
UNION



REFERENCE	PIPE SIZE, INCHES												
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4
A	1 9/16	1 13/16	1 15/16	2	2 1/8	2 3/4	3	3	3 1/4	3 5/8	4 1/8	4 7/8	5
Weight	.145	.130	.170	.255	.330	.505	.790	.815	1.250	1.745	2.865	5.000	5.800

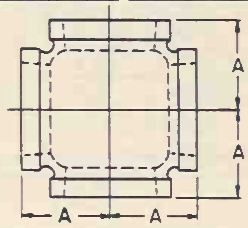
COUPLING

FOR HALF COUPLINGS AND HEAVY WALL COUPLINGS SEE PAGE 8



REFERENCE	PIPE SIZE, INCHES														
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6
A	19/32	3/4	29/32	1 1/16	1 11/32	1 5/8	1 31/32	2 15/64	2 23/32	3 5/16	3 15/16	4 7/16	4 15/16	6 1/16	7 3/16
B	15/16	1 1/32	1 5/32	1 5/16	1 9/16	1 13/16	2 1/16	2 5/16	2 9/16	2 7/8	3 1/16	3 7/16	3 7/16	4 1/8	4 1/8
Weight	.020	.025	.035	060	100	.135	.230	310	.500	730	1.015	1.740	2.040	3.300	4.500

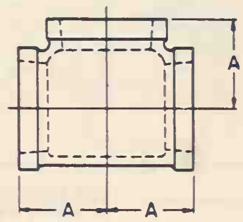
CROSS



REFERENCE	PIPE SIZE, INCHES												
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4
A	11/16	13/16	15/16	1 1/8	1 5/16	1 7/16	1 3/4	1 15/16	2 1/4	2 11/16	3 1/8	3 7/16	3 3/4
Weight	.050	.085	.155	215	.340	.565	.825	1.115	2.115	2.730	4.000	5.200	6.210

TEE

FOR LATERALS SEE PAGE 2



REFERENCE	PIPE SIZE, INCHES														
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6
A	11/16	13/16	15/16	1 1/8	1 5/16	1 7/16	1 3/4	1 15/16	2 1/4	2 11/16	3 1/8	3 7/16	3 3/4	4 1/2	5 1/8
Weight	.060	.070	.130	.180	285	435	.745	1.060	1.760	2.250	3.035	4.135	5.580	9.510	13.000

REDUCING TEE

NOTE: In the listing of reducing tees, the last dimension shown is the size of the branch.

Size	Wt.
1/2" x 1/2" x 1/4"	195
1/2" x 1/2" x 3/8"	190
1/2" x 1/2" x 3/4"	.320
3/4" x 1/2" x 1/2"	.320
3/4" x 1/2" x 3/4"	305
3/4" x 3/4" x 3/8"	.315
3/4" x 3/4" x 1/2"	.305
3/4" x 3/4" x 1"	.465
1" x 1/2" x 1/2"	190
1" x 3/4" x 1/2"	.515
1" x 3/4" x 3/4"	495
1" x 3/4" x 1"	.465
1" x 1" x 3/8"	495

Size	Wt.
1" x 1" x 1/2"	.485
1" x 1" x 3/4"	465
1" x 1" x 1 1/4"	850
1" x 1" x 1 1/2"	1.300
1 1/4" x 3/4" x 1 1/4"	.830
1 1/4" x 1" x 3/4"	.885
1 1/4" x 1" x 1"	855
1 1/4" x 1 1/4" x 1/2"	.850
1 1/4" x 1 1/4" x 3/4"	.850
1 1/4" x 1 1/4" x 1"	800
1 1/4" x 1 1/4" x 1 1/2"	1.170
1 1/2" x 3/4" x 1 1/2"	1.220
1 1/2" x 1" x 1"	1.300

Size	Wt.
1 1/4" x 1" x 1 1/2"	1.180
1 1/2" x 1 1/4" x 1"	1.230
1 1/2" x 1 1/4" x 1 1/4"	1.170
1 1/2" x 1 1/2" x 1/2"	1.245
1 1/2" x 1 1/2" x 3/4"	1.220
1 1/2" x 1 1/2" x 1"	1.180
1 1/2" x 1 1/2" x 1 1/4"	1.115
1 1/2" x 1 1/2" x 2"	1.280
2" x 1 1/2" x 1 1/2"	1.315
2" x 1 1/2" x 2"	1.755
2" x 2" x 1/2"	0.995
2" x 2" x 3/4"	1.290
2" x 2" x 1"	1.300

Size	Wt.
2" x 2" x 1 1/4"	1.325
2" x 2" x 1 1/2"	1.470
2" x 2" x 2 1/2"	1.910
2 1/2" x 2" x 2"	1.925
2 1/2" x 2 1/2" x 2"	2.095
3" x 3" x 2"	2.690
4" x 4" x 2"	4.015
4" x 4" x 3"	5.095
6" x 6" x 4"	10.850

Figure 21-5 Pipe fittings (*Courtesy of Latrobe Foundry Machine and Supply Company*)

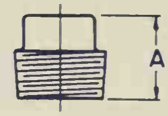
AVAILABLE STYLES AND SIZES

PLUG

COUNTERSUNK PLUGS

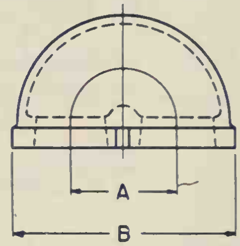
REFERENCE	PIPE SIZE, INCHES														
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6
A	5/8	11/16	13/16	7/8	1	1 3/16	1 7/16	1 3/8	1 9/16	1 11/16	1 13/16	2	2 3/16	2 3/8	2 9/16
Weight	010	015	020	030	055	090	150	215	315	560	755	.910	1.500	2.150	3.500

COUNTERSUNK PLUGS - Square Head Size Range 3/8" through 4"
Dimension Standard - ANSI B16.14-1949



RETURN BEND - Close

REFERENCE	PIPE SIZE, INCHES								
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2
A	–	–	–	1 1/4	1 1/2	1 3/4	2 1/4	2 1/2	3 1/4
B	–	–	–	2 5/8	3 5/32	3 29/32	4 21/32	5 7/32	6 19/32
Weight	–	–	–	205	275	440	780	1 000	1 840



LOCK NUT

REFERENCE	PIPE SIZE, INCHES									
	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3
A	–	5/32	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	15/16
Weight	–	015	020	025	045	080	105	175	345	425	740

REDUCERS

Size	Weight
1/4" x 1/8"	.040
3/8" x 1/8"	.060
3/8" x 1/4"	.060
1/2" x 1/4"	.100
1/2" x 3/8"	.095
3/4" x 1/4"	.150
3/4" x 3/8"	.130
3/4" x 1/2"	.160
1" x 1/2"	.215

Size	Weight
1" x 3/4"	.240
1 1/4" x 3/4"	.330
1 1/4" x 1"	.340
1 1/2" x 3/4"	.480
1 1/2" x 1"	.490
1 1/2" x 1 1/4"	.560
2" x 1"	.710
2" x 1 1/4"	.745

Size	Weight
2" x 1 1/2"	.825
2 1/2" x 2"	1.180
2 1/2" x 1 1/2"	1.200
3" x 2"	1.790
3" x 2 1/2"	1.750
4" x 3"	3.375
5" x 4"	4.75
6" x 4"	5.00
6" x 5"	5.00

NIPPLES - Close

ADDITIONAL NIPPLES *

Pipe Size	Length	Weight	Pipe Size	Length	Weight	Pipe Size	Length	Weight	Pipe Size	Length	Weight
1/8"	3/4"	.005	3/4"	1 3/8"	.045	1 1/2"	1 3/4"	.135	3"	2 5/8"	.570
1/4"	7/8"	.010	1"	1 1/2"	.075	2"	2"	.210	3 1/2"	2 3/4"	.720
3/8"	1"	.015	1 1/4"	1 5/8"	.105	2 1/2"	2 1/2"	.415	4"	2 7/8"	.895
1/2"	1 1/8"	.030									

* NIPPLES 1. Long Nipples a. Size Range — 1/8" through 4"
b. Length — through 12"

Figure 21-6 Pipe fittings (*Courtesy of Latrobe Foundry Machine and Supply Company*)

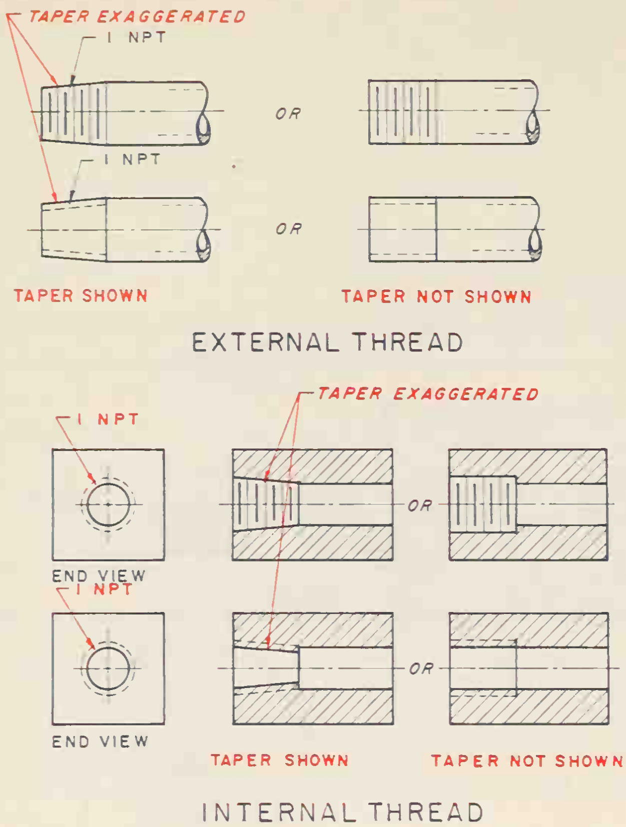


Figure 21-7 Pipe thread conventions

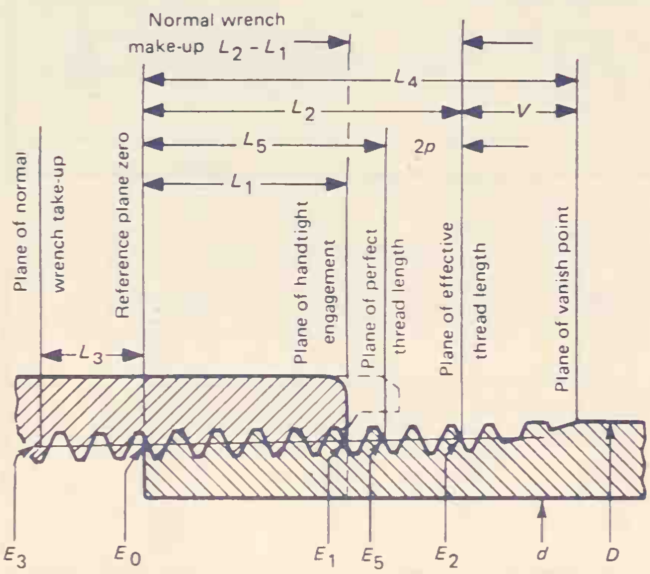


Figure 21-8 Pipe thread notation (*Reprinted from* ANSI/ASME *Standard* B1.20.1–1983. *Courtesy of* ANSI/ASME)

Welded Fittings and Joints

Some piping applications, such as high-pressure and high-temperature systems, require permanent fittings and joints. When this is the case, welded fittings are used. To accommodate the welding process, the connection ends of welded fittings as well as the ends of adjoining pipe are usually beveled. Welded fittings usually weigh less than flanged or screwed fittings, and they are easier to insulate.

Flanged Fittings and Joints

Some piping applications require that the piping systems occasionally be disassembled. When this is the case, flanged fittings are appropriate. Flanged fittings and adjoining pipes are bolted together. On occasion, flanged fittings and pipe may be welded together. However, they are normally bolted or glued together. Figure 21-9 contains size, weight, and dimensional data for the most common type of flanged fittings: 90° elbows, 45° elbows, tees, and reducers.

Types of Valves

Fluids and gases do not just flow freely through piping systems. They must be regulated, and at certain points stopped. There are a number of different types of valves, including gate, globe, jet, swiveled joint, ball, check, and butterfly. The most frequently used of these are gate, globe, and check valves. These commonly used types of valves are illustrated in Figures 21-10, 21-11, and 21-12.

Gate Valves

Gate valves are used to turn the flow of liquids through a pipe on or off without restricting the flow of the liquids through the valve or with as little restriction as possible. Gate valves are not meant to be used to regulate the degree of flow. Figures 21-13 and 21-14 contain dimensional data for two commonly used gate valve configurations.

Globe Valves

Globe valves are used to turn the flow of liquids through a pipe on and off, and they are used also to regulate the flow of fluids through the valve to the desired level. Figures 21-15 and 21-16 contain dimensional data for two commonly used configurations of globe valves.

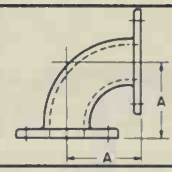
Check Valves

Check valves are used to restrict the flow of liquids through a pipe in only one direction. A backward flow is checked by the valve, which is activated by any change in the direction of flow. Figures 21-17 and 21-18 contain dimensional data for two commonly used configurations of check valves.

AVAILABLE STYLES AND SIZES

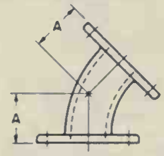
90° ELBOW

REFERENCE	PIPE SIZE, INCHES					
	1½	2	2½	3	4	6
A	4	4½	5	5½	6½	8
Weight	5	6¼	8	8½	10	20



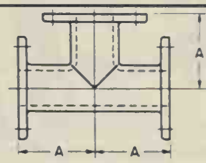
45° ELBOW

REFERENCE	PIPE SIZE, INCHES					
	1½	2	2½	3	4	6
A	2¼	2½	3	3	4	5
Weight	3	4	10	6	6½	16



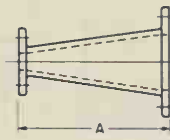
TEE

REFERENCE	PIPE SIZE, INCHES					
	1½	2	2½	3	4	6
A	4	4½	5	5½	6½	8
Weight	5	9	13	13½	20	30



REDUCER

REFERENCE	PIPE SIZE, INCHES					
	2 x 1½	2½ x 1½ 2½ x 2	3 x 2 3 x 2½	4 x 3	6 x 3	6 x 4
A	5	5½	6	7*	9*	9*
Weight	4	6	8	9	12¼	14
						356-F



*Face-to-face dimension

All 3'' fittings have a 7 1/2'' flange diameter, a 6'' bolt circle diameter, 4 bolt holes and 3/4'' diameter bolt holes.

All 1 1/2'' fittings have a 5'' flange diameter, a 3 7/8'' bolt circle diameter, 4 bolt holes and 5/8'' diameter bolt holes.

All 4'' fittings have a 9'' flange diameter, a 7 1/2'' bolt circle diameter, 8 bolt holes and 3/4'' diameter bolt holes.

All 2'' fittings have a 6'' flange diameter, a 4 3/4'' bolt circle diameter, 4 bolt holes and 3/4'' diameter bolt holes.

All 6'' fittings have an 11'' flange diameter, a 9 1/2'' bolt circle diameter, 8 bolt holes and 7/8'' diameter bolt holes.

All 2 1/2'' fittings have a 7'' flange diameter, a 5 1/2'' bolt circle diameter, 4 bolt holes and 3/4'' diameter bolt holes.

Figure 21-9 Pipe fittings (*Courtesy of Latrobe Foundry Machine and Supply Company*)

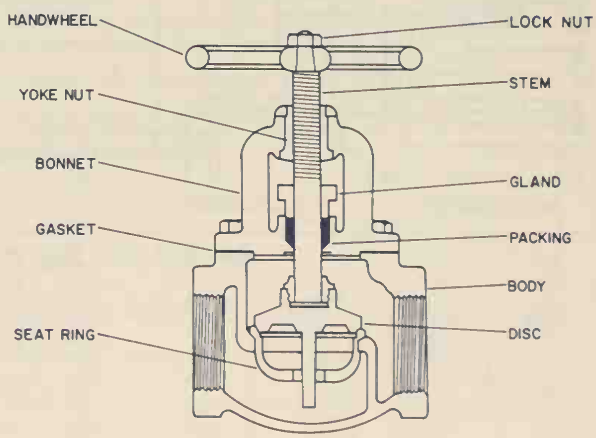


Figure 21-11 Globe valve

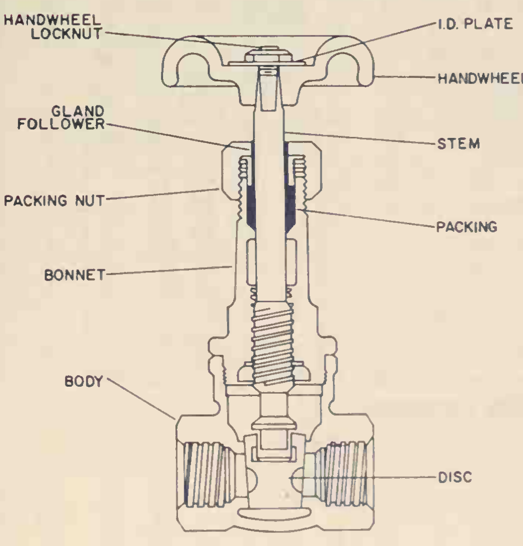


Figure 21-10 Gate valve

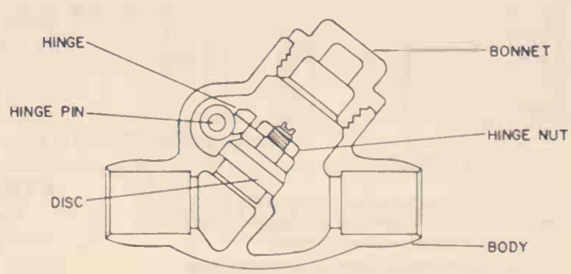
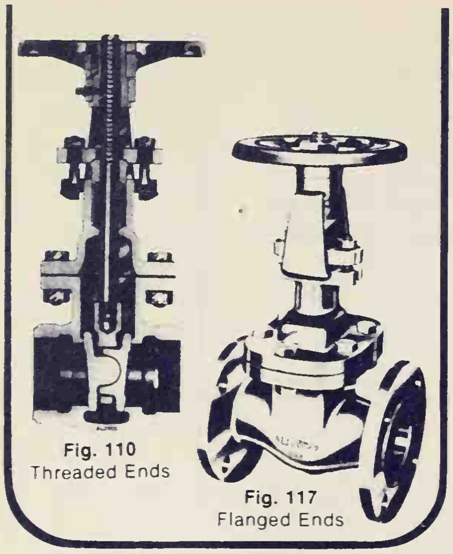


Figure 21-12 Check valve



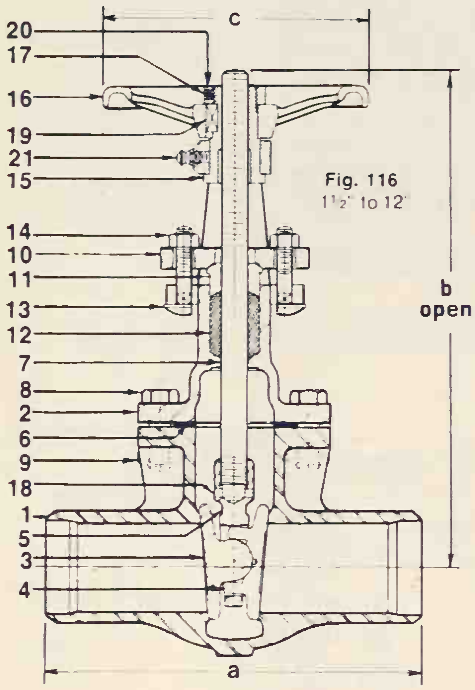
STAINLESS STEEL GATE

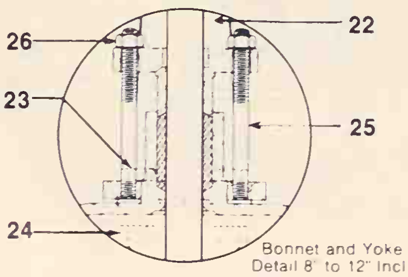
CLASS 150

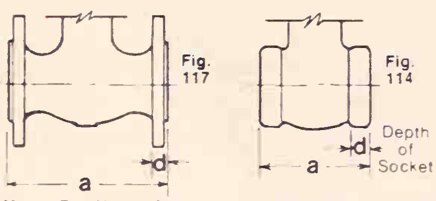
FIGURES: 110 (½" to 2"), **114** (½" to 2"), **116** (1½" to 12"), **117** (½" to 12")

DESIGN DESCRIPTION:

Outside Screw and Yoke
Bolted Bonnet
Rising Stem
Non-Rising Handwheel
Integral Seats
Threaded Ends (Fig 110)
Socket Weld Ends (Fig 114)
Buttwelding Ends (Fig 116)
Flanged Ends (Fig 117)
Male-Female Bonnet Joint Sizes ½" to 1" Incl.
Double Disc Ball-and-Socket Type Wedge
Flat Faced Flanged Valves, Specify Fig 117-FF







Note: For Valve Services at Temperatures above 700°F, the Aloyco Engineering Department should be consulted for materials and features.

For Engineering Specifications and Data, see Engineering Section of Catalog.

PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO	DESCRIPTION	ALOYCO 18-8 SMO
1 body*	A351 GR CF8M	15 yoke bushing†	wrought B16 or cast B584 C83600
2 bonnet	A351 GR CF8M	16 handwheel	malleable iron
3 male disc	wrought type 316 or	17 yoke nut set screw	type 303
4 female disc	cast A351 GR CF8M	18 disc arm pin	type 316
5 disc arm	A351 GR CF8M	19 handwheel key	steel
6 gasket†	comp asbestos or teflon		
7 stem	type 316	20 yoke bushing nut†	wrought B16 or cast B584-C83600
8 bonnet bolt	A193 GR B8		
9 bonnet bolt nut	A194 GR 8F	21 grease fitting	steel
10 gland plate	A351 GR CF8M	22 yoke	CF8
11 gland follower	wrought-type 316 or cast A351 GR CF8M	23 yoke bolt	A193 GR B8
		24 yoke bolt nut	A194 GR 8F
12 packing†	braided asbestos or teflon	25 gland stud	A193 GR B8
13 gland bolt	A193 GR B8	26 gland stud nut	A194 GR 8F
14 gland bolt nut	A194 GR 8F		

Remarks: *Body material on threaded and welding end valves is ELC grade
Other Alloys available (Refer to Introduction)
†Unless otherwise specified, these valves may be supplied at the manufacturer's option with: PTFE Gasket and Packing; Type 303 yoke bushing and nut. Such valves are limited to a temperature of 550 F and are so tagged.

DIMENSIONS IN MM AND INCHES:

SIZE	MM INCH	15 ½	20 ¾	25 1	32 1¼	40 1½	50 2	65 2½	80 3	100 4	150 6	200 8	250 10	300 12
a (110, 114)	mm	70	80	89	108	114	121						—	—
	inch	2¾	3	3½	4¼	4½	4¾							
a (116)	mm	—	—	—	—	165	216	241	283	305	403	419	457	502
	inch					6½	8½	9½	11⅛	12	15⅞	16½	18	19¾
a (117)	mm	108	118	127	—	165	178	191	203	229	267	292	330	356
	inch	4¼	4⅝	5		6½	7	7½	8	9	10½	11½	13	14
b (110, 114)	mm	210	210	238	277	286	337	—	—	—	—	—	—	—
	inch	8¼	8¼	9⅜	10⅞	11¼	13¼							
b (116, 117)	mm	210	210	235	—	291	337	394	432	527	781	1016	1219	1524
	inch	8¼	8¼	9¼	—	11 [illegible]/16	13¼	15½	17	20¾	30¾	40	48	60
c	mm	89	100	100	127	127	150	178	191	250	305	356	406	457
	inch	3½	4	4	5	5	6	7	7½	10	12	14	16	18
d (114)	mm	13	13	13	13	13	16	—	—	—	—	—	—	—
	inch	½	½	½	½	½	⅝							
d (117)	mm	11	11	11	—	14	16	18	19	24	25	29	30	32
	inch	7/16	7/16	7/16	—	9/16	⅝	11/16	¾	15/16	1	1⅛	1 3/16	1¼

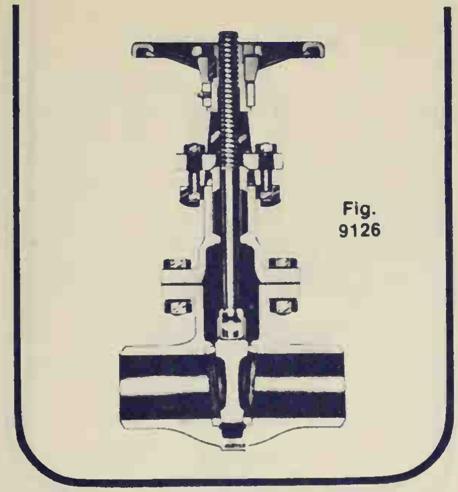
WEIGHTS IN KG AND POUNDS:

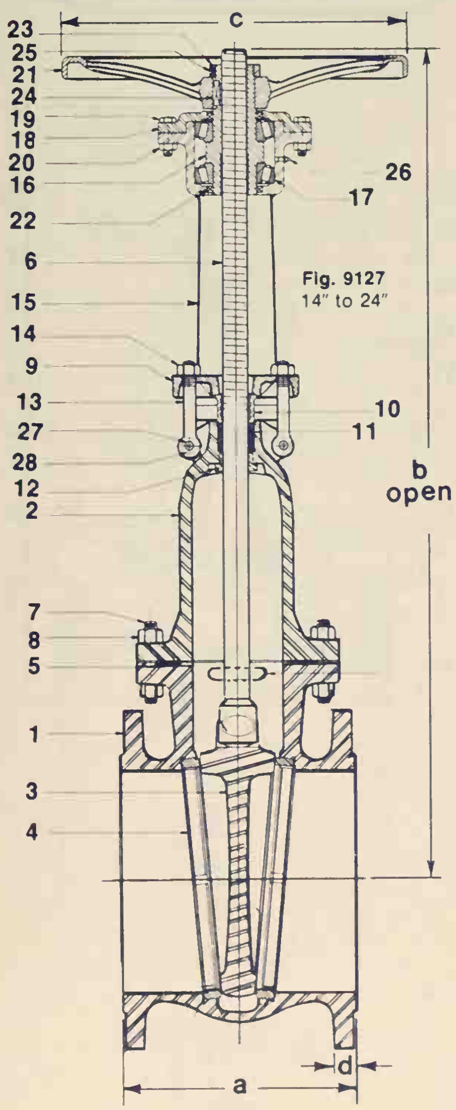
		15	20	25	32	40	50	65	80	100	150	200	250	300
110, 114	kg	2.8	2.9	4.0	5.9	7.0	9.0	—	—	—	—	—	—	—
	lb	6.3	6.5	9	13	15.5	20							
116	kg	—	—	—	—	7.0	10	14	16	26	56	91	151	223
	lb					15.5	21	30	35	63	124	201	332	492
117	kg	3.6	4.3	5.4	—	9.9	14	19	24	40	72	124	206	305
	lb	8	9.5	12		22	30	42	51	88	158	275	455	675

APPLICABLE CLASS 150 STANDARDS:

End Flanges, ANSI B16 5
Pipe Threads, ANSI B2.1
Design, API 603
Wall Section, ANSI B16.34
SW Ends (Bore and Depth), ANSI B16.11
BW Ends (Schedule 40), ANSI B16 25 and B16.10
Face-to-Face, ANSI B16.10
Pressure-Temperature Ratings, ANSI B16.34-1977

Figure 21-13 Gate valve data (*Courtesy of Crane-Aloyco, Inc.*)





STAINLESS STEEL GATE

CLASS 150

FIGURES: 9126, 9127 (14" to 24")

DESIGN DESCRIPTION:

Outside Screw and Yoke	For Flat Faced Flanged Valves, Specify Fig. 9127-FF
Bolted Bonnet	Roller Bearing Yoke
Rising Stem	Renewable Seat Rings
Non-rising Handwheel	Buttwelding Ends (Fig. 9126)
Solid Wedge	Flanged Ends (Fig. 9127)

PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO	DESCRIPTION	ALOYCO 18-8 SMO
1 body*	A351 GR CF8M	16 yoke bushing	B584 alloy C86200
2 bonnet	A351 GR CF8M	17 roller bearing	steel
3 wedge	A351 GR CF8M	18 yoke cap	CF8
4 seat ring	A351 GR CF8M	19 yoke cap bolt	A193 GR B8
5 gasket	comp. asbestos	20 yoke cap bolt nut	A194 GR 8F
6 stem	type 316	21 handwheel	malleable iron
7 bonnet studbolt	A193 GR B7	22 oil seal	flax
8 bonnet studbolt nut	A194 2H .	23 yoke bushing nut	B584 alloy C86200
9 gland plate	A351 GR CF8M	24 handwheel key	steel
10 gland follower	A351 GR CF8M	25 yoke nut set screw	type 303
11 packing	braided asbestos	26 grease fitting	steel
12 stem hole bushing	A351 GR CF8M	27 hinge bolt	A193 GR B8
13 gland eyebolt	A193 GR B8	28 hinge bolt nut	A294 GR 8F
14 gland eyebolt nut	A194 GR 8F	29 yoke studbolt**	A193 GR B8
15 yoke	CF8	30 yoke studbolt nut**	A194 GR 8F

Remarks: *Body material on welding end valves to be ELC grade
**Not shown.
Other Alloys Available. Refer to Introduction.

Note: For Valve Services at Temperatures above 700°F, the Aloyco Engineering Department should be consulted for materials and features.

DIMENSIONS IN MM AND INCHES:

SIZE	MM / INCH	350 / 14	400 / 16	450 / 18	500 / 20	600 / 24
a(9126)	mm	571	610	660	711	813
	inch	22½	24	26	28	32
a(9127)	mm	381	406	432	457	508
	inch	15	16	17	18	20
b	mm	1765	1870	2140	2369	2753
	inch	69½	73⅝	84¼	93¼	108⅜
c	mm	508	559	610	660	762
	inch	20	22	24	26	30
d(9127) thickness of flange	mm	35	37	40	43	48
	inch	1⅜	1 7/16	1 9/16	1 11/16	1⅞

WEIGHTS IN KG AND POUNDS:

9126	kg	342	474	535	708	1043
	lb	754	1046	1180	1560	2300
9127	kg	419	559	644	848	1234
	lb	924	1232	1420	1870	2720

APPLICABLE CLASS 150 STANDARDS

End Flanges, ANSI B16.5	Buttwelding Ends (Schedule 40), ANSI B16.25 and B16.10
Design, ANSI B16.34	Face-to-Face, ANSI B16.10
Wall Section, API 600	Pressure-Temperature Ratings, ANSI B16.34-1977

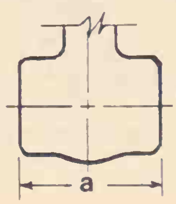


Fig. 9126

Figure 21-14 Gate valve data (*Courtesy of Crane-Aloyco, Inc.*)

STAINLESS STEEL GLOBE

CLASS 150

FIGURES: 422 (½″ to 2″), 427 (½″ to 6″)

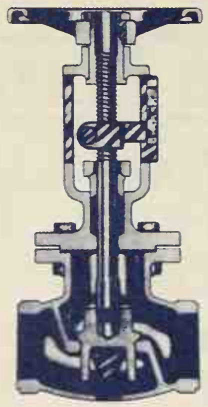


Fig. 422
Threaded Ends

DESIGN DESCRIPTION:

"V" Port Throttling
Bolted Bonnet
Outside Screw and Yoke
Position Indicator
Rising Stem
Non-rising Handwheel
Threaded Ends (Fig. 422)
Flanged Ends (Fig. 427)
When Flat Face End Flanges are Required Order as 427-FF

PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO	DESCRIPTION	ALOYCO 18-8 SMO
1 body	A351 GR CF8M	13 yoke bushing	cast B584 alloy 836 or wrought B16 half hard
2 bonnet	A351 GR CF8M	14 handwheel	malleable iron
3 disc	A351 GR CF8M	15 indicator	CF-16F
4 stem	type 316	16 indicator bolt	A193 GR B8
5 gasket	PTFE	17 escutcheon pins	type 304
6 bonnet bolts	A193 GR B8	18 indicating plate	type 304
7 bonnet bolt nuts	A194 GR 8F	19 yoke bushing nut	cast B584 alloy 836 or wrought B16 half hard
8 gland plate	CF8M	20 handwheel key	steel
9 gland follower	type 316	21 disc pin	type 316
10 packing	PTFE	22 yoke nut set screw	type 303
11 gland bolts	A193 GR B8		
12 gland bolt nuts	A194 GR 8F		

Other Alloys available. (Refer to Introduction)

DIMENSIONS IN MM AND INCHES:

SIZE	MM / INCH	15 / ½	20 / ¾	25 / 1	40 / 1½	50 / 2	65 / 2½	80 / 3	100 / 4	150 / 6
a	mm	86	95	108	140	165	—	—	—	—
	inch	3⅜	3¾	4¼	5½	6½				
a (F)	mm	108	117	127	165	203	216	241	292	406
	inch	4¼	4⅝	5	6½	8	8½	9½	11½	16
b	mm	180	235	259	283	308	330	368	419	584
	inch	7¹¹⁄₁₆	9¼	10³⁄₁₆	11⅛	12⅛	13	14½	16½	23
c	mm	102	127	127	152	178	191	254	305	356
	inch	4	5	5	6	7	7½	10	12	14

WEIGHTS IN KG AND POUNDS:

		15 / ½	20 / ¾	25 / 1	40 / 1½	50 / 2	65 / 2½	80 / 3	100 / 4	150 / 6
422	kg	1.8	2.7	4.5	7.2	9.5	—	—	—	—
	lb	4	6	10	16	21				
427	kg	2.7	4	5.9	9.5	13	20	26	43	78
	lb	6	9	13	21	29	43	58	95	173

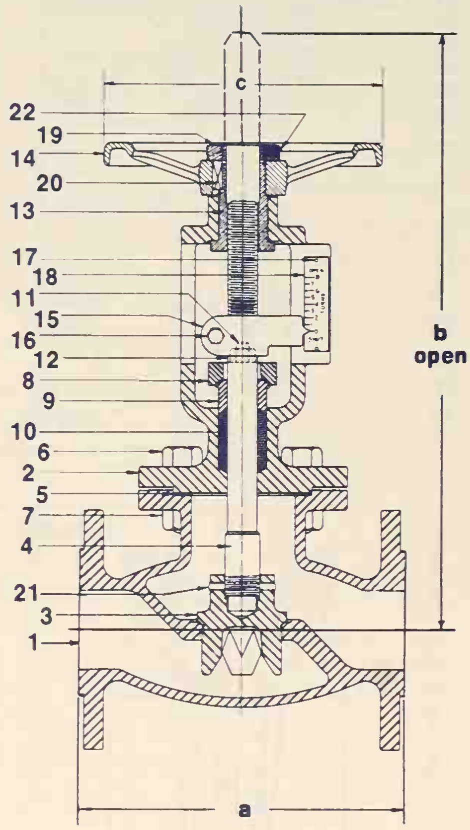


Fig. 427
Sizes ½″ to 6″

APPLICABLE CLASS 150 STANDARDS:

End Flanges, ANSI B16.5
Wall Section, ANSI B16.34
Face-to-Face, ANSI B16.10
Pressure-Temperature Ratings, ANSI B16.34-1977
Pipe Threads, ANSI B2.1

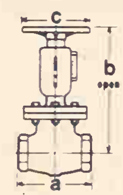
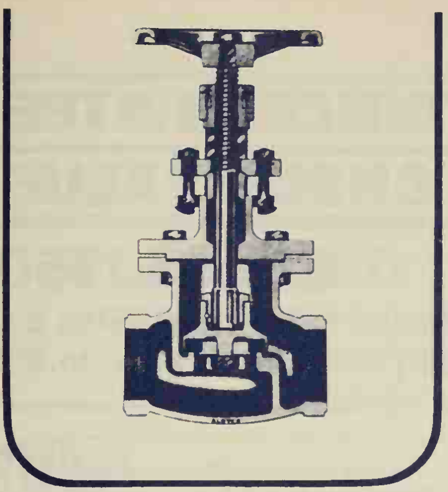


Fig. 422 (½″ to 2″)

Figure 21-15 Globe valve data (*Courtesy of Crane-Aloyco, Inc.*)



STAINLESS STEEL GLOBE

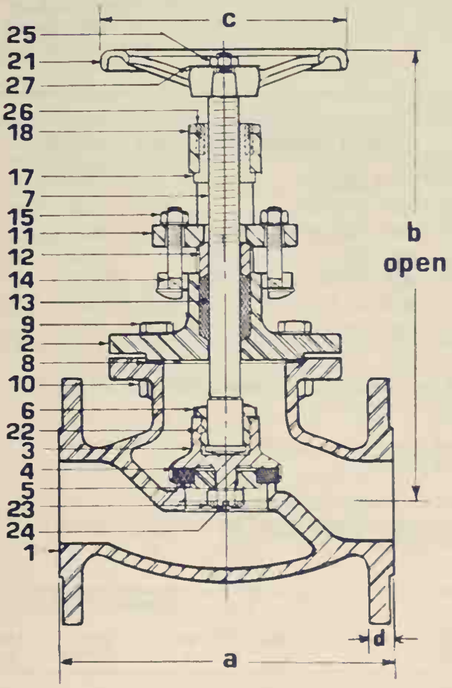
CLASS 150

FIGURES: 502 (½″ to 2″), 504 (½″ to 2″), 507 (½″ to 10″)

DESIGN DESCRIPTION:

Outside Screw and Yoke
Bolted Bonnet
Renewable PTFE Disc
Retained Gasket
Rising Stem and Handwheel
For Flat Faced Flanged Valve
  Specify Fig. 507 FF

Integral Seat
Threaded Ends (Fig. 502)
Socket Weld Ends (Fig. 504)
Flanged Ends (Fig. 507)
Valves in Sizes 8″ and 10″ Have
  Disc Guide Below Seat



PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO	DESCRIPTION	ALOYCO 18-8 SMO
1 body*	A351 GR CF8M	14 gland bolt	A193 GR B8
2 bonnet	A351 GR CF8M	15 gland bolt nut	A194 GR 8F
3 disc holder	cast-CF8M, wrought-type 316	16 yoke ***	CF8
4 disc	PTFE	17 yoke bushing	B16 half hard
5 disc holder plate	cast-CF8M,	18 yoke bushing nut	B16 half hard
6 swivel nut	wrought-type 316	19 yoke bolt ***	A193 GR B8
7 stem	type 316	20 yoke bolt nut ***	A194 GR 8F
8 gasket	PTFE	21 handwheel	malleable
9 bonnet bolt	A193 GR B8	22 swivel nut pin	type 316
10 bonnet bolt nut	A194 GR 8F	23 disc holder plate nut**	type 316
11 gland plate	CF8M	24 disc holder nut pin	type 316
12 gland follower	cast-CF8M, wrought-type 316	25 handwheel nut	type 303
13 packing	PTFE	26 yoke nut pin	type 303
		27 I.D. plate	type 304

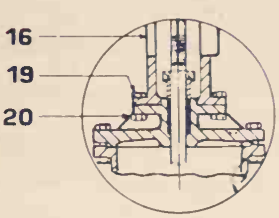
Remarks: *Body material on threaded and welding end valves is ELC grade
**Sizes ½″ to 2″ incl
***Sizes 8″ and 10″ only
Other Alloys Available. Refer to Introduction
Note: For Valve Services at Temperatures above 700 F, the Aloyco Engineering Department should be consulted for materials and features.

DIMENSIONS IN MM AND INCHES:

SIZE	MM / INCH	15 / ½	20 / ¾	25 / 1	40 / 1½	50 / 2	65 / 2½	80 / 3	100 / 4	150 / 6	200 / 8	250 / 10
a(502,504)	mm	86	95	108	140	165	—	—	—	—	—	—
	inch	3⅜	3¾	4¼	5½	6½						
a(507)	mm	108	117	127	165	203	216	241	292	406	495	622
	inch	4¼	4⅝	5	6½	8	8½	9½	11½	16	19½	24½
b(502,504)	mm	165	210	248	283	305	—	—	—	—	—	—
	inch	6½	8¼	9¾	11⅛	12						
b(507)	mm	165	210	251	283	305	327	359	425	533	622	822
	inch	6½	8¼	9⅞	11⅛	12	12⅞	14⅛	16¾	21	24½	32⅜
c	mm	67	76	102	127	152	178	203	254	305	406	457
	inch	2⅝	3	4	5	6	7	8	10	12	16	18
d(504) Depth of Socket	mm	10	13	13	13	16	—	—	—	—	—	—
	inch	⅜	½	½	½	⅝						
d(507) Flange Thickness	mm	11	11	11	14	16	17	19	24	25	29	30
	inch	7/16	7/16	7/16	9/16	⅝	11/16	¾	15/16	1	1⅛	1 3/16

WEIGHTS IN KG AND POUNDS:

		15 / ½	20 / ¾	25 / 1	40 / 1½	50 / 2	65 / 2½	80 / 3	100 / 4	150 / 6	200 / 8	250 / 10
502,504	kg	2.7	5	5	7.3	11	—	—	—	—	—	—
	lb	6	10	10	16	24						
507	kg	5	6.4	6.4	10	15	20.8	26	43	78	128.8	188.7
	lb	10	14	14	22	34	46	58	95	173	284	416



Separable Yoke Detail
Sizes 8″ and 10″ only

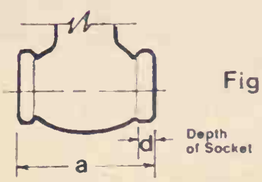


Fig. 502 & 504

APPLICABLE CLASS 150 STANDARDS:

End Flanges, ANSI B16.5
Wall Section, ANSI B16.34
Face-to-Face, ANSI B16.10
Pipe Threads, ANSI B2.1

Socket Weld Ends (Bore and Depth), ANSI B16.11
Pressure-Temp. Ratings, ANSI B16.34-1977
  Maximum Service Temperature, 450°F

Figure 21-16 Globe valve data (*Courtesy of Crane-Aloyco, Inc.*)

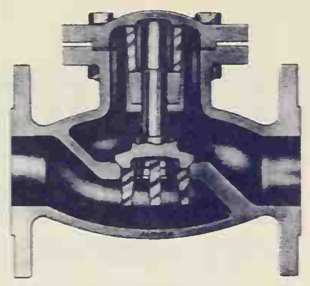


Fig. 557
Flanged Ends

STAINLESS STEEL LIFT CHECK VALVES

CLASS 150

FIGURES: 550 (¼" to 2"), 554 (¼" to 2"), 556 (½" to 6"), 557 (½" to 6")*

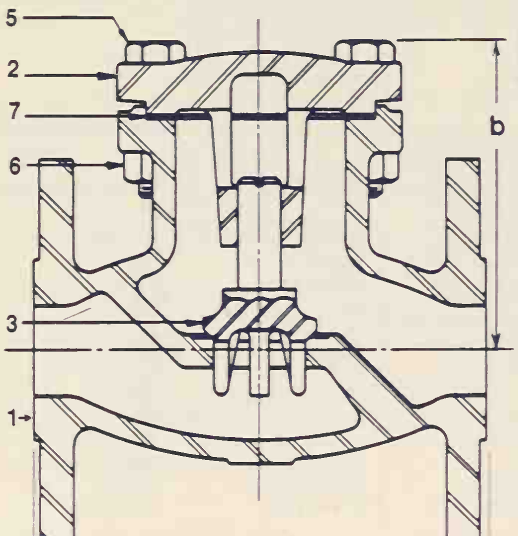
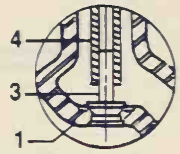


Fig. 557
Sizes ½" to 6"

DESIGN DESCRIPTION:

Horizontal Type
Bolted Cover
Retained Gasket
Regrinding Disc
Integral Seat

Threaded Ends (Fig. 550)
Socket Weld Ends (Fig. 554)
Buttwelding Ends (Fig. 556)
Flanged Ends (Fig. 557)



Disc Detail
Sizes ¼" to ¾" incl.

PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO
1 body*	A351 GR CF8M
2 cover	A351 GR CF8M
3 disc	cast CF8M or wrought type 316
4 disc guide**	type 316
5 cover bolt	A193 GR B8
6 cover bolt nut	A194 GR 8F
7 gasket	comp. asbestos

Remarks: *Body material on threaded and welding end valves is ELC grade. Other Alloys available. (Refer to Introduction)
**Sizes ¼" to ¾" incl.
†Unless otherwise specified, these valves may be supplied at the manufacturer's option with: PTFE Gasket.

Note: For Valve Services at Temperatures above 700°F, the Aloyco Engineering Department should be consulted for materials and features.

DIMENSIONS IN MM AND INCHES:

SIZE	MM / INCH	6 / ¼	10 / ⅜	15 / ½	20 / ¾	25 / 1	40 / 1½	50 / 2	65 / 2½	80 / 3	100 / 4	150 / 6
a (550,554)	mm	79	79	86	95	108	140	165	—	—	—	—
	inch	3⅛	3⅛	3⅜	3¾	4¼	5½	6½				
a (556,557)	mm	—	—	108	117	127	165	203	216	241	292	406
	inch			4¼	4⅝	5	6½	8	8½	9½	11½	16
b	mm	67	67	67	76	86	102	116	133	146	168	200
	inch	2⅝	2⅝	2⅝	3	3⅜	4	4 9/16	5¼	5¾	6⅝	7⅞
d (554)	mm	10	10	10	13	13	13	16	—	—	—	—
	inch	⅜	⅜	⅜	½	½	½	⅝				
d (557)	mm	—	—	11	11	11	14	16	17	19	24	25
	inch			7/16	7/16	7/16	9/16	⅝	11/16	¾	15/16	1

WEIGHTS IN KG AND POUNDS:

550,554	kg	1.4	1.4	1.8	2.3	2.9	5.9	7.3	—	—	—	—
	lb	3	3	4	5	6.3	13	16				
556	kg	—	—	2	2.7	3.4	6.8	10	12	18.6	28	51
	lb			4.5	6	7.5	15	22	26	41	61	112
557	kg	—	—	2.3	3	4.1	8	12.7	14	22	34	68
	lb			5	7	9	17.5	28	31	48	75	150

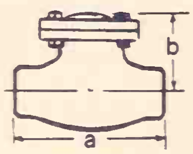


Fig. 556
Buttwelding Ends
½" to 6"

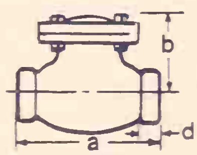


Fig. 550
Threaded Ends
Fig. 554
Socket Weld Ends

APPLICABLE CLASS 150 STANDARDS:

End Flanges, ANSI B16.5
Wall Section, ANSI B16.34
Face-to-Face, ANSI B16.10
Pipe Threads, ANSI B2.1
SW Ends (Bore and Depth), ANSI B16.11
BW Ends (Sch. 40), ANSI B16.25 and B16.10
Pressure-Temp. Ratings, ANSI B16.34-1977

Figure 21-17 Check valve data (*Courtesy of Crane-Aloyco, Inc.*)

STAINLESS STEEL LIFT CHECK VALVES

CLASS 600

FIGURES: 4550-A (½″ to 2″)
4554-A (½″ to 2″)
4557-A (½″ to 2″)

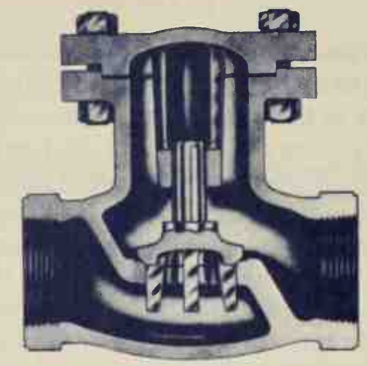


Fig. 4550-A
Threaded Ends

DESIGN DESCRIPTION:

Bolted Cover
Integral Seat
Horizontal Type
Threaded Ends (Fig. 4550-A)
Socket Weld Ends (Fig. 4554-A)
Buttwelding Ends (Fig. 4557-A)

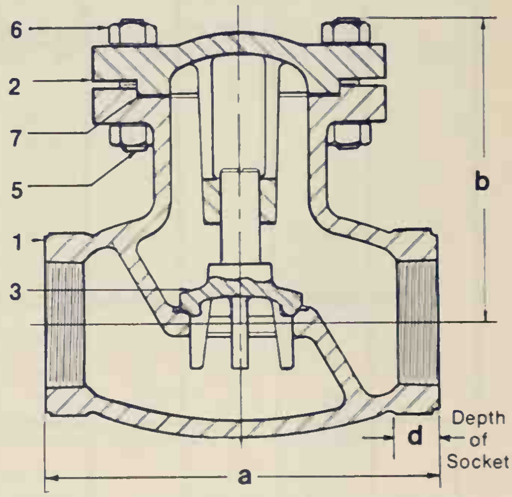
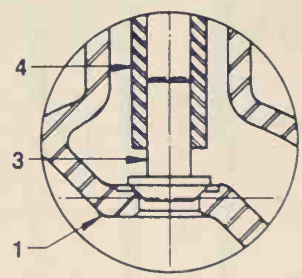


Fig. 4550-A
Sizes ½″ to 2″

PARTS AND MATERIAL LIST:

DESCRIPTION	ALOYCO 18-8 SMO
1 body	A351 GR CF8M
2 cover	A351 GR CF8M
3 disc	type 316
4 disc guide (½″ and ¾″)	type 316
5 cover studbolt	A193 GR B8
6 cover studbolt nut	A194 GR 8F
7 gasket	comp. asbestos

Other Alloys Available. Refer to Introduction.



Disc Detail
Sizes ½″ and ¾″

DIMENSIONS IN MM AND INCHES:

SIZE		15	20	25	40	50
	MM / INCH	½	¾	1	1½	2
a (4550-A, 4554-A)	mm	95	108	127	165	191
	inch	3¾	4¼	5	6½	7½
a (4557-A)	mm	165	191	216	241	387
	inch	6½	7½	8½	9½	15¼
b	mm	94	94	97	148	165
	inch	3 11/16	3 11/16	3 13/16	5 13/16	6½
d (4554-A)	mm	10	13	13	13	16
	inch	⅜	½	½	½	⅝
d (4557-A)	mm	14	16	17	22	25
	inch	9/16	⅝	11/16	⅞	1

WEIGHTS IN KG AND POUNDS:

4550-A, 4554-A	kg	2.3	3	5	10	14
	lb	5	7	11	22	30
4557-A	kg	5	6.3	10	15	22
	lb	11	14	22	32	48

APPLICABLE CLASS 600 STANDARDS:

End Flanges, ANSI B16.5
Wall Section, ANSI B16.34
Face-to-Face, ANSI B16.10
Buttwelding Ends (Schedule 40), ANSI B16.25 and B16.10
Pipe Threads, ANSI B2.1
Pressure-Temperature Rating, ANSI B16.34-1977
Socket Weld Ends (Bore and Depth), ANSI B16.11

Note: For Valve Services at Temperatures above 700°F, the Aloyco Engineering Department should be consulted for materials and features.

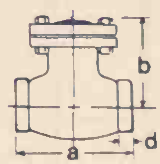


Fig. 4554-A
Socket Weld Ends
½″ to 2″

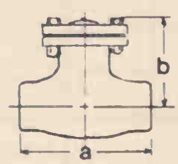


Fig. 4557-A
Buttwelding Ends
½″ to 2″

Figure 21-18 Check valve data (*Courtesy of Crane-Aloyco, Inc.*)

Pipe Drawings

Pipe drawings are used like any other design drawing, to convey the intentions of the designer and engineer to the trades people who will actually construct the piping system. There are two types of pipe drawings: single-line and double-line. Figure 21-19 is an example of a double-line drawing. Figure 21-20 is an example of the single-line version of the same drawing. Single-line drawings, since they are schematic, can be drawn much faster. However, drafters and engineers should be familiar both with double-line and single-line versions of pipe drawings, since both have applications on the job.

Single-Line Drawings

Single-line pipe drawings consist of schematic, symbolic representations of valve fittings connected by a single line that represents the center line of the pipe. Figure 21-21 contains all of the various schematic symbols used for representing pipe fittings and valves on single-line pipe drawings. Figure 21-22 contains the graphic symbols used for representing piping on single-line pipe drawings.

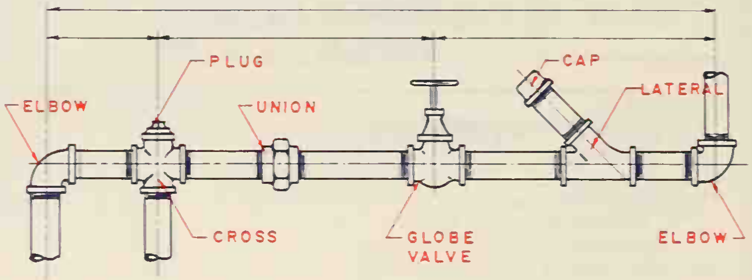


Figure 21-19 Double-line pipe drawing

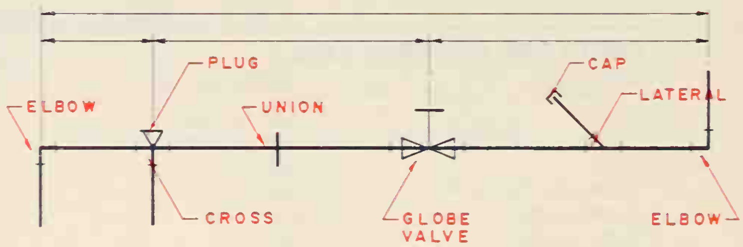


Figure 21-20 Single-line pipe drawing

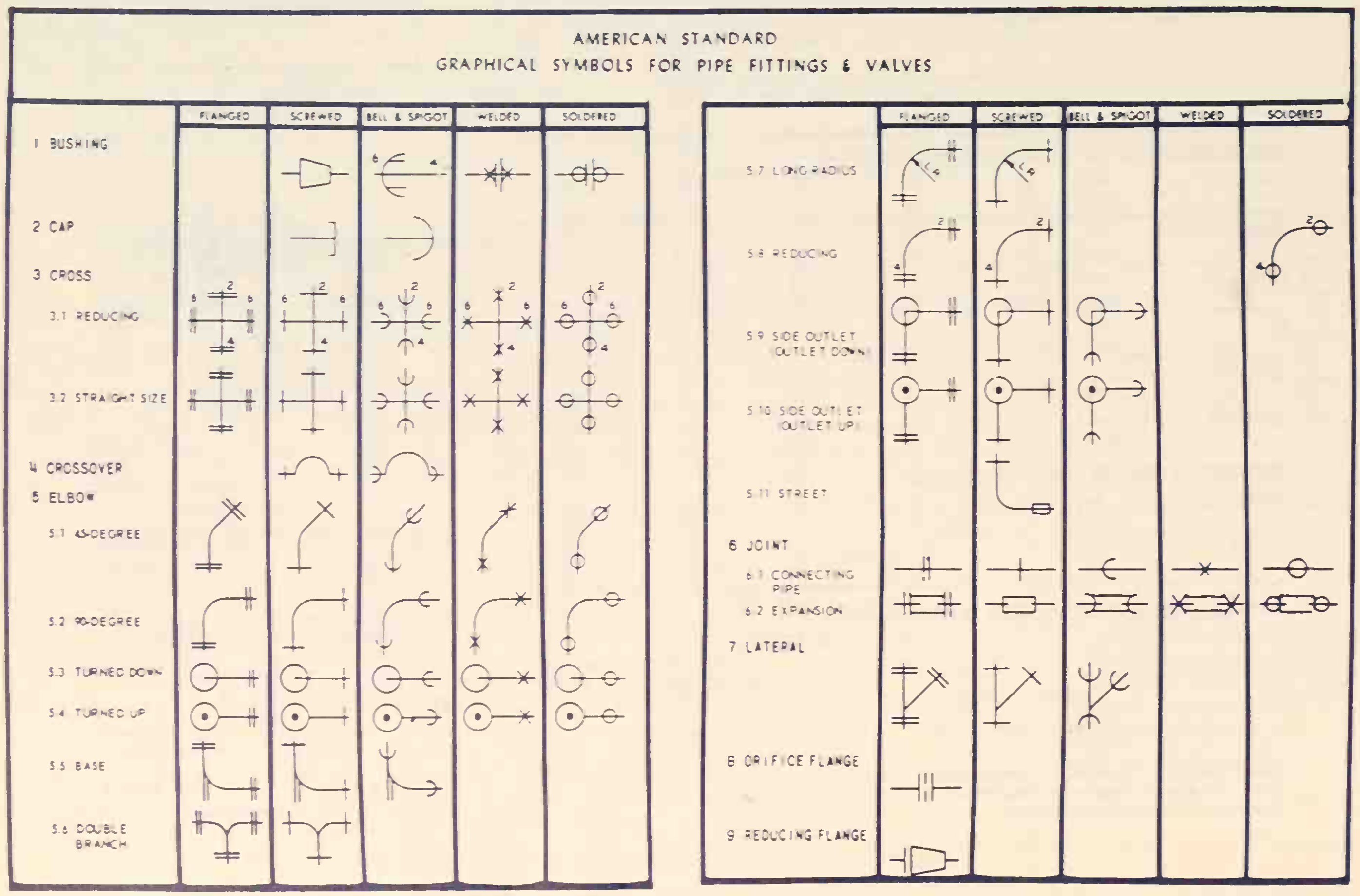


Figure 21-21

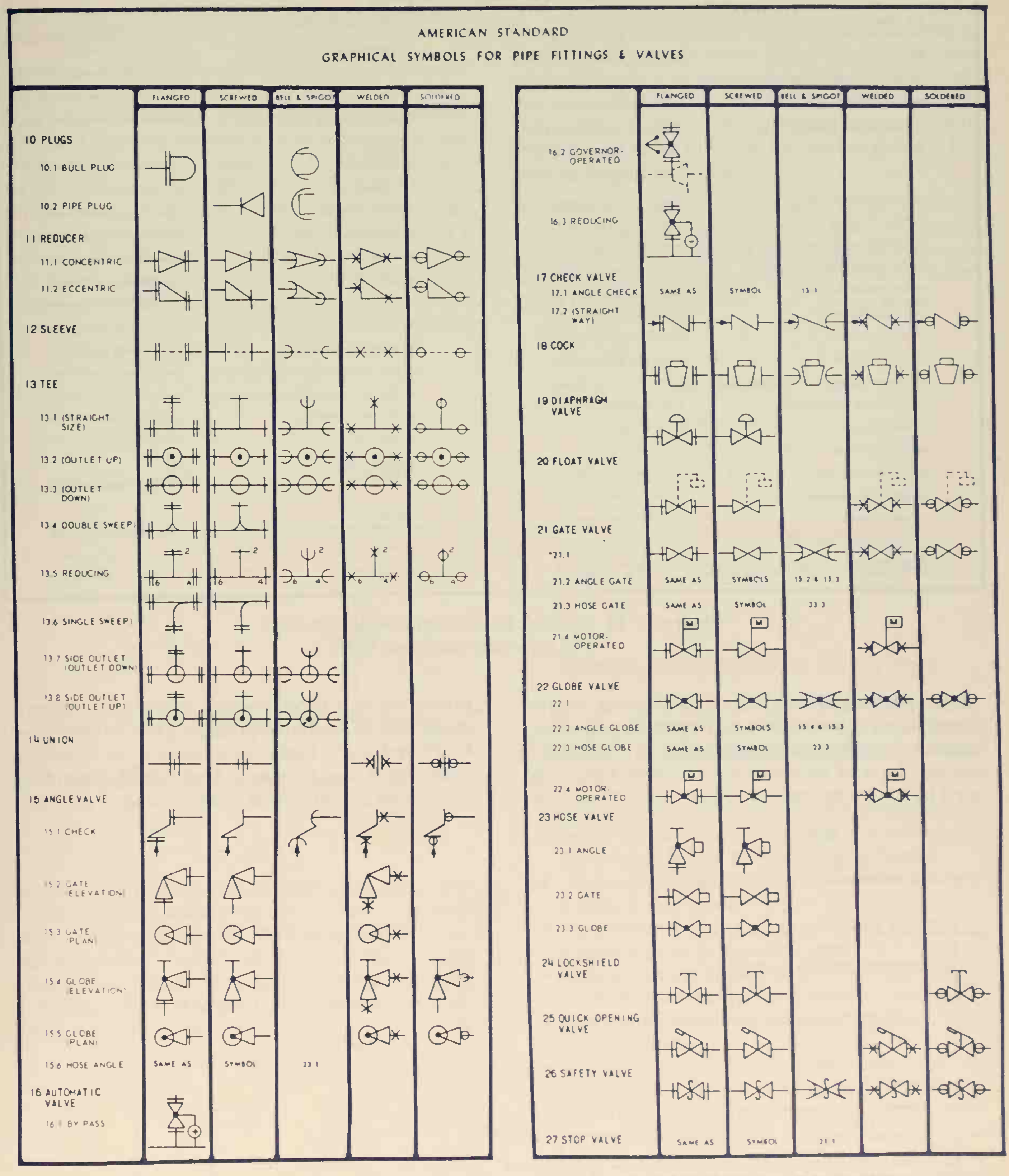


Figure 21-21 Symbols for fittings and valves (*Reprinted from* ASA Z32.2.3—1949. *Courtesy of* ASME)

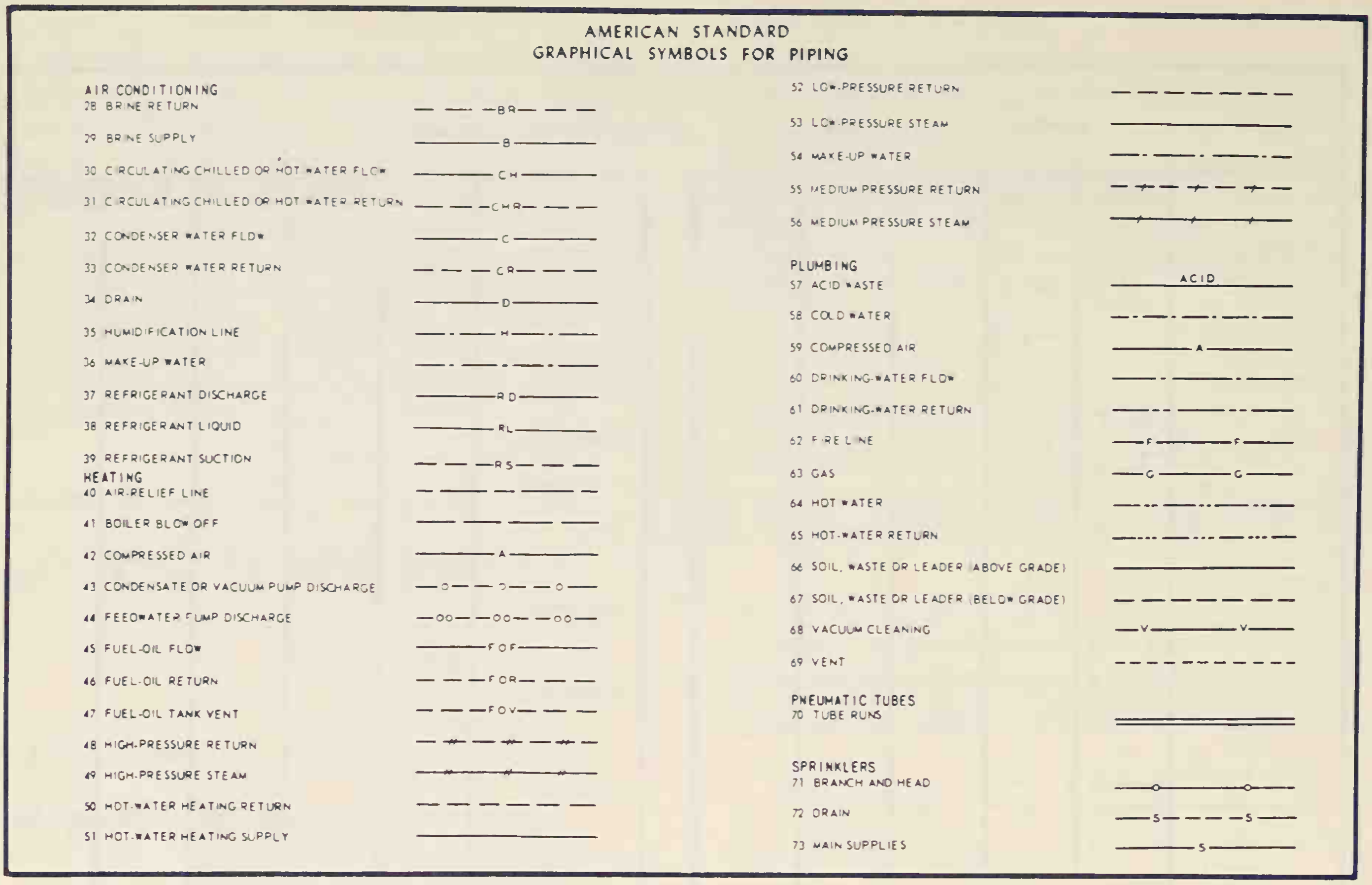


Figure 21-22 Symbols for piping (*Reprinted from* ASA Z32.2.3—1949. *Courtesy of* ASME)

Like mechanical drawings, pipe drawings may be drawn using orthographic or isometric projection. Single-line orthographic projection is the recommended form of representation in most cases. Figure 21-23 is an example of single-line orthographic projection of a pipe drawing. Single-line isometric projection, as illustrated in Figure 21-24, is often used for assembly and layout work because the drawing is easier for trades people to understand. Regardless of whether you are using orthographic or isometric

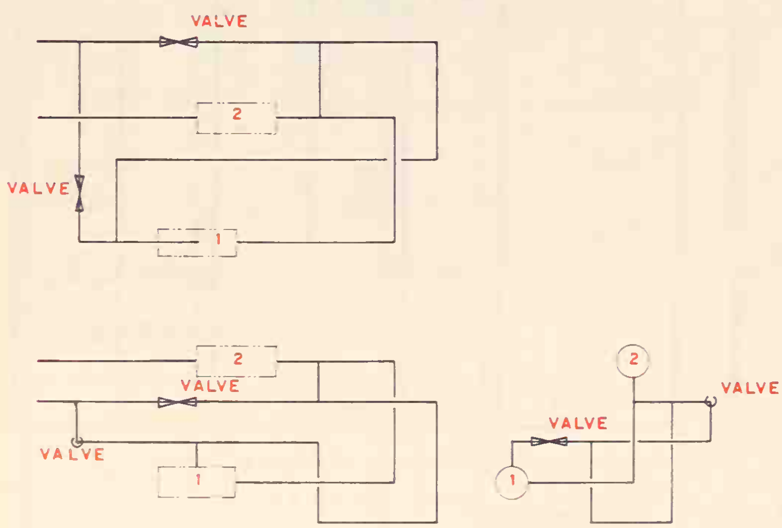


Figure 21-23 Orthographic single-line pipe drawing

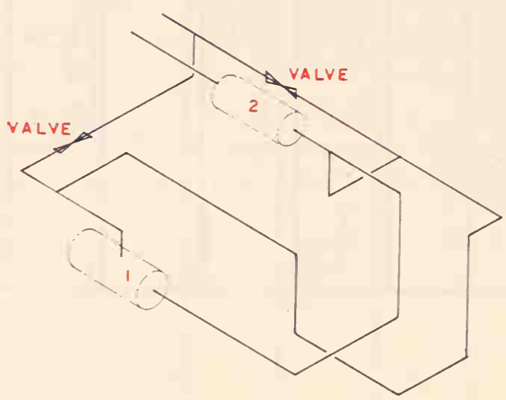


Figure 21-24 Isometric single-line pipe drawing

projection, there are certain drawing conventions with which you should be familiar. The most important of these are crossings, connections, fittings, and machine/devices.

Crossings. When lines representing pipe on a drawing cross but do not intersect or make connections, they are usually drawn without breaks. However, on occasion it will be necessary to show breaks so that trades people using the plans will be absolutely sure as to which pipe is nearest to them and which is farthest away. When such a need arises, breaks can be used as illustrated in Figure 21-25. When using a break, it should be wide enough to be easily seen but not so wide as to create an inordinate gap. A widely used rule of thumb is to make the break from five to ten times the thickness of the lines representing the pipe.

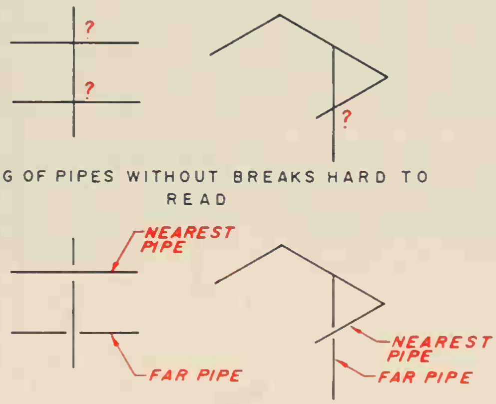


Figure 21-25 Drawing crossing pipe

Connections. All of the various means of making connections at joints and fittings fall into two categories: permanent and detachable. On single-line pipe drawings, permanent connections are indicated by using a heavy dot. Detachable connections are indicated by a single thick line. Both of these methods are illustrated in Figure 21-26.

Figure 21-26 Drawing pipe connections

Fittings. When drawing fittings on single-line drawings it is sometimes necessary to be able to indicate whether a pipe is coming toward the viewer or going away from the viewer. It is also necessary at times to indicate whether the viewer is looking at a front view of the fitting or a rear view. All of the various different types of single-line drawing situations that you may confront when drawing fittings are covered in Figure 21-21. Refer to Figure 21-21 when drawing any type of single-line fitting symbol.

Machines and Devices. Most piping systems will tie into machines, devices, and other types of apparatus, Figure 21-27. When this is the case, the machines, devices, and other types of apparatus can be drawn using thin phantom lines.

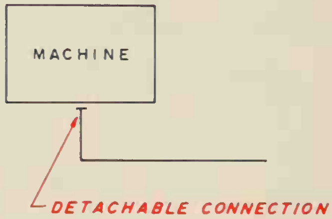


Figure 21-27 Drawing adjoining machinery

Dimensioning Pipe Drawings

There are several dimensioning rules that apply specifically to pipe drawings with which you should be familiar. The most important of these are summarized below.

- Dimensions for pipes and pipe fittings should be shown from center to center of pipe and to the outside face of the pipe end or flange.
- The length of pipe is not shown on the drawing except in rare cases.
- Pipe sizes are shown on the drawing using leader lines or as a general note.
- Fitting sizes are shown on the drawing using leader lines or as a general note.
- Pipes with bends should be dimensioned from vertex to vertex.
- The radii of bent pipe should be indicated using a leader line. Supplementary angles of bent pipes should be dimensioned in the normal manner.
- Outside diameters and wall thicknesses of pipe may be indicated on the drawing using a leader line or may be made part of a general note.
- A bill of material should be developed and placed directly on the pipe drawing or attached to it.

Single-Line Isometric Piping Drawings

Isometric piping drawings are prepared in a manner similar to mechanical piping drawings. The lines representing pipes are drawn parallel to either the X, Y, or Z axis, Figure 21-28. Flanges are represented using short strokes of equal thickness, Figure 21-29. Notice that flanges for horizontal pipe are drawn vertically and flanges for vertical pipe are drawn at the appropriate 30° angle to the horizontal.

Figure 21-30 illustrates the various methods used for drawing valves. The unidirectional dimensioning illustrated in Figure 21-31 should be used in isometric piping drawings.

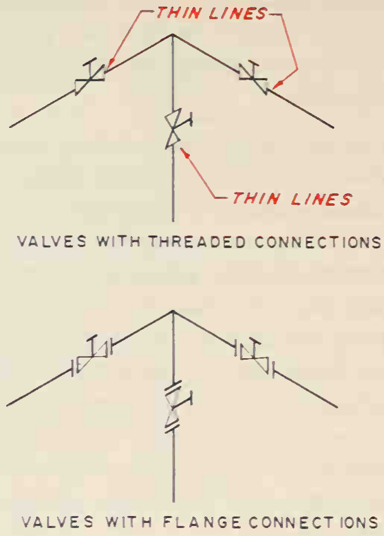


Figure 21-30 Drawing valves

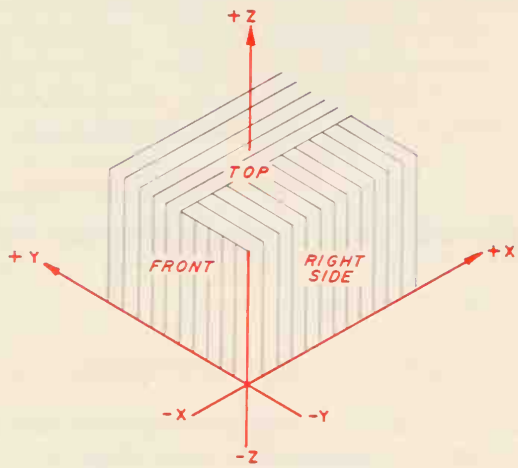


Figure 21-28 Isometric axes

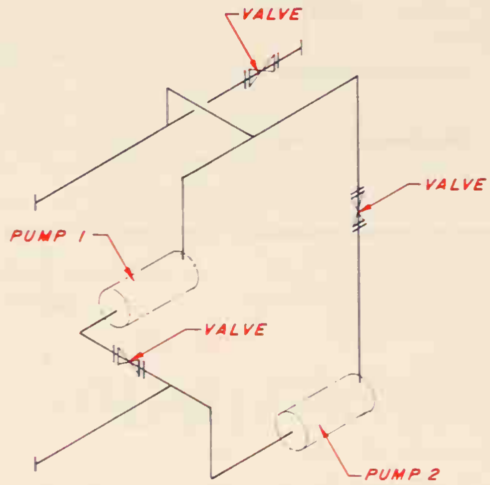


Figure 21-31 Isometric pipe drawing

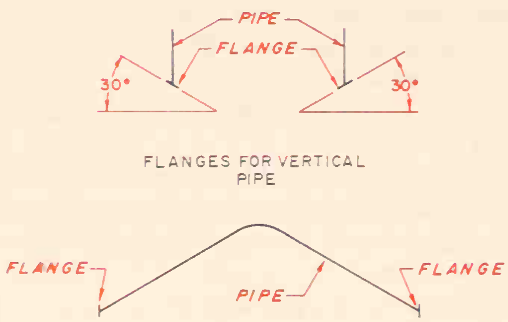


Figure 21-29 Drawing flanges

Review

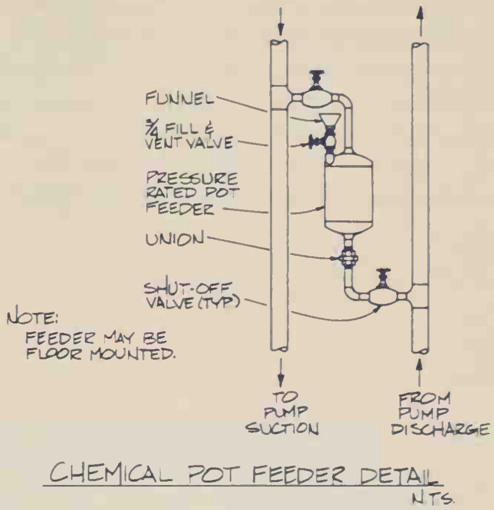
1. Explain why engineering and drafting students should be proficient in the preparation of pipe drawings.
2. What are the five most widely used types of pipe?
3. What are the three broad classifications of pipe fittings?
4. What are the three most widely used categories of valves?
5. Sketch the symbols for the following:

Flanged lateral	Fuel-oil flow
Screwed sleeve	Hot-water heating return
Welded union	Low-pressure steam
Flanged gate valve	Cold-water line
Screwed globe valve	Gas line

Chapter Twenty-One Problems

Problem 21-2

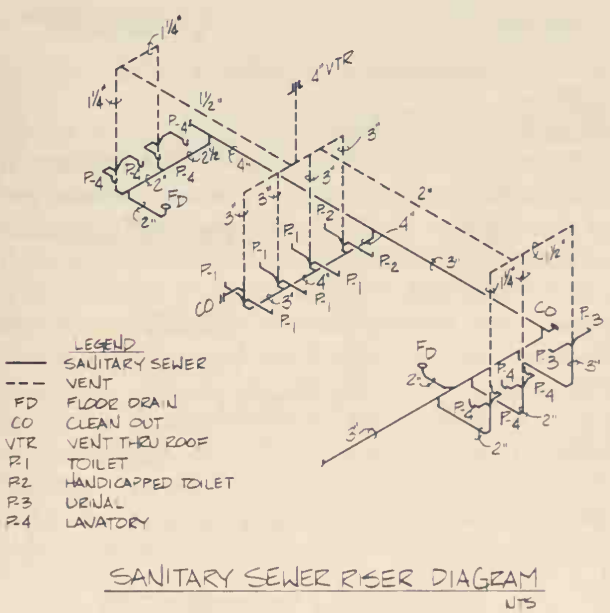
Problem 21-2 is a double-line orthographic pipe drawing. Convert it into a single-line orthographic drawing.



Problem 21-2

Problem 21-1

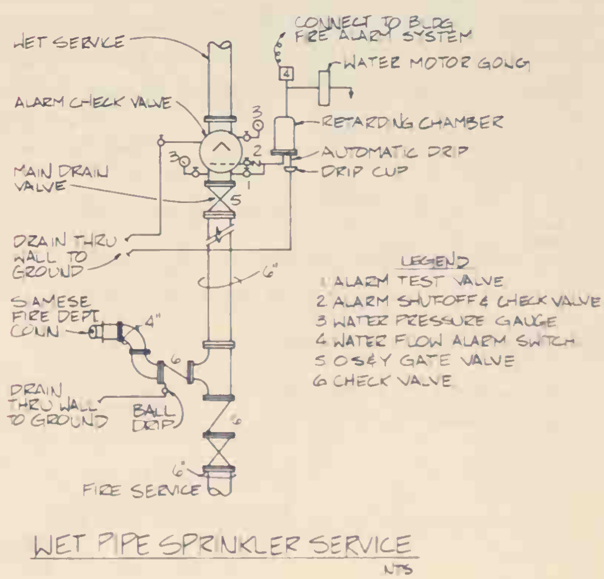
Problem 21-1 is a single-line isometric pipe drawing. Convert this drawing into a single-line orthographic drawing showing the following views of the system: top, front, right side, and left side.



Problem 21-1

Problem 21-3

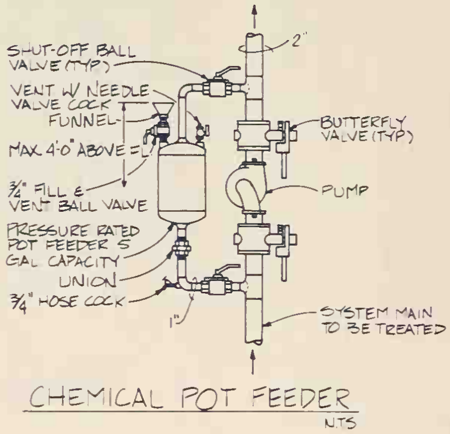
Problem 21-3 is a double-line orthographic pipe drawing. Convert it into a single-line orthographic drawing.



Problem 21-3

Problem 21-4

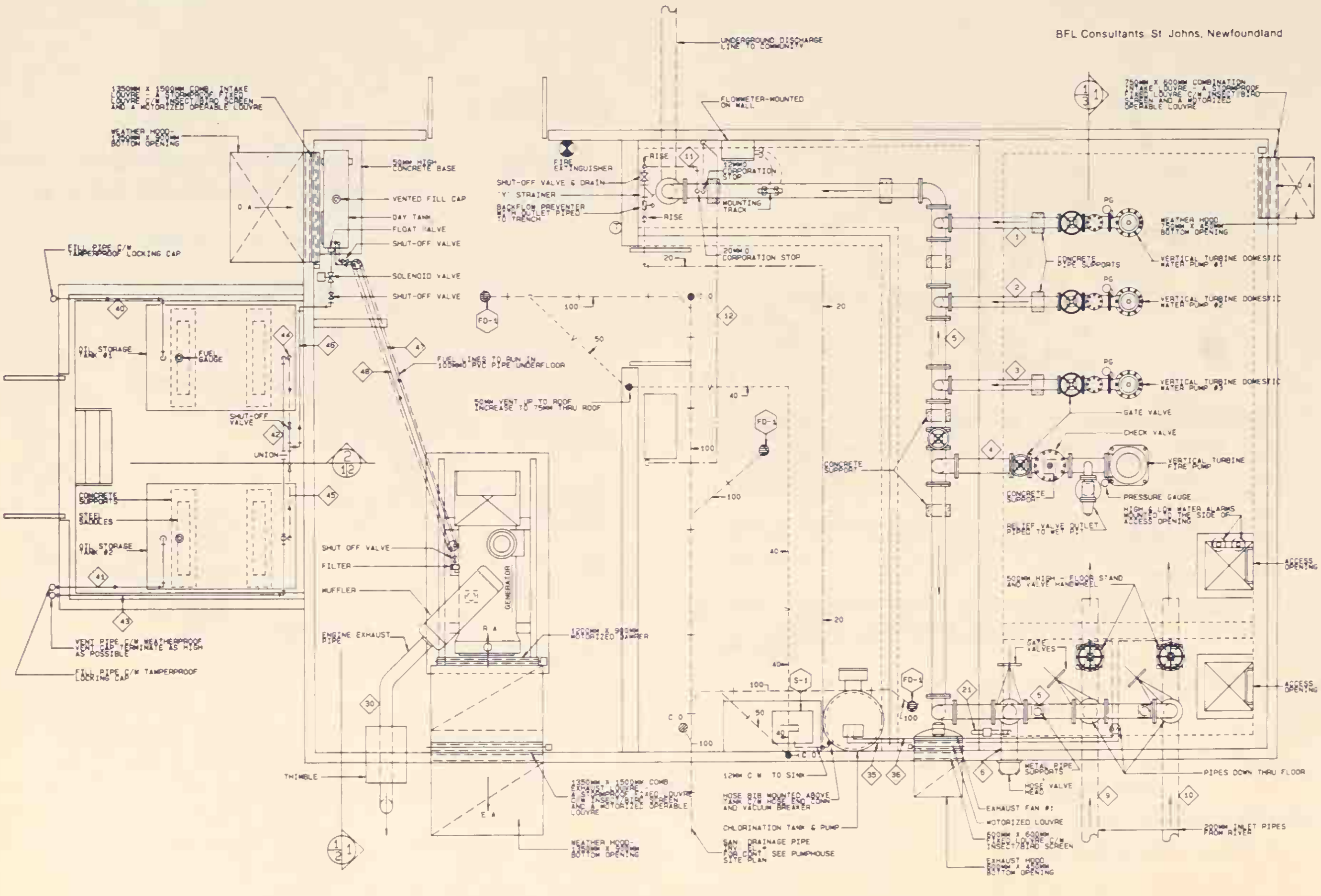
Problem 21-4 is a double-line orthographic pipe drawing. Convert it into a single-line orthographic drawing.



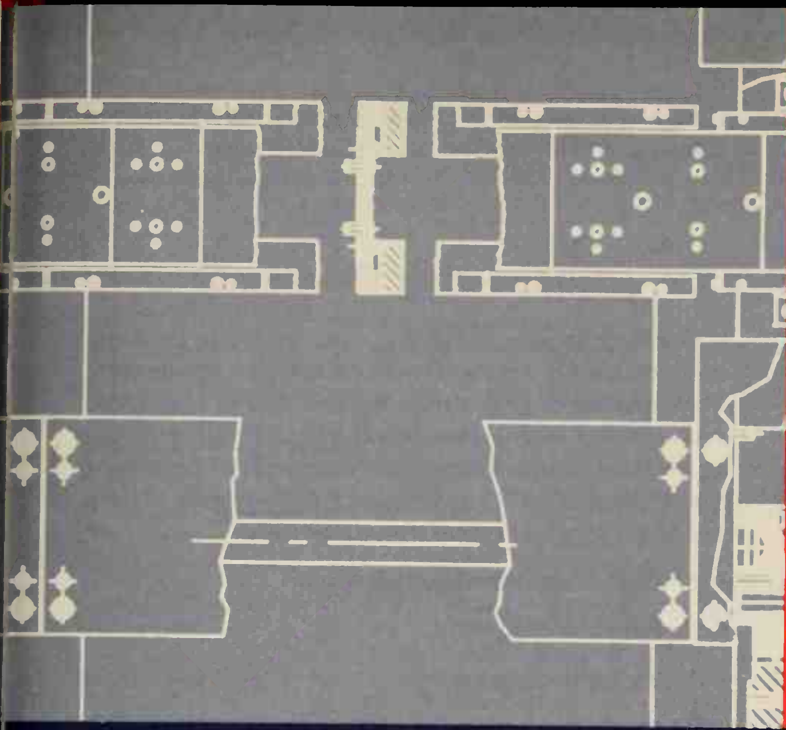
Problem 21-4

Problem 21-5

Problem 21-5 is a double-line representation of a piping system. Reconstruct the drawing as shown in single-line representation.



Problem 21-5 Courtesy VersaCAD, Inc.



CHAPTER 22

Electrical engineers use a variety of different types of drawings to communicate their designs. The most prominent of these are schematic, connection, block, and logic diagrams, and printed circuit board drawings. Each of these different types of drawings is covered in this chapter. However, before attempting to prepare an electronics drawing, engineers and drafters must become familiar with the various symbols used.

ELECTRONIC DRAFTING

Electronics Symbols

Electronic products are made of numerous different types of electronic components. Each of these components can be represented symbolically and pictorially. The most frequently used components are antennas, batteries, capacitors, diodes, grounds, inductors, meters, resistors, switches, transformers, and transistors. Other less frequently used components include amplifiers, bells, buzzers, circuit breakers, connectors, crystals, delays, envelopes, fuses, headsets, lamps, motors, magnets, phase shifters, pickup heads, rectifiers, relays, relay coils, repeaters, safety interlocks, speakers, terminal boards, thermal elements, and thermocouples. Figure 22-1 illustrates the symbols for these electronic components.

Schematic Diagrams

Schematic diagrams are used to show what components are contained on a circuit board and which components connect with which, Figure 22-2. It should be noted that the actual location of a component on a circuit board cannot be determined by looking at a schematic diagram. Schematics show components and connections, but they do not show their actual locations.

Rules for Drawing Schematics

Drafters prepare finished schematic diagrams from sketches provided by engineers. Figure 22-3 is an example of an engineer's sketch and the corresponding finished schematic diagram. The general rules which should be applied in drawing schematic diagrams are:

1. Inputs go left.
2. Outputs go right.
3. Break connectors and jumble pins.
4. Grounds point downward.
5. Curved side of capacitors points to ground.
6. Arrange relay symbols.
7. Remove doglegs.
8. Avoid crossovers.
9. Don't cramp and crowd components.
10. Group leads.
11. Remove four-way ties.
12. Number symbols from left to right and top to bottom.

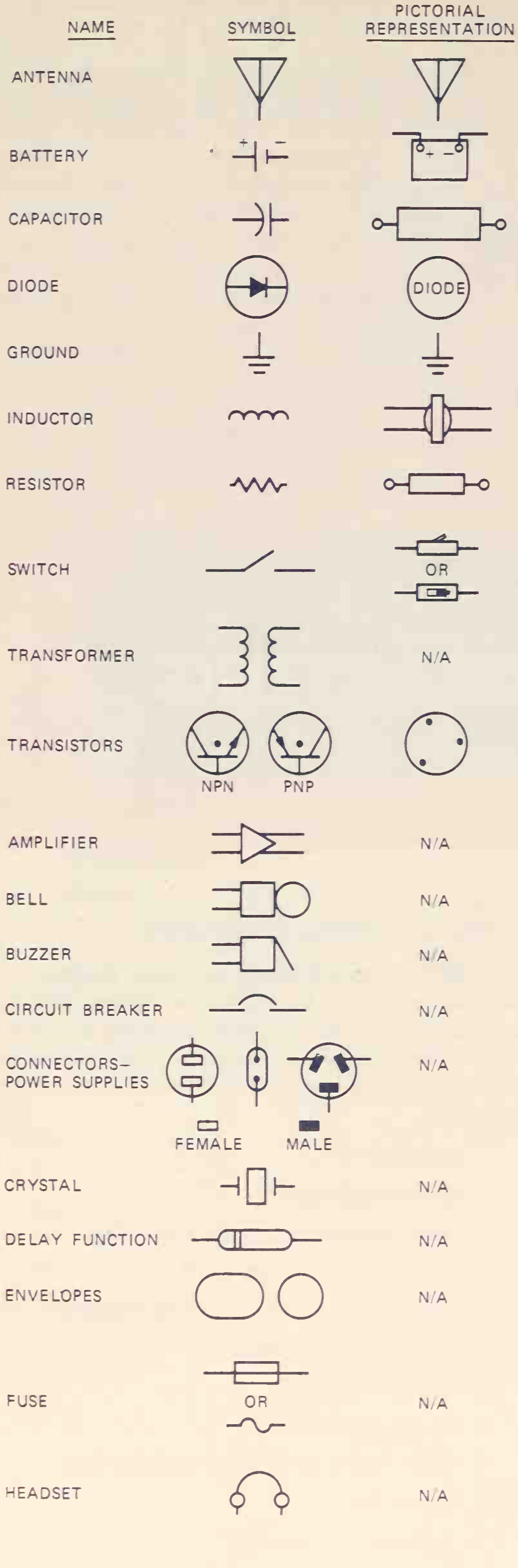


Figure 22-1 Electronics drafting symbols

Figure 22-4 is an example of a schematic diagram drawn according to the rules stated above.

Connection Diagrams

Connection diagrams are used to show how the components in an electronic system are connected. They are used as a guide in assembling electronic systems and maintaining electronic equipment. You might have used a connection diagram in connecting a new stereo, VCR, or compact disk system. There are four types of connection diagrams:

1. Point-to-point diagrams
2. Baseline diagrams
3. Highway diagrams
4. Lineless diagrams

Point-to-Point Diagrams

This type of connection diagram shows the various terminal connection locations and the routing paths of every wire in an electronic system. Point-to-point diagrams are used primarily with simple circuits. They can be difficult to read when circuits are complex and contain many wires. Figure 22-5 is an example of a point-to-point diagram. The steps in drawing such a diagram are:

1. Draw the various electronic components in the actual locations they hold in the circuit.
2. Draw the wire paths.
3. Label the wire colors.

Baseline Diagrams

This type of connection diagram shows all wire paths running into a single baseline. Baseline diagrams are easier to read and follow than point-to-point diagrams, but they can be misleading because they do not show the electronic components in their proper positions. Figure 22-6 is an example of a baseline diagram. The following steps are used in drawing such a diagram:

1. Draw a thick single line that will serve as the baseline.
2. Draw the electronic components placing half above the baseline and half below it.
3. Draw lines from each connection point to the baseline. The lines must be perpendicular to the baseline.
4. Label each wire path with a destination code.

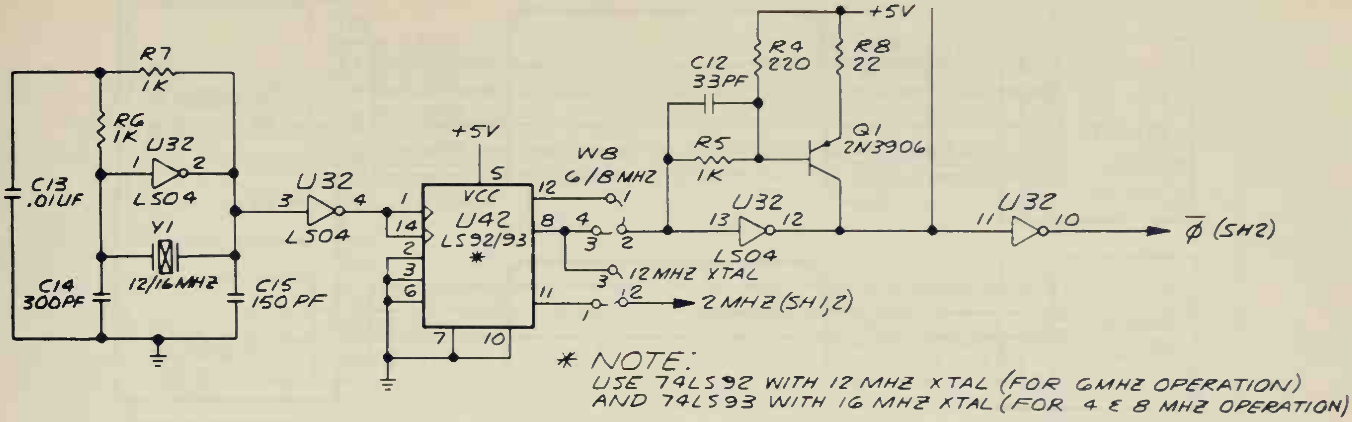


Figure 22-2 Schematic diagram (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick,* ©1989 *by Delmar Publishers Inc.*)

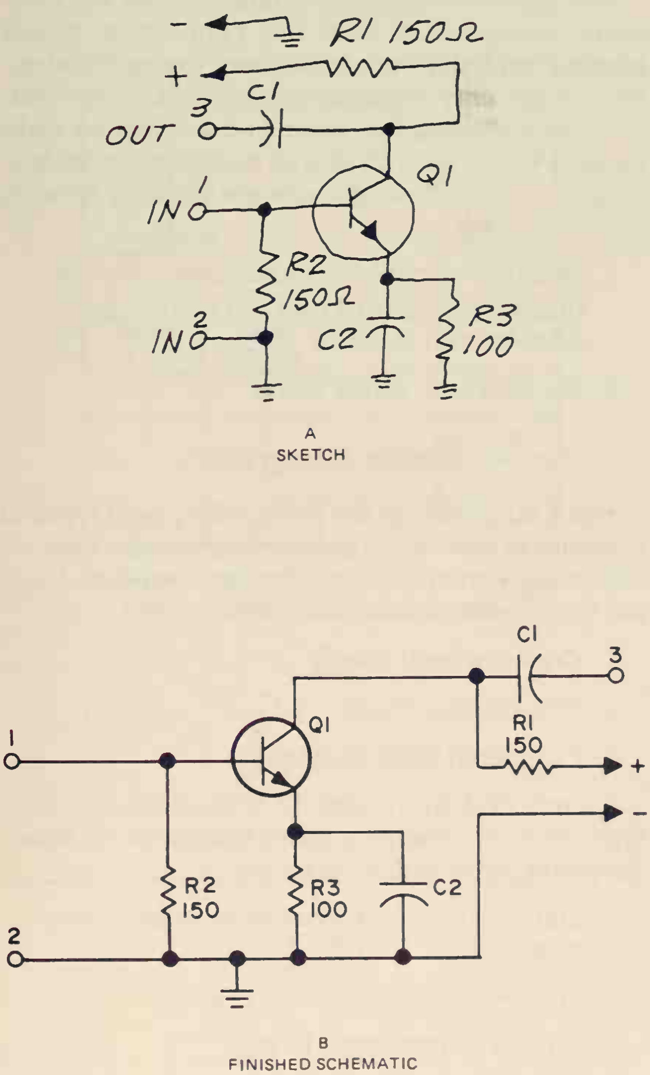


Figure 22-3 Sketch with finished schematic (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick,* ©1989 *by Delmar Publishers Inc.*)

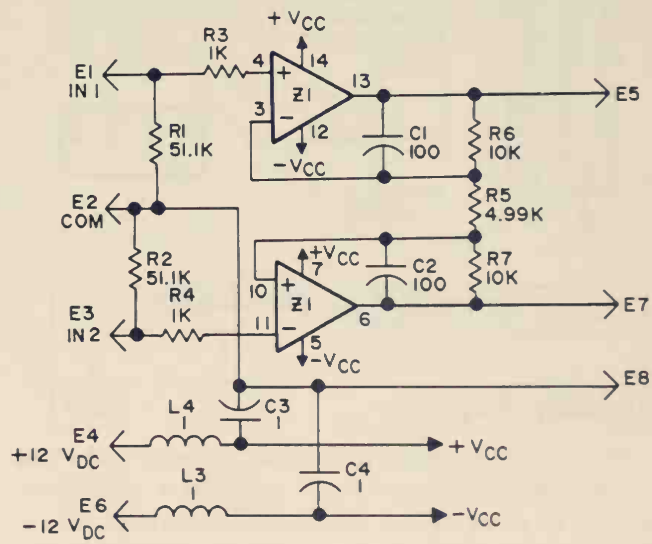


Figure 22-4 Schematic diagram (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick,* ©1989 *by Delmar Publishers Inc.*)

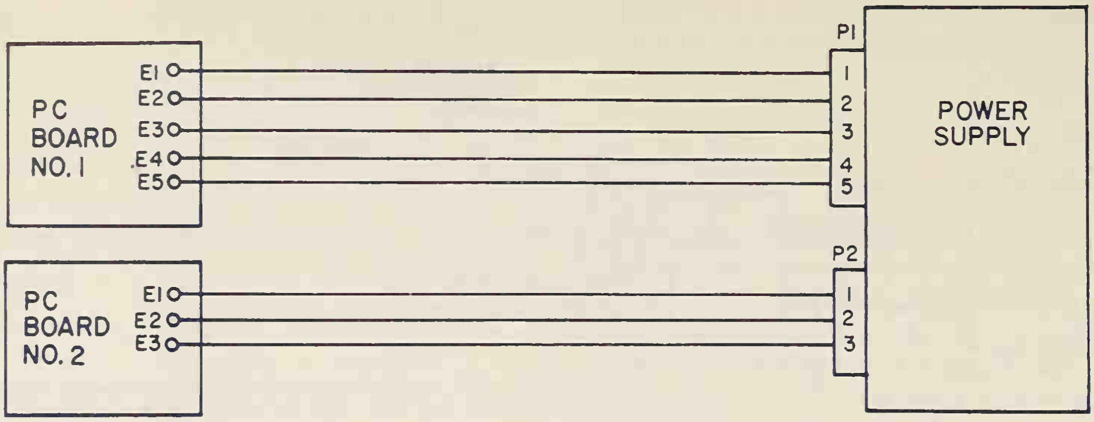


Figure 22-5 Point-to-point diagram (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, *by* James M. Kirkpatrick, ©1989 *by* Delmar Publishers Inc.)

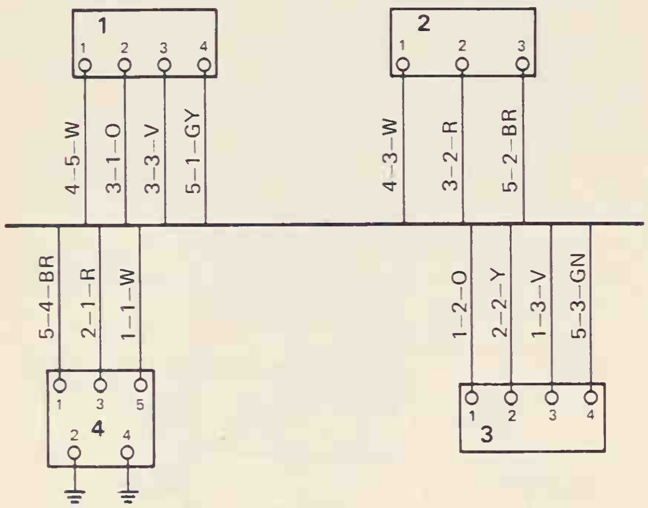


Figure 22-6 Baseline diagram

Highway Diagrams

This type of connection diagram collects wires that run along similar paths and combines them into groups of wires called "highways." As with point-to-point diagrams, the components are located in the positions they will hold in the actual circuit. Figure 22-7 is an example of a highway diagram. The following steps are used in drawing such a diagram:

1. Draw the electronic components in their proper positions.
2. Lightly sketch in the wire paths to determine where potential highways exist.
3. Darken the highways, the lines from the connection points to the highways, and the components.
4. Label the wire paths with a destination code, component number, and wire color.

Lineless Diagrams

This type of connection diagram shows the electronic components with the connection points labeled, but it does not show wires. Instead of wires, the components are accompanied by a table which contains a designation, color, and destination code for each wire. Figure 22-8 is an example of a lineless diagram. The following steps are used in drawing such a diagram:

1. Draw the electronic components in the approximate locations they will hold in the actual circuit.
2. Construct the wiring table.

Block Diagrams

Block diagrams are the most widely used types of diagrams in electronics engineering settings. They are also used a great deal in other applications. There are three types of block diagrams.

1. Organizational charts
2. Process flow charts
3. Functional block diagrams

Figures 22-9, 22-10, and 22-11 illustrate the three types of block diagrams. Block diagrams are drawn according to the following steps:

1. Lightly lay out the boxes at an approximate size.
2. Lightly lay out connecting lines.
3. Darken all horizontal lines.
4. Darken all vertical lines.
5. Draw circles (when required).
6. Draw arrowheads.
7. Letter text moving from left to right.

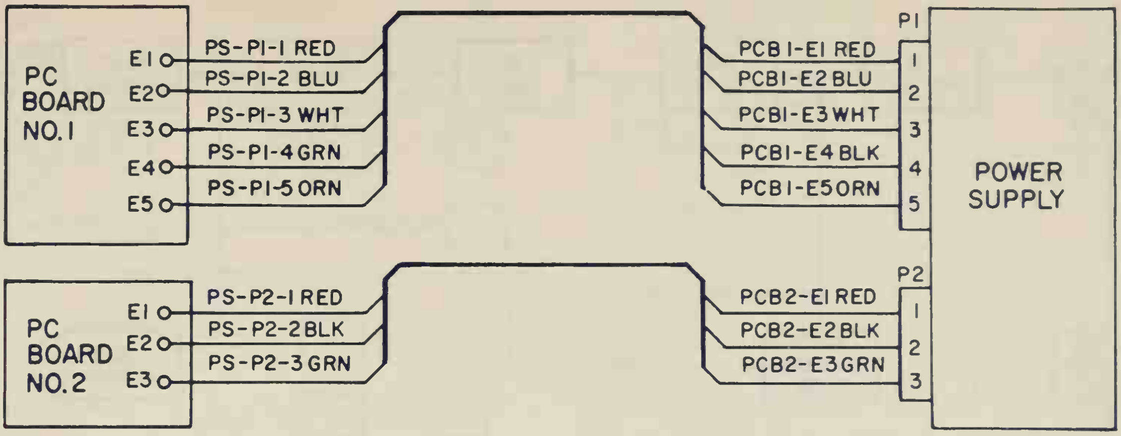
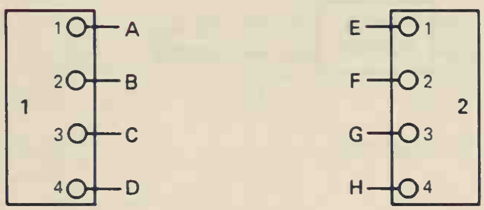


Figure 22-7 Highway diagram (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick,* © 1989 *by Delmar Publishers Inc.*)



WIRE I.D.	WIRE COLOR	FROM	TO
A	W	1–1	2–4
B	V	1–2	2–3
C	Y	1–3	2–2
D	BL	1–4	2–1

Figure 22-8 Lineless diagram

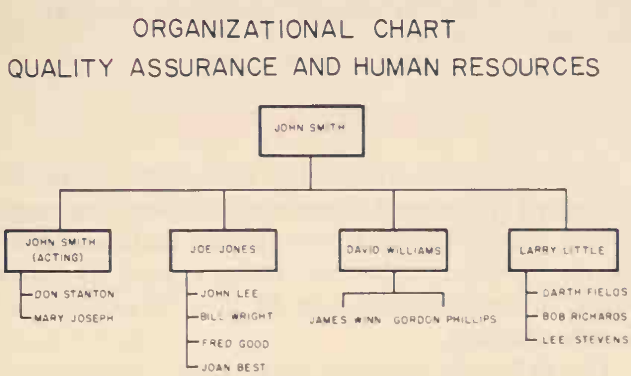


Figure 22-9 Organizational chart

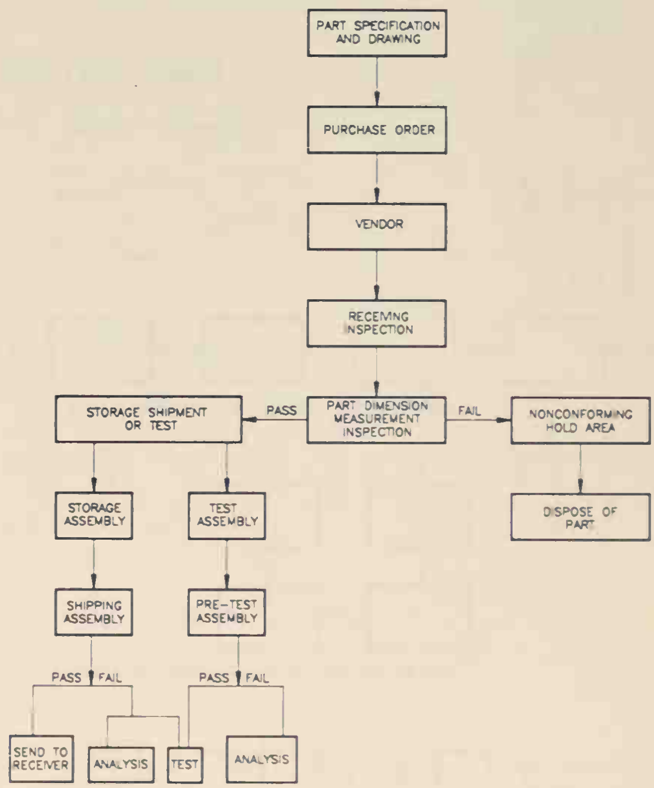


Figure 22-10 Process flow chart

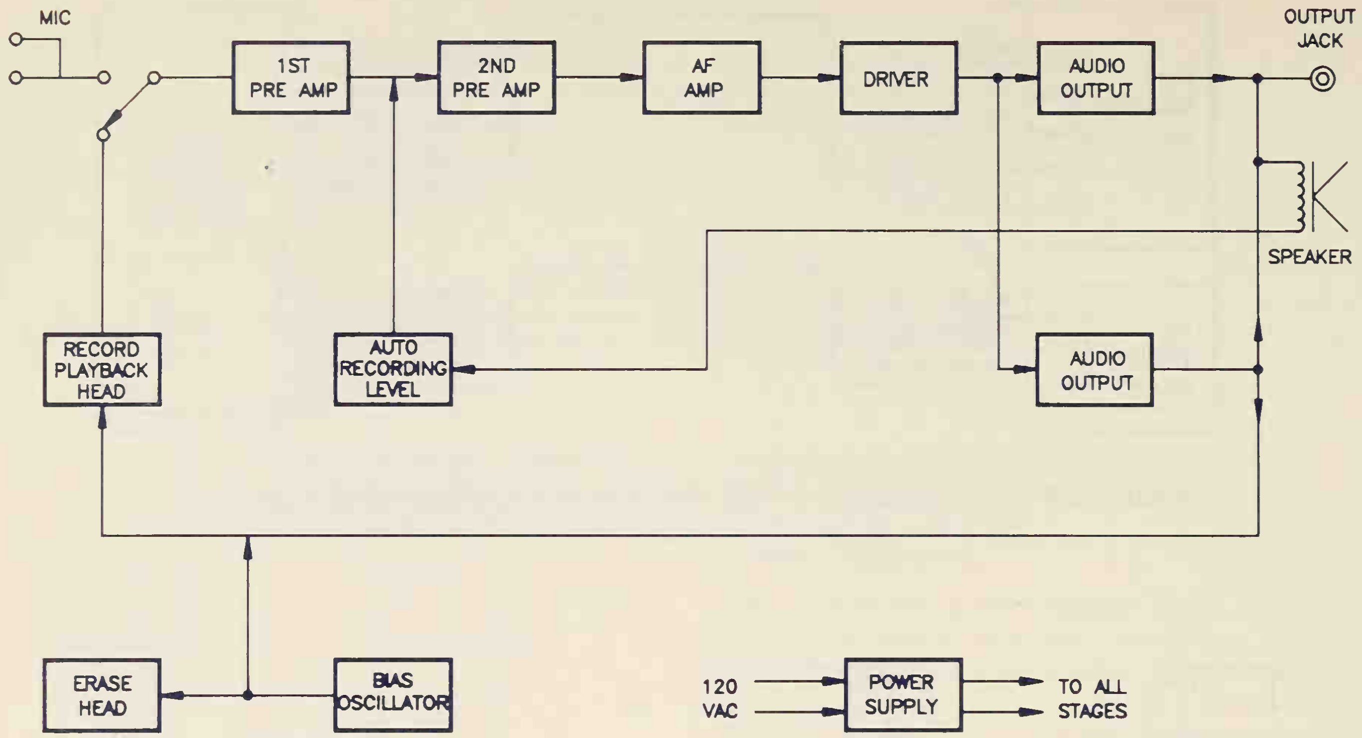


Figure 22-11 Functional block diagram

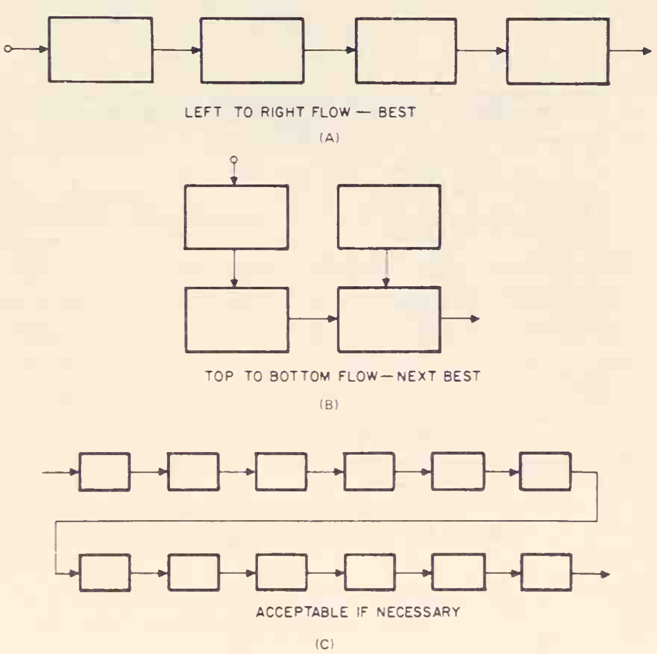


Figure 22-12 Acceptable flow patterns (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick,* © 1989 *by Delmar Publishers Inc.*)

Rules for Drawing Block Diagrams

There are several rules of thumb which should be observed where drawing block diagrams. These rules lend a degree of standardization to block diagrams and make them easier to read.

1. Whenever possible, draw all boxes the same size.
2. Whenever possible, show the flow from left to right (Figure 22-12).
3. When a left-to-right flow is not possible, top-to-bottom flow is acceptable.
4. Crossovers and doglegs should be avoided (Figure 22-13).

Logic Diagrams

Logic diagrams are used in conjunction with the design of integrated circuits (ICs). They are most widely used with electronic circuits that are based on the binary numbering concept, such as those found in computers. Figure 22-14 is an example of a logic diagram.

The principle components in logic diagrams are called "gates." A gate is a miniature circuit that performs a specific function within a larger circuit. The

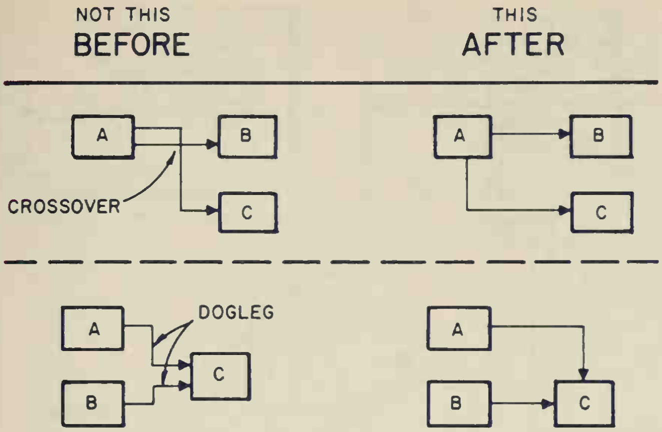


Figure 22-13 Avoiding crossovers and doglegs (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)

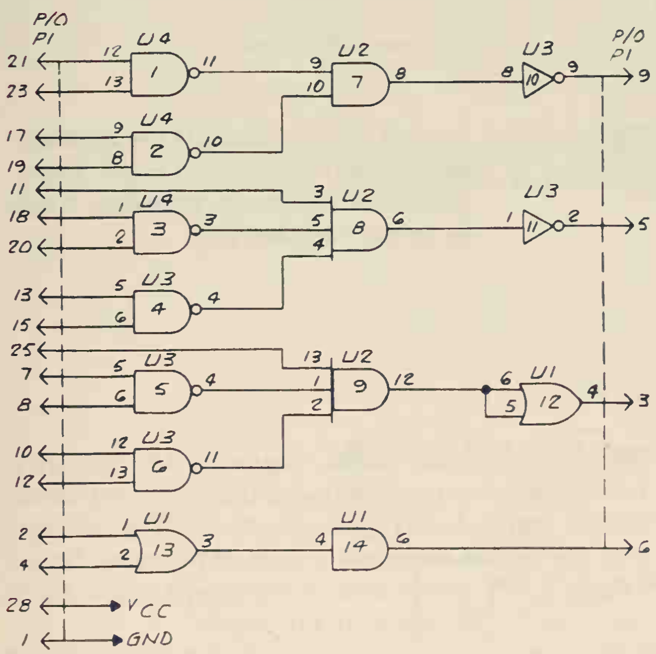
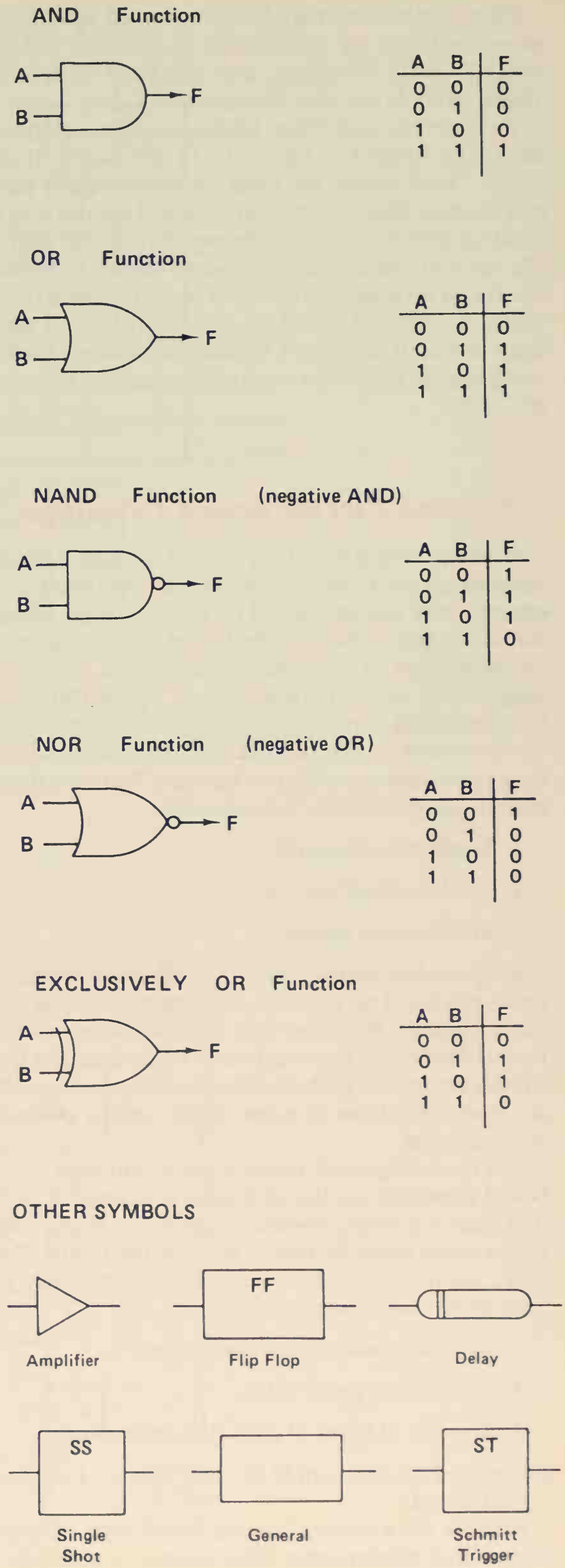


Figure 22-14 Logic diagram (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)

most widely used gates are illustrated in Figure 22-15. The gates are:

1. AND gate
2. OR gate
3. NAND gate (negative AND gate)
4. NOR gate (negative OR gate)



AND Function

A	B	F
0	0	0
0	1	0
1	0	0
1	1	1

OR Function

A	B	F
0	0	0
0	1	1
1	0	1
1	1	1

NAND Function (negative AND)

A	B	F
0	0	1
0	1	1
1	0	1
1	1	0

NOR Function (negative OR)

A	B	F
0	0	1
0	1	0
1	0	0
1	1	0

EXCLUSIVELY OR Function

A	B	F
0	0	0
0	1	1
1	0	1
1	1	0

Figure 22-15 Logic symbols

Other symbols that are frequently used with these gates are those for AMPLIFIER, FLIP FLOP, DELAY, SINGLE SHOT, GENERAL and SCHMITT TRIGGER. These symbols are also illustrated in Figure 22-15.

The number and letter tables which accompany each gate symbol in Figure 22-15 are called "truth tables." Truth tables are used for analyzing the various outputs that a particular gate will produce as a result of different combinations of inputs. For example, an AND gate such as the one shown in Figure 22-15 can be analyzed using its accompanying truth table. An input of "O" at "A" and "1" at "B" will produce an ouput of "O" at "F." Logic diagrams are drawn using special templates or symbols menus in the case of CADD.

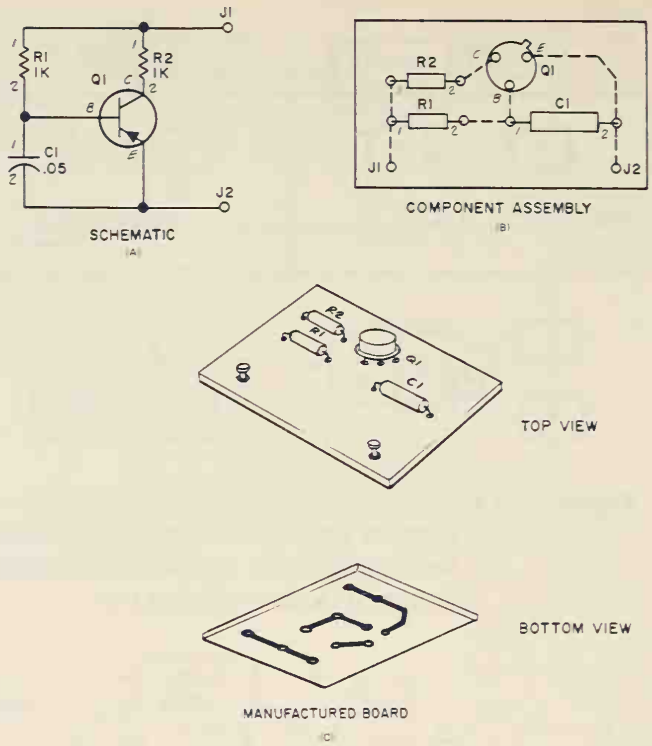


Figure 22-16 Printed circuit boards (*From Electronic Drafting and Printed Circuit Board Design, 2nd Edition, by James M. Kirkpatrick, © 1989 by Delmar Publishers Inc.*)

Printed Circuit Board Drawings

A printed circuit board is a special laminated board upon which electronic components are mounted. The components are connected by metal "traces" which run along the surface of the board. Figure 22-16 is an illustration of a printed circuit board. This is a single-sided printed circuit board. In the top view, the electronics components can be seen as mounted on the board. In the bottom view, the traces which connect the components can be seen. There are three main types of printed circuit boards:

1. Single-sided boards
2. Double-sided boards
3. Multilayered boards

Single-sided boards have the electronic components mounted on one side and the connecting circuit etched on the other side. Double-sided boards have components mounted on one side also, but the circuits are etched on both sides. Multilayered boards are made up of two or more single- and/or double-sided boards.

The most frequently made types of printed circuit board drawings are the drill plan and artwork. The drill plan is a typical mechanical drawing that shows where holes are to be drilled through the board. The drill plan includes a hole schedule that contains at least three components.

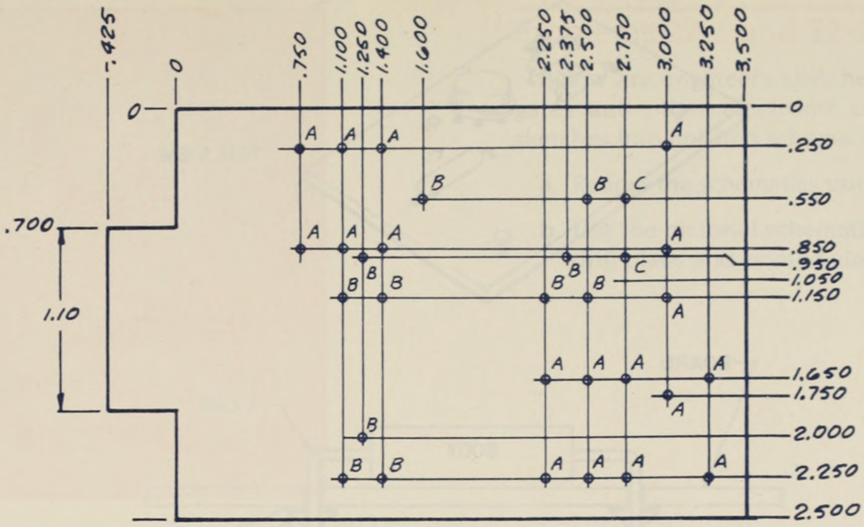
1. Hole designation (usually a letter)
2. Hole size or description
3. Number of holes of each designation

Figure 22-17 is an example of a drill plan for a printed circuit board.

Artwork for a printed circuit board may be produced on a photoplotter, CAD system, or with tape. The artwork shows the circuit that will be etched on the printed circuit board, Figure 22-18. Artwork is usually layed out at least twice the size of the actual board, and reduced photographically. Figure 22-18 also shows the component side of the same board. Figure 22-19 shows how components are actually mounted on a printed circuit board.

The process of preparing printed circuit board drawings involves four steps.

1. Study the schematic and make a list of all electronic components it contains.
2. Redraw the schematic, substituting pictorial representations of each symbol. You will have to consult manufacturers catalogs for the dimensions of components.
3. Rearrange the components in such a way as to produce the best conductor paths for the circuit. Avoid arrangements that will cause sharp turns, acute angles, and doglegs in conductor paths. Keep the paths as short as possible.
4. Prepare the printed circuit board drawings at a scale of 2, 3, 4, or 5 to 1.



HOLE SCHEDULE		
LTR	DESCRIPTION	QTY
A	.040 DIA	18
B	.031 DIA	11
C	.020 DIA	2

Figure 22-17 Drill plan (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)

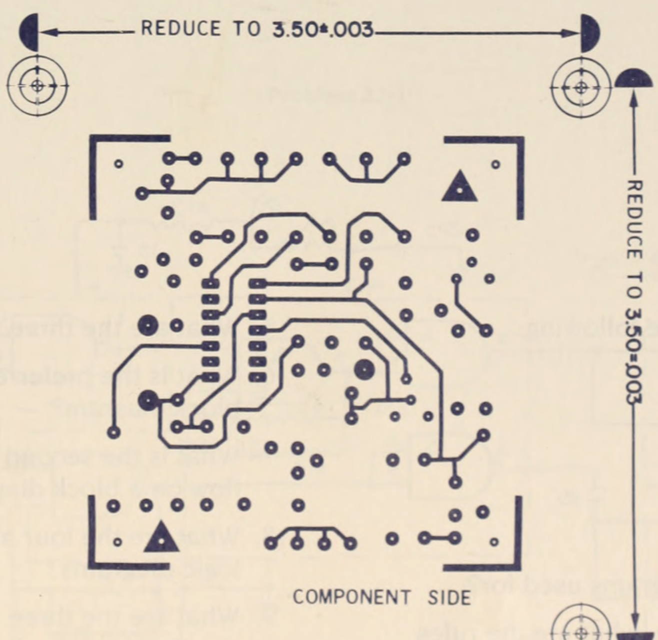


Figure 22-18 Artwork

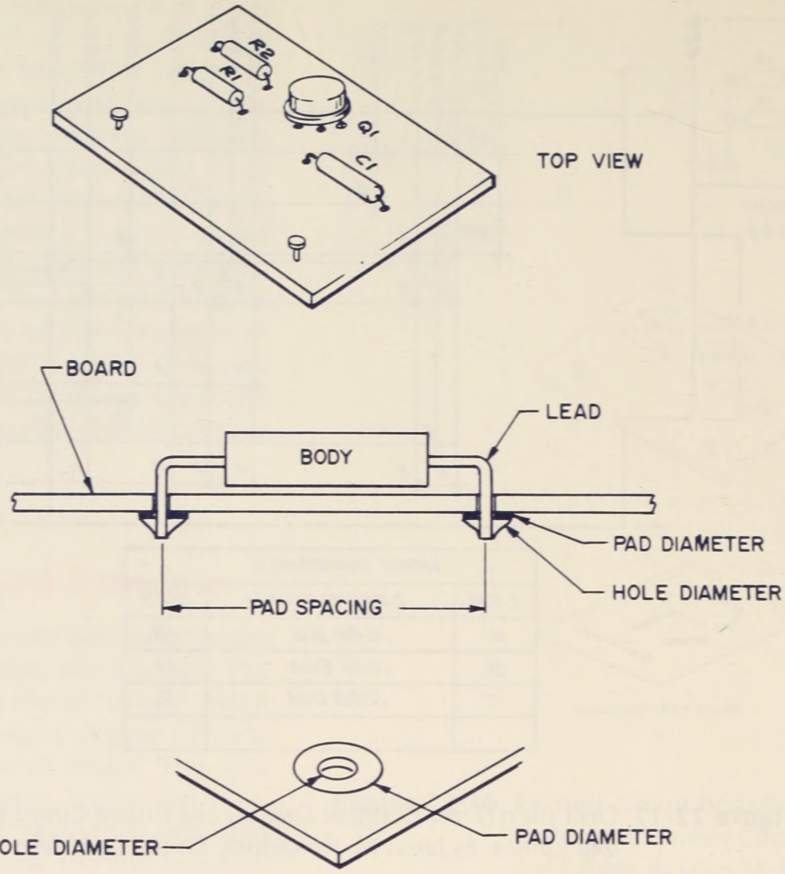


Figure 22-19 Mounting components (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)

Review

1. Draw the symbols for the following:
   - Capacitor
   - Diode
   - Resistor
   - Transistor
   - Delay
   - Rectifier
2. What are schematic diagrams used for?
3. On a schematic diagram, what are the rules pertaining to inputs, outputs, and grounds?
4. What are the four types of connection diagrams?
5. What are the three types of block diagrams?
6. What is the preferred direction of flow on a block diagram?
7. What is the second preferred direction of flow on a block diagram?
8. What are the four most widely used gates in logic diagrams?
9. What are the three main types of printed circuit boards?
10. What are the components of a drill plan for a printed circuit board?

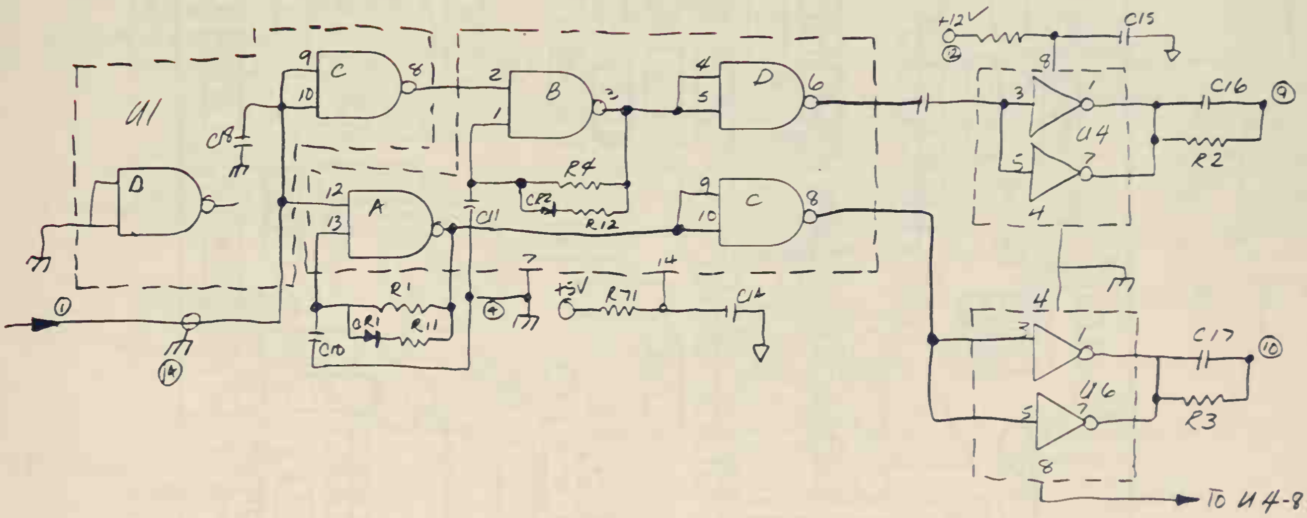
Chapter Twenty-Two Problems

Problems 22-1 and 22-2

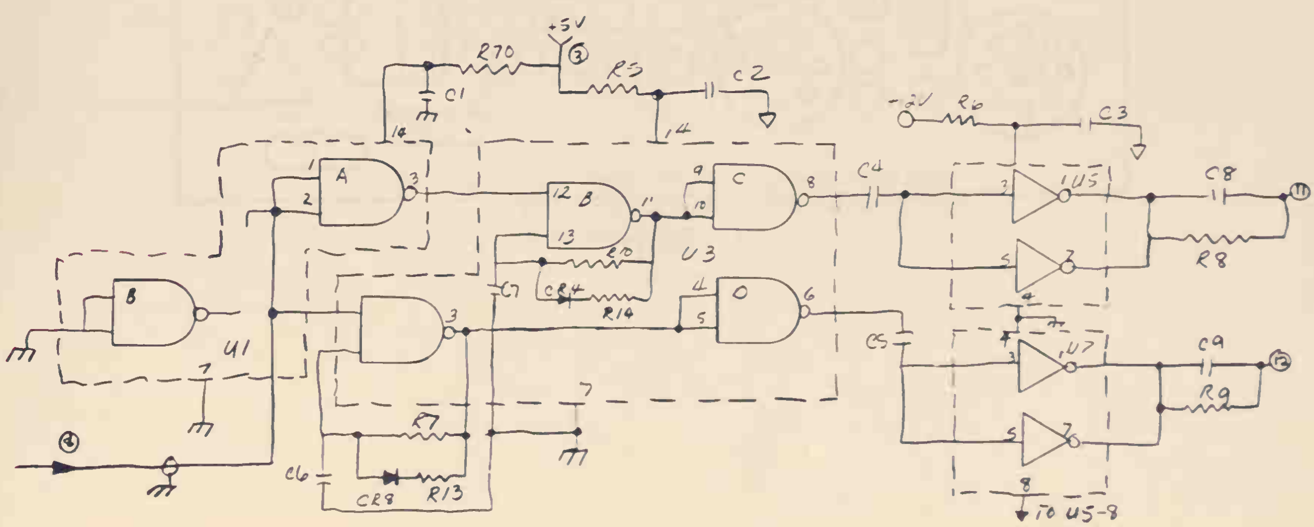
Below are engineer's sketches containing several logic gates and other electronic components. Convert the sketches into finished schematics.

a. Redraw the schematics using pictorial representations.

b. Use the pictorial schematics as guides in developing drill plans and printed circuit board artwork.



Problem 22-1



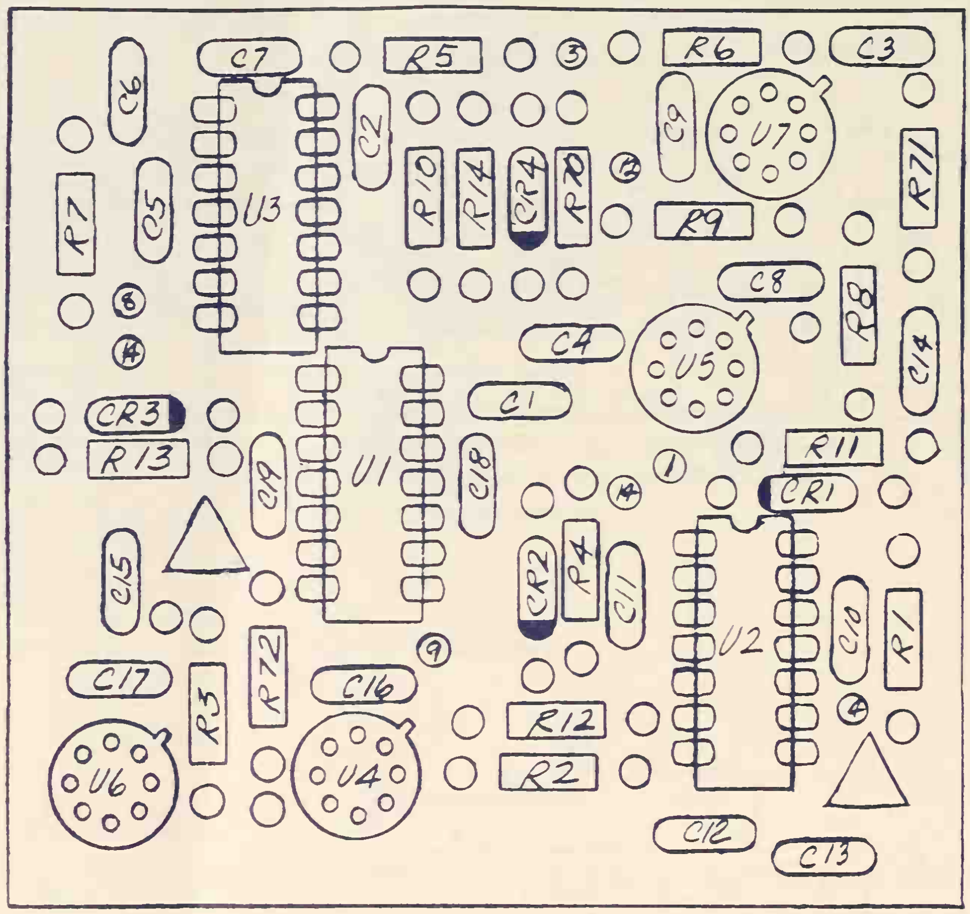
Problem 22-2

Problem 22-3

Problem 22-3 is a sketch of a pictorial schematic. Using it as a guide, complete the following tasks:

a. Develop the symbolic schematic plan from which such a pictorial schematic might have been drawn.

b. Make a drill plan and printed circuit board artwork using the pictorial schematic as a guide.

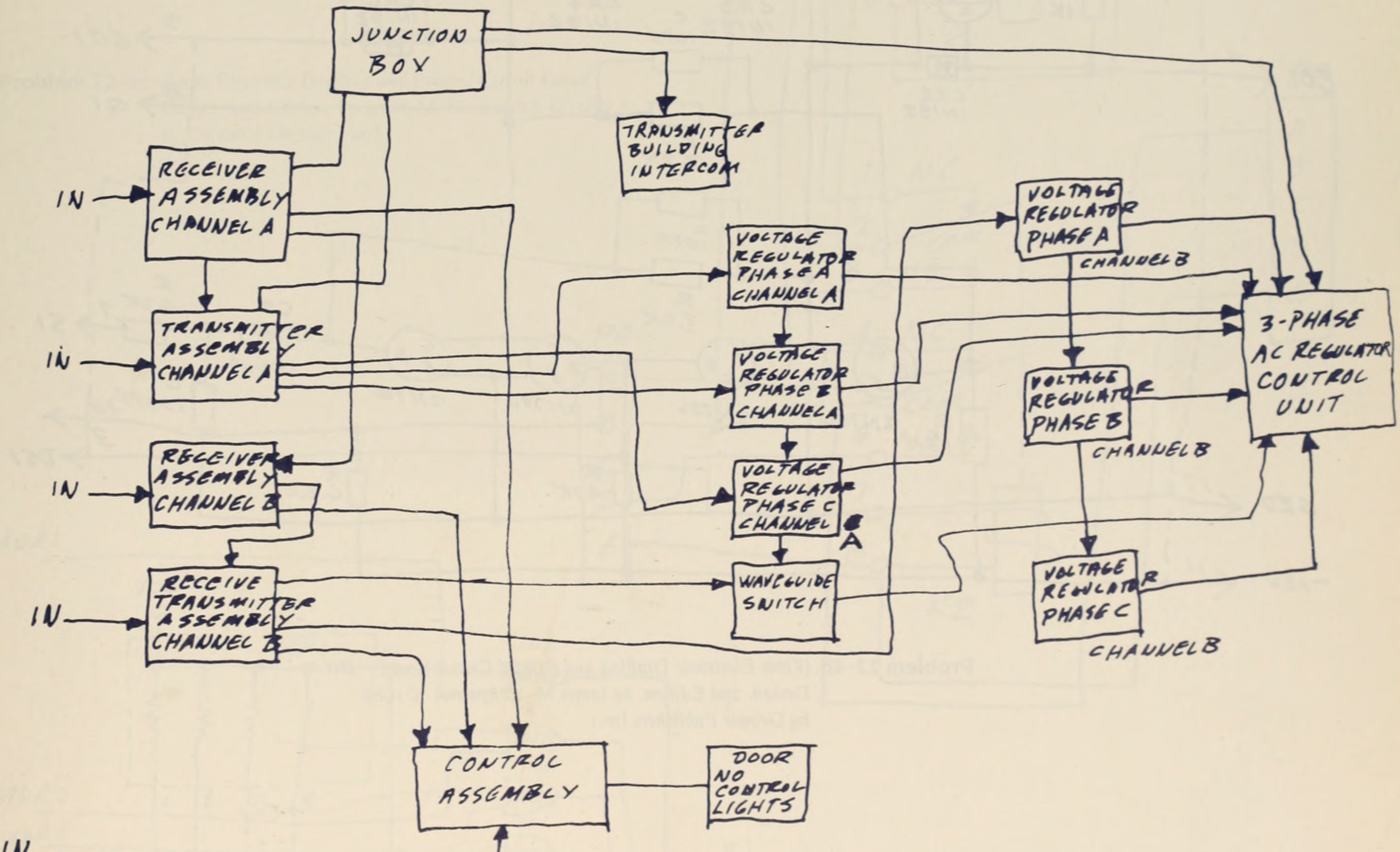


Problem 22-3

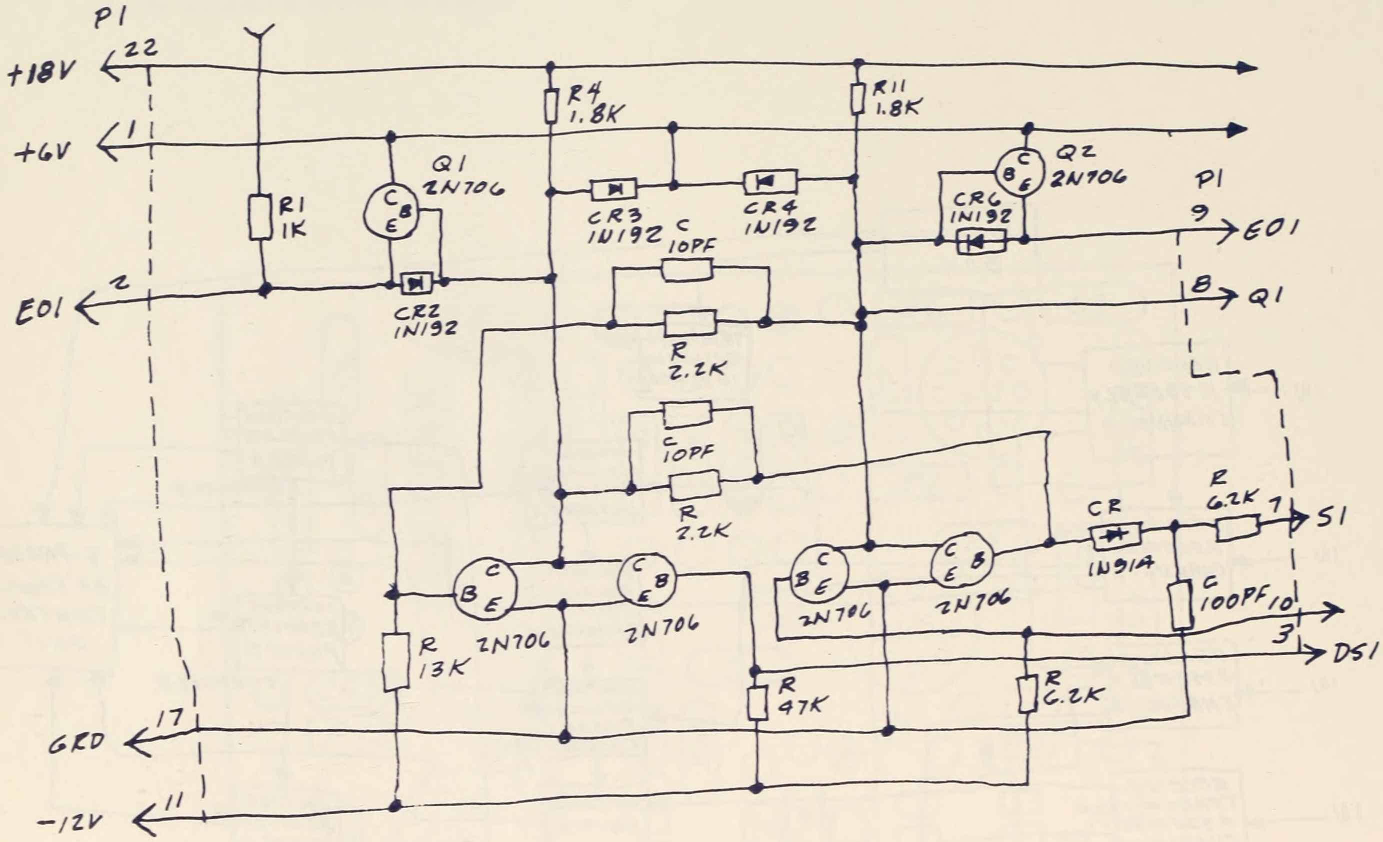
Problem 22-4

Following the rules and steps set forth in this chapter, lay out and draw finished diagrams from the sketches provided.

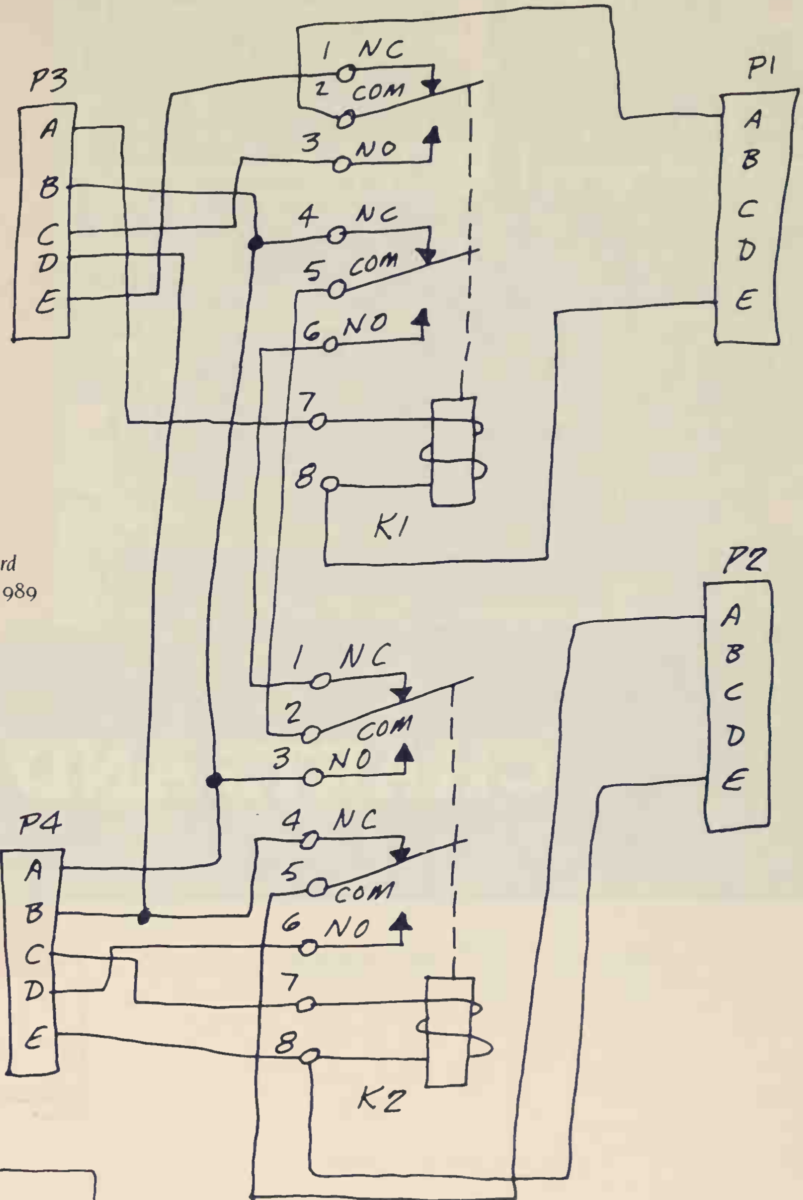
a. Block diagram
b. Schematic diagram
c. Schematic diagram
d. Logic diagram



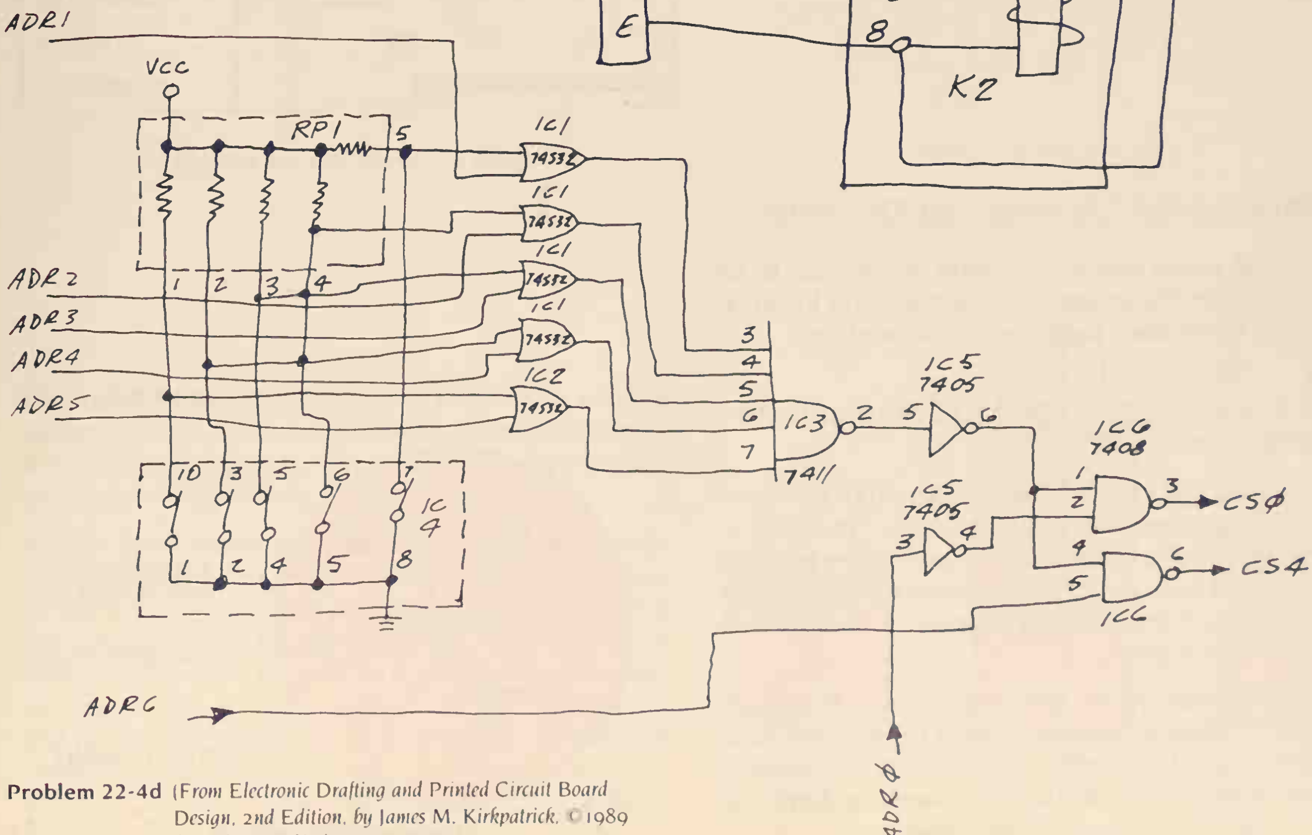
Problem 22-4a (From *Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, © 1989 by Delmar Publishers Inc.)



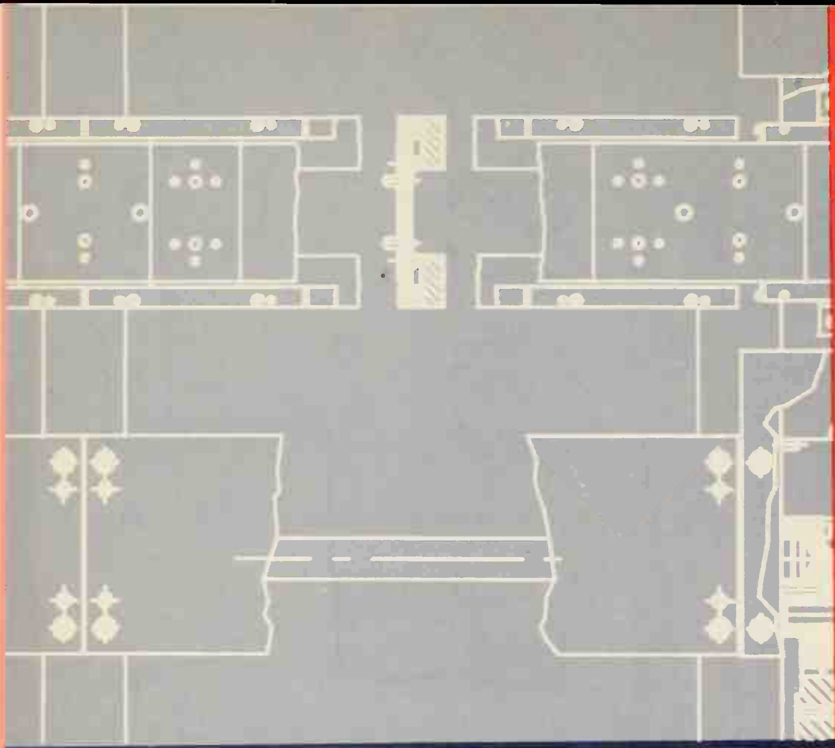
Problem 22-4b (*From Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)



Problem 22-4c (From *Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)



Problem 22-4d (From *Electronic Drafting and Printed Circuit Board Design*, 2nd Edition, by James M. Kirkpatrick, ©1989 by Delmar Publishers Inc.)



CHAPTER 23

Ubiquitous charts and graphs in technology communicate information, and provide a means to generate information. Therefore, this chapter focuses on these two functional attributes, and describes how to prepare charts and graphs. Each type readily falls into one of the two functional classes—to communicate or to generate—although some may function in both. This chapter begins by placing each type in its primary function, accompanied by appropriate figures.

CHARTS AND GRAPHS

Functional Classes: An Overview

The two major classes of charts and graphs to be discussed are those used to communicate information and those used to generate information.

Charts and Graphs Used to Communicate Information

Pie Charts. Pie charts look like circular pies and usually represent 100% of a budget, Figure 23-1. Hence, the cliche "That's how they slice the (money) pie." School newspapers show these annually. A pie chart appears later in this chapter in conjunction with spreadsheets.

Bar Charts. Bar charts, either horizontal or vertical, most often show relative amounts, Figure 23-2A; however, they are frequently used to show the relative timing of activities in the form of planning chart, Figure 23-2B.

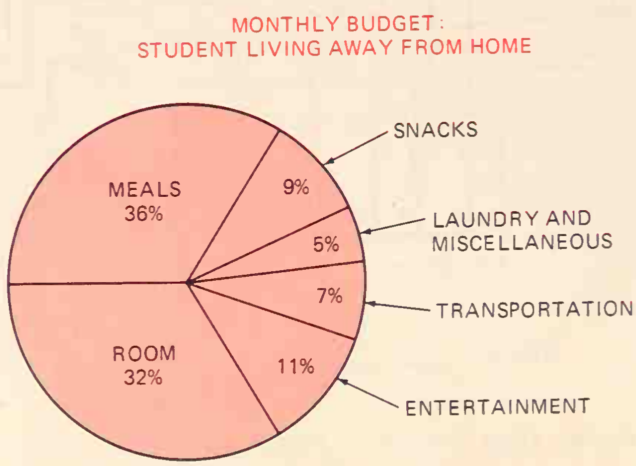


Figure 23-1 Pie chart

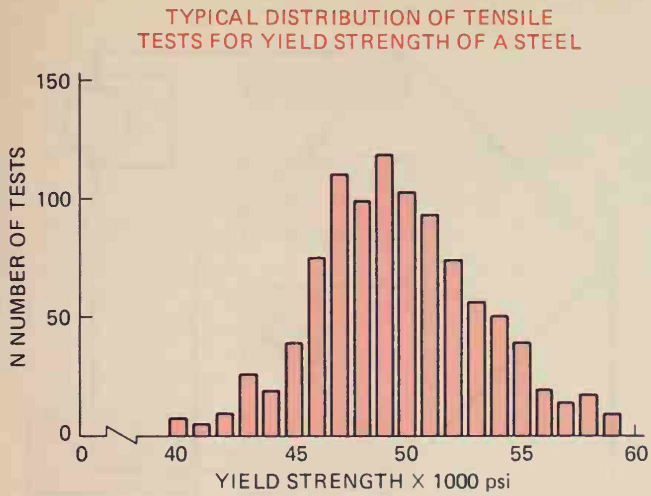


Figure 23-2A Bar chart

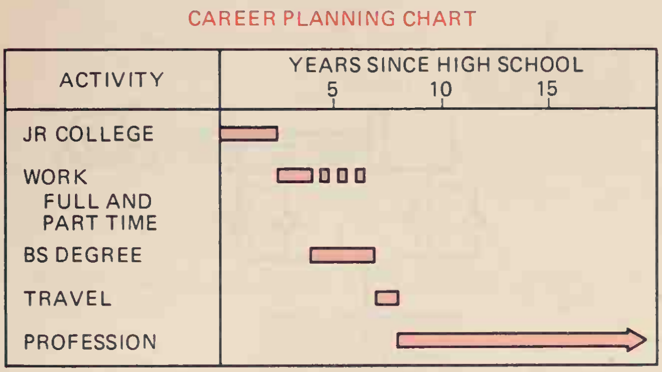


Figure 23-2B Planning chart

Pictorial Charts. Pictorial charts employing varying sizes of figures seem to be favored by newspapers as a means of illustrating relative amounts to the general public, Figures 23-3A and 23-3B.

Profile Charts. Material science texts use profile charts to illustrate the roughness of the surface of a metal by slicing the metal at a shallow angle and showing the cut surface in a magnified plot, Figure 23-4A. A cross section of a portion of a continent, with condensed scales, is used to show terrain characteristics in a profile chart. Civil engineers prepare profile charts to determine how much earth to remove or replace ("cuts and fills") when constructing a highway through a hilly terrain, Figure 23-4B.

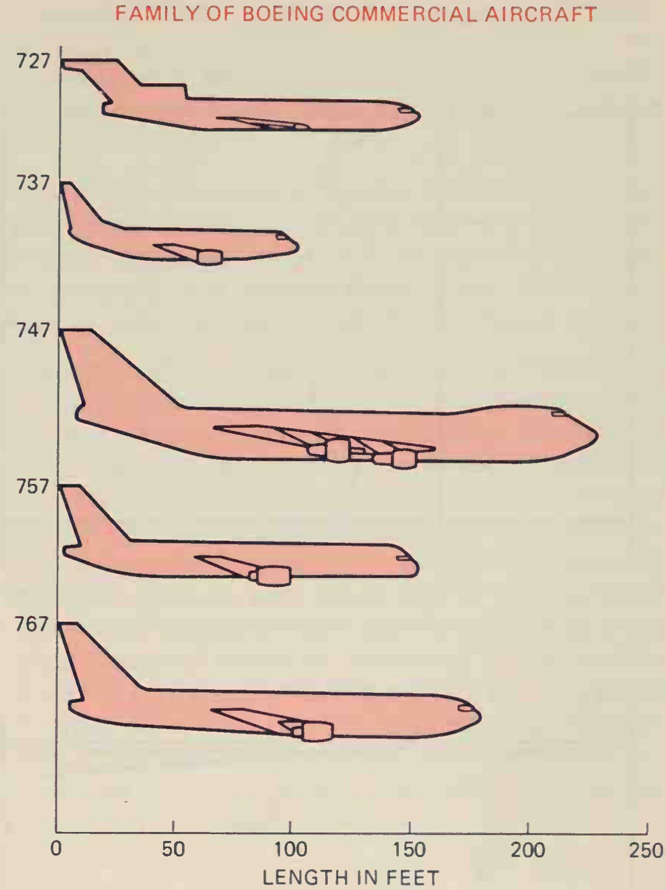


Figure 23-3A Pictorial bar chart

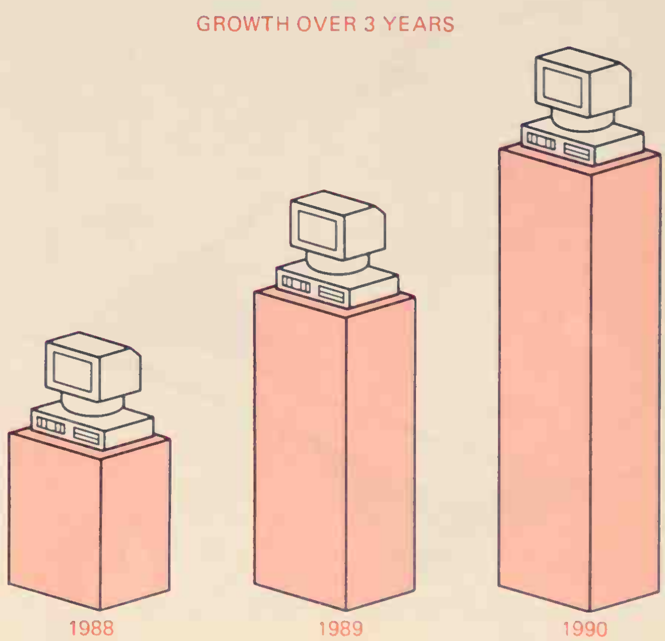


Figure 23-3B Pictorial bar chart

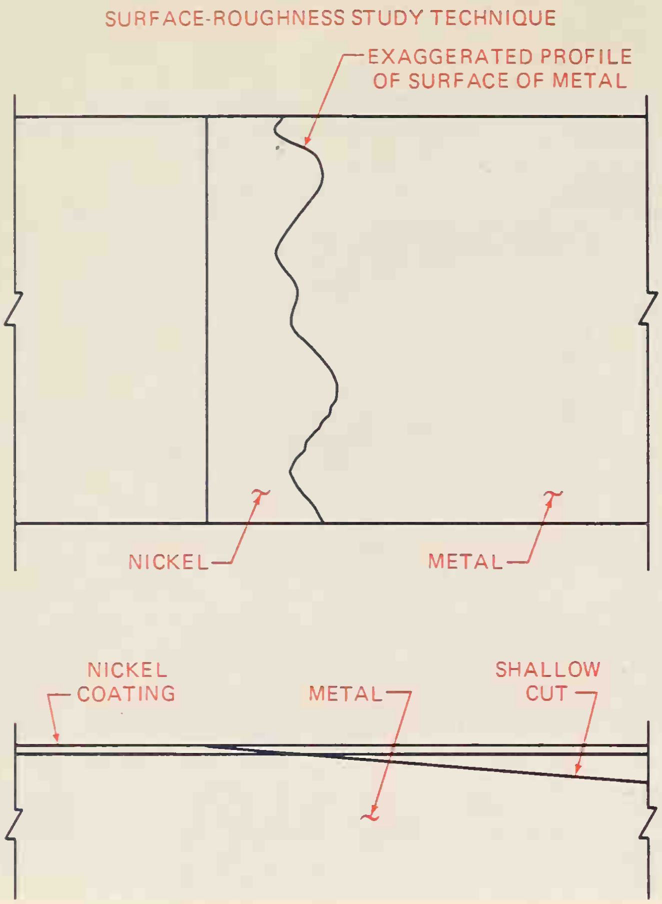


Figure 23-4A Profile chart: material science engineering

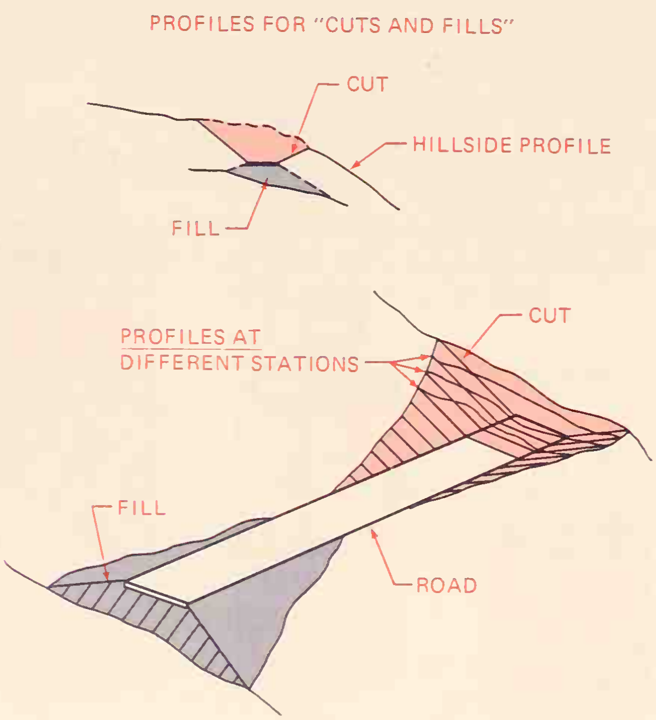


Figure 23-4B Cuts and fills profiles: civil engineering

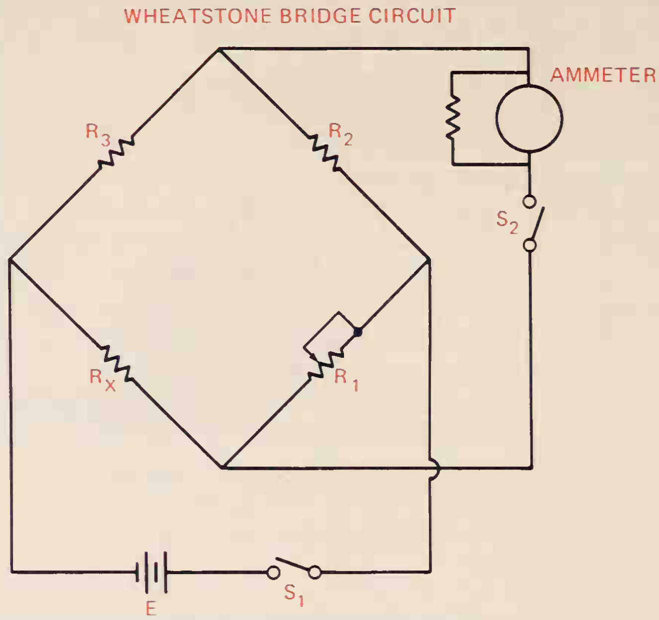


Figure 23-5A Electrical schematic

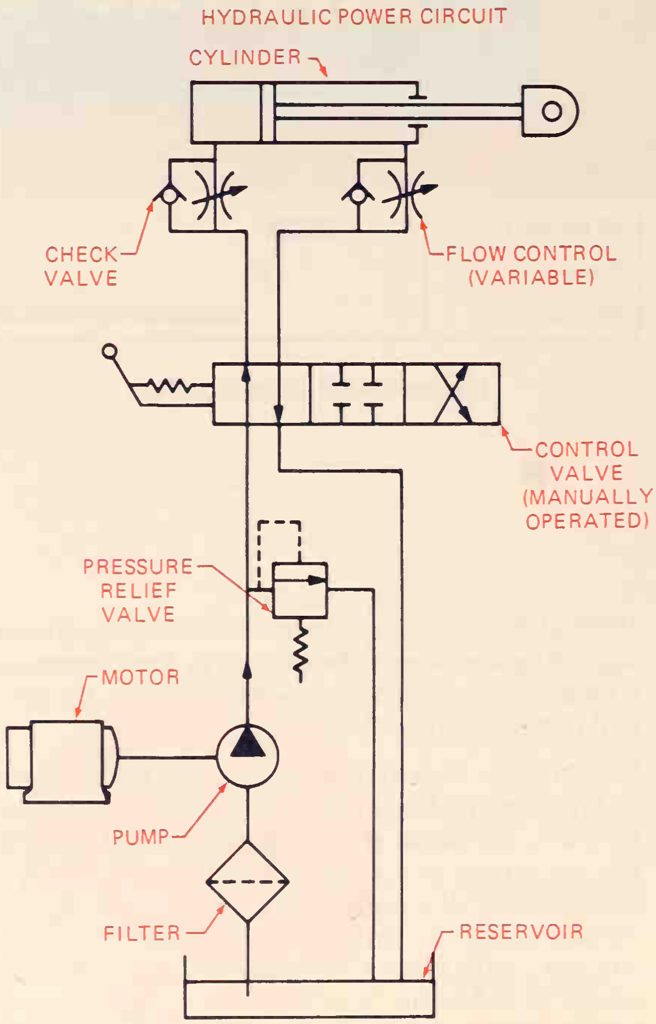


Figure 23-5B Hydraulic power schematic

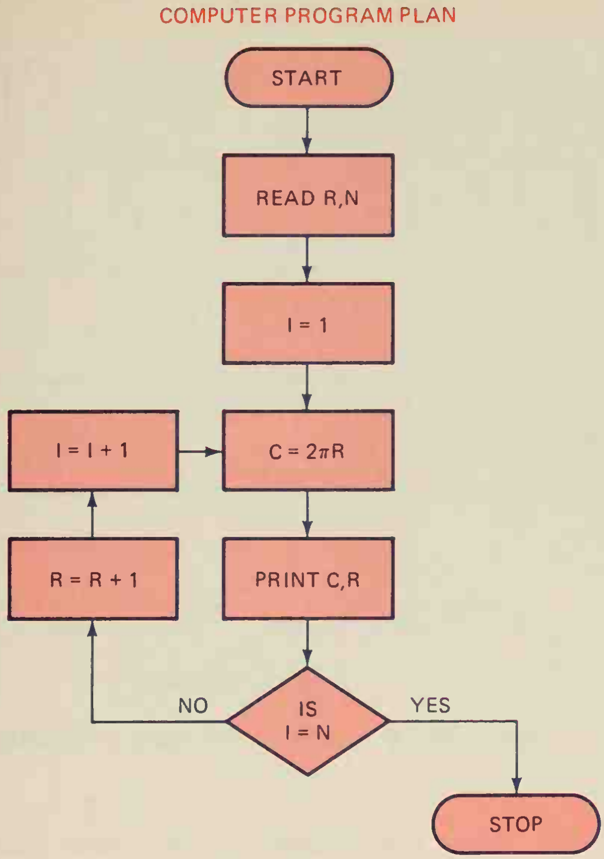


Figure 23-6A Flow chart: computer program

Schematic Charts. Electrical and electronic schematics of circuits are the most common, Figure 23-5A; however, there are others, such as piping, hydraulic power (Figure 23-5B), logic, fault tree, and failure tree schematics.

Flow Charts. Students encounter flow charts in computer programming courses, Figure 23-6A. Other uses include flow of information in an organization, flow of materials in a manufacturing plant, and flow of energy uses in an agricultural facility, Figure 23-6B.

Linear Coordinate Graphs. Basic science (mathematics, physics, biology, and chemistry) and engineering science (statics, dynamics, kinematics, strength of materials, materials, and thermodynamics) textbooks save thousands of words by using linear coordinate graphs, in both two-dimensional and three-dimensional formats, Figures 23-7A and 23-7B. Newspapers use them to save space and to communicate effectively. One important use in technology is to show "ranges of values" or "error bars" at data points, Figures 23-7C and 23-7D. The range of the Dow Jones Average during any one day is an excellent illustration. Error bars on data points representing an experiment show the ranges of accuracy that can be expected for certain conditions.

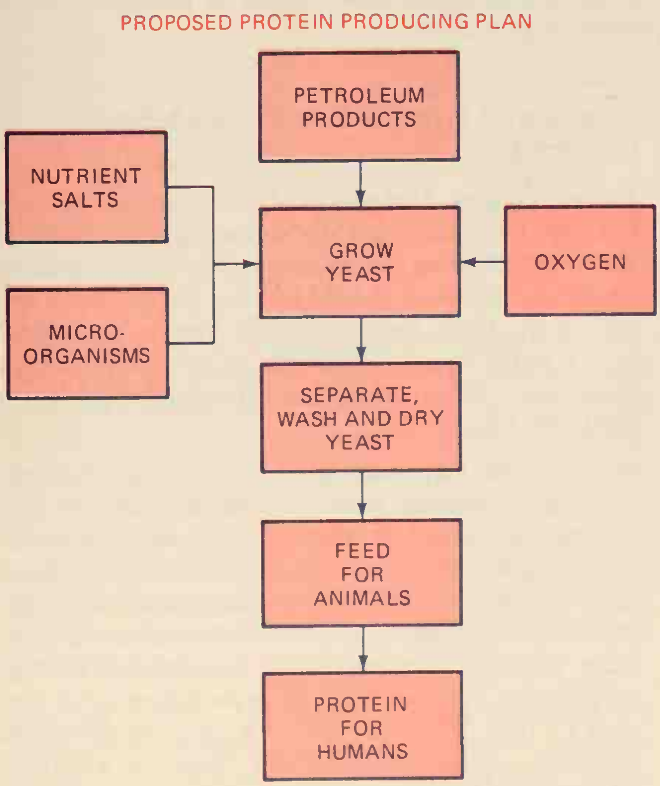


Figure 23-6B Flow chart: agricultural process

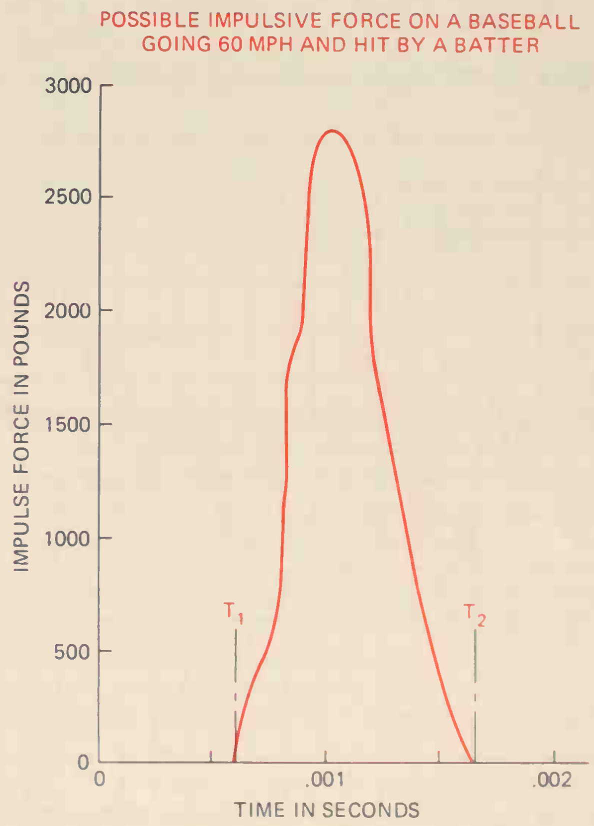


Figure 23-7A Linear coordinates: impulsive force vs. time

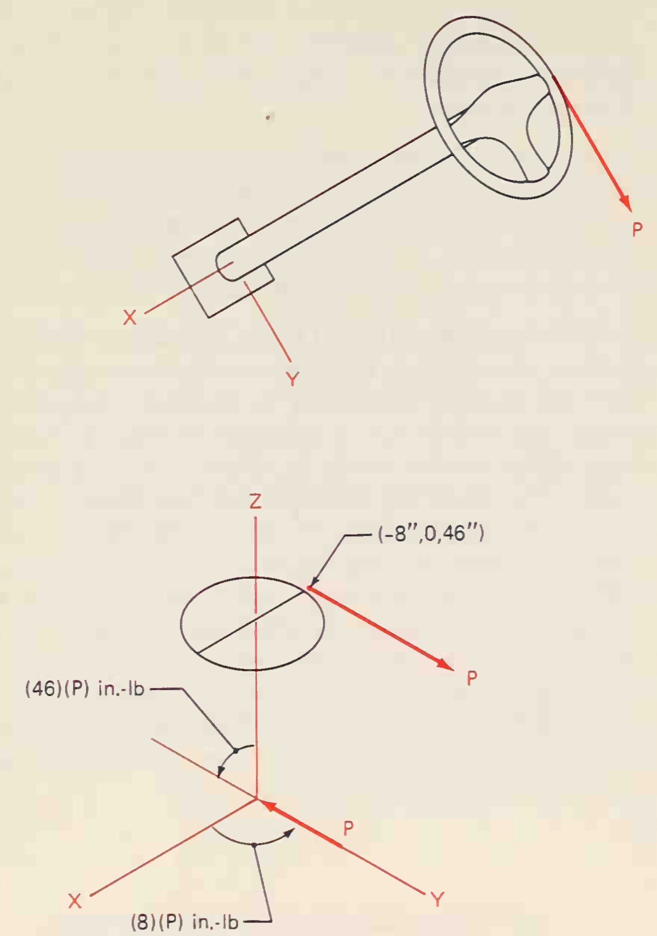


Figure 23-7B Linear coordinates: three-dimensional

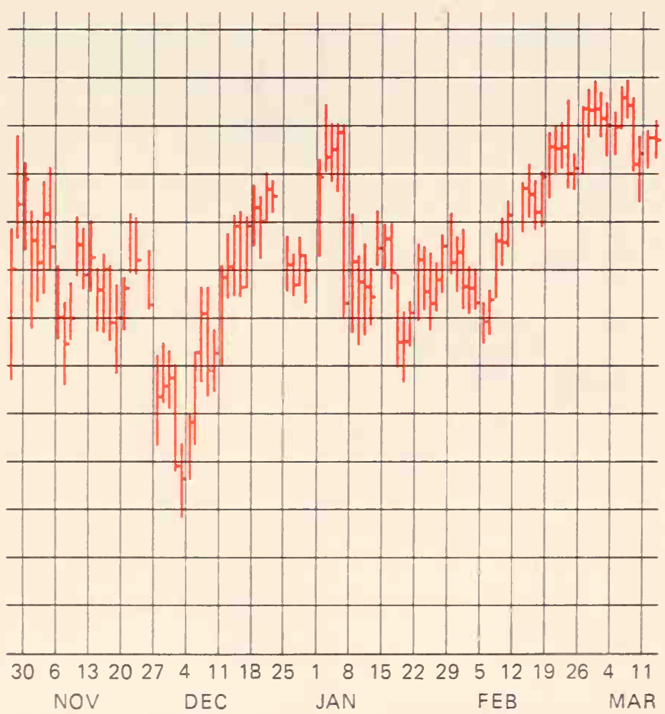


Figure 23-7C Linear coordinates: ranges of values

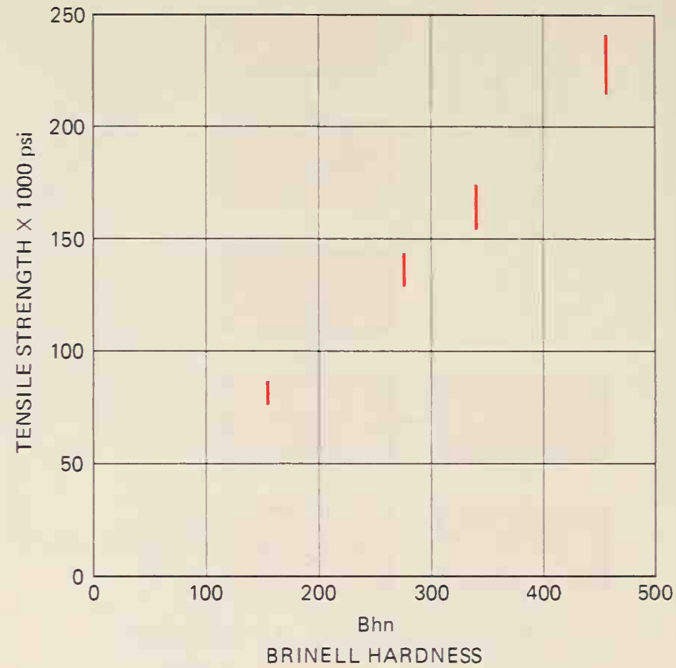


Figure 23-7D Linear coordinates: error bars

Polar Graphs. Polar graphs are 360° maps usually used to show the effect of a point source of energy (heat, light, electromagnetic sound) at varying distances from the source. Radio and TV stations use these to determine their local coverage. The use of polar graph paper saves hours in preparing these plots, Figure 23-8.

Charts and Graphs Used to Generate Information

Trilinear Graphs. Metallurgical and chemical personnel use these equilaterally shaped graphs to illustrate how differing percentages of three elements of a mixture behave or should behave. For example, the sum of the three perpendiculars, one to each side, from a point equal the altitude of the triangle which would be 100% in all cases. Commercial grids are available, Figure 23-9.

Linear Graphs. Grids for linear graphs are ruled uniformly along the horizontal and the vertical axes. This type is used here to introduce the general equation of a straight line, $y = mx + b$, where m is the slope, x the independent variable, y the dependent variable, and b the intercept along the vertical axis. Furthermore, $y = mx + b$ appears here because it is used in conjunction with graphs to generate information, Figures 23-10A, 23-10B, and 23-10C. A more complete discussion appears later in this chapter in a section on empirical equations. Log-linear and log-log applications are also included.

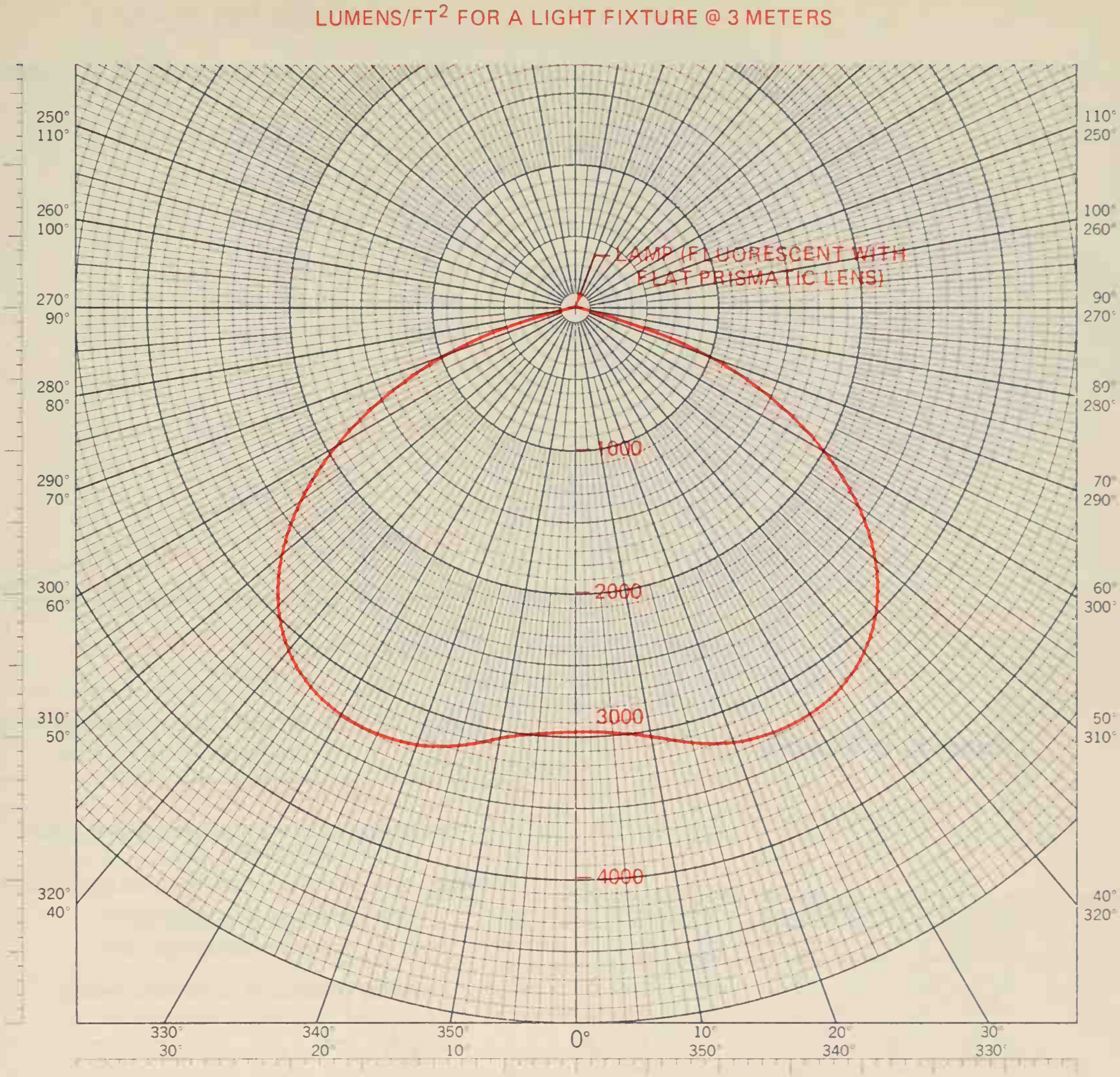


Figure 23-8 Polar coordinates graph

Log-Linear Graphs. Log-linear or semilogarithmic grids are linear, or uniformly ruled, along the horizontal axis and logarithmic, or ruled proportionately to the logarithms of numbers, along the vertical axis, Figure 23-11. Curves with equations y = b(e**mx) plot as straight lines on log-linear graphs. Therefore, if data from an experiment is plotted on a log-linear grid, and the data forms a straight line, then an equation for the data may be generated in the form y = b(e**mx). The variables are defined in the linear graph discussion. The number e = 2.718282.

Log-Log Graphs. Log-log or logarithmic grids are ruled proportionately to the logarithms of numbers along both the horizontal and vertical axes. Curves with equations y = b(x**m), plot as straight lines on log-log grid sheets, Figures 23-12A and 23-12B. Therefore, if data from an experiment plots as a straight line on log-log paper, an equation for the data may be generated in the form y = b(x**m). The variables are defined in the linear graph discussion.

Nomographs. Nomographs or nomograms are graphical representations of formulas along straight or curved, graduated lines which are used to find an unknown value of one variable, given the others, Figures 23-13A, 23-13B, and 23-13C. Not only do nomographs save time, but they allow the user to visualize ranges of possible values. For example, a designer can generate a number of alternatives quickly, and work toward an optimum solution. Several nomograms are discussed later in this chapter.

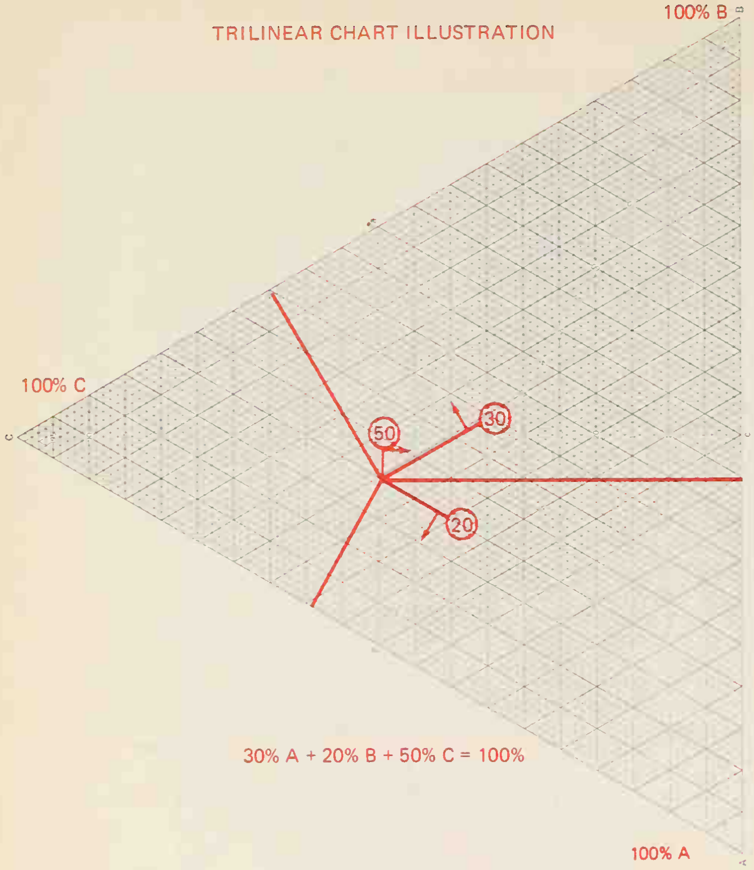


Figure 23-9 Trilinear graph

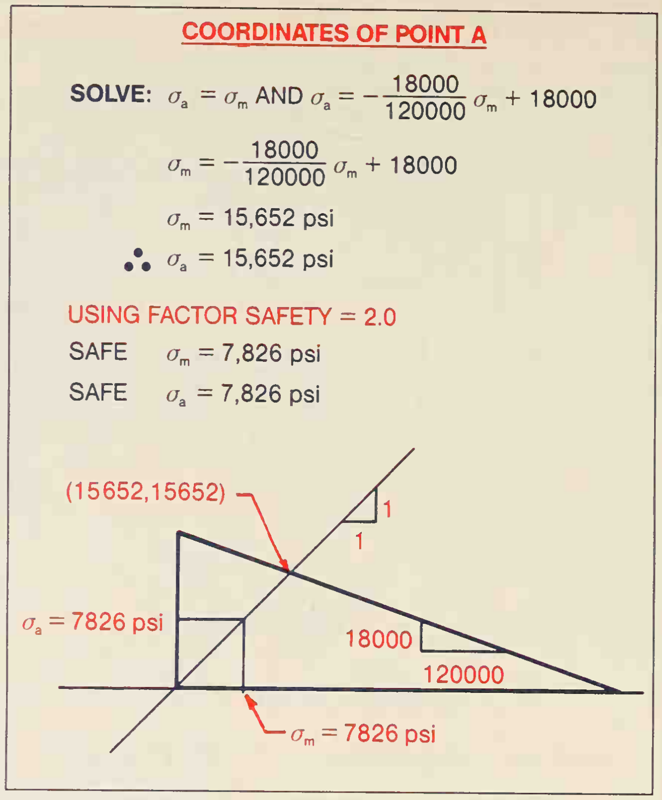


Figure 23-10B Straight line equations: fatigue analysis

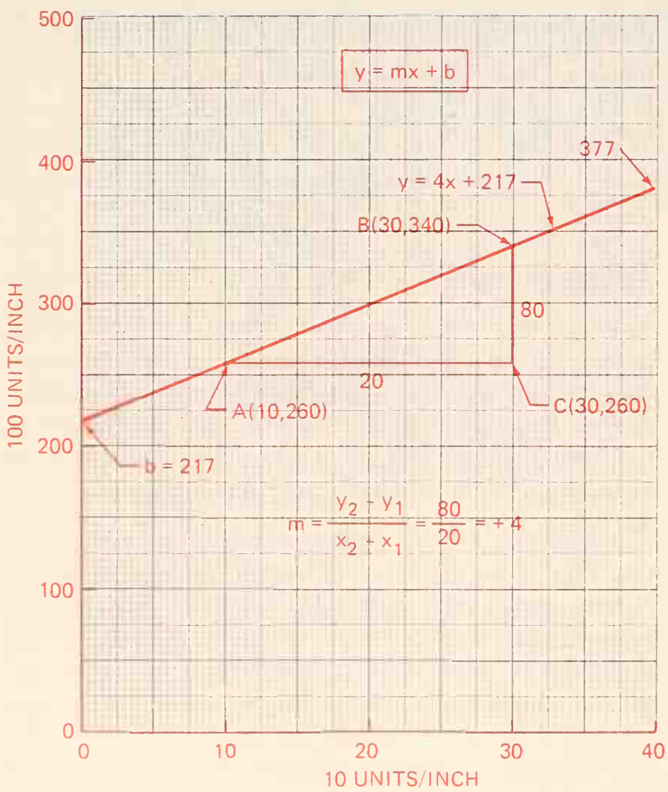


Figure 23-10A Straight line equation: y = mx + b

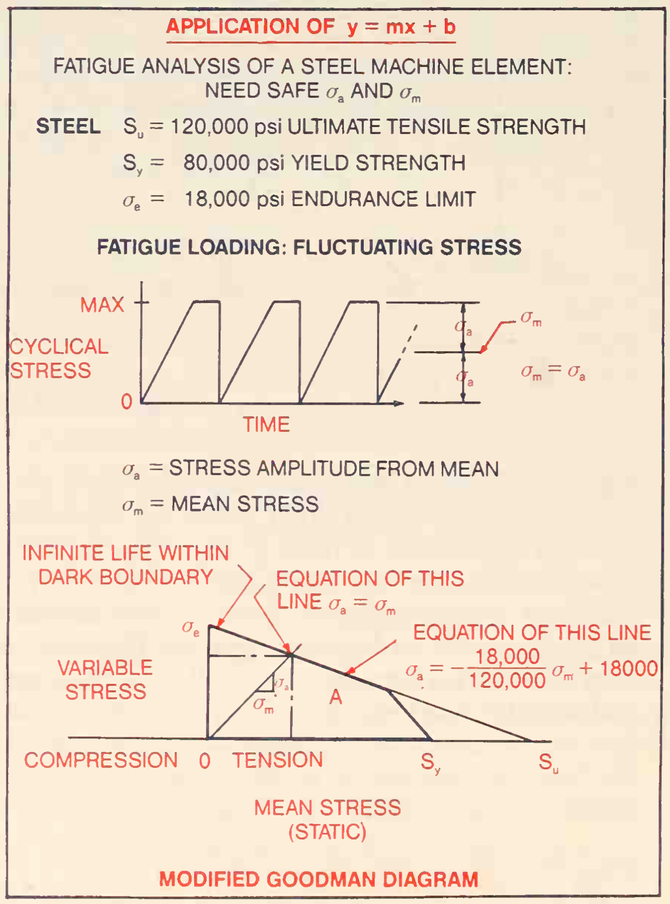


Figure 23-10C Straight line equations: fatigue analysis

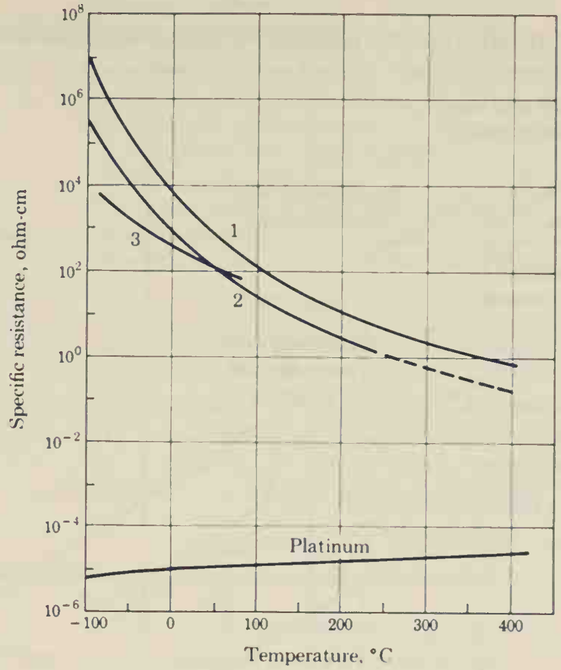


Figure 23-11 Log-linear graph (semilogarithmic) (*From* Holman, J.P., Experimental Methods for Engineers, *copyright* 1966, *McGraw-Hill Book Company. Used with permission.*)

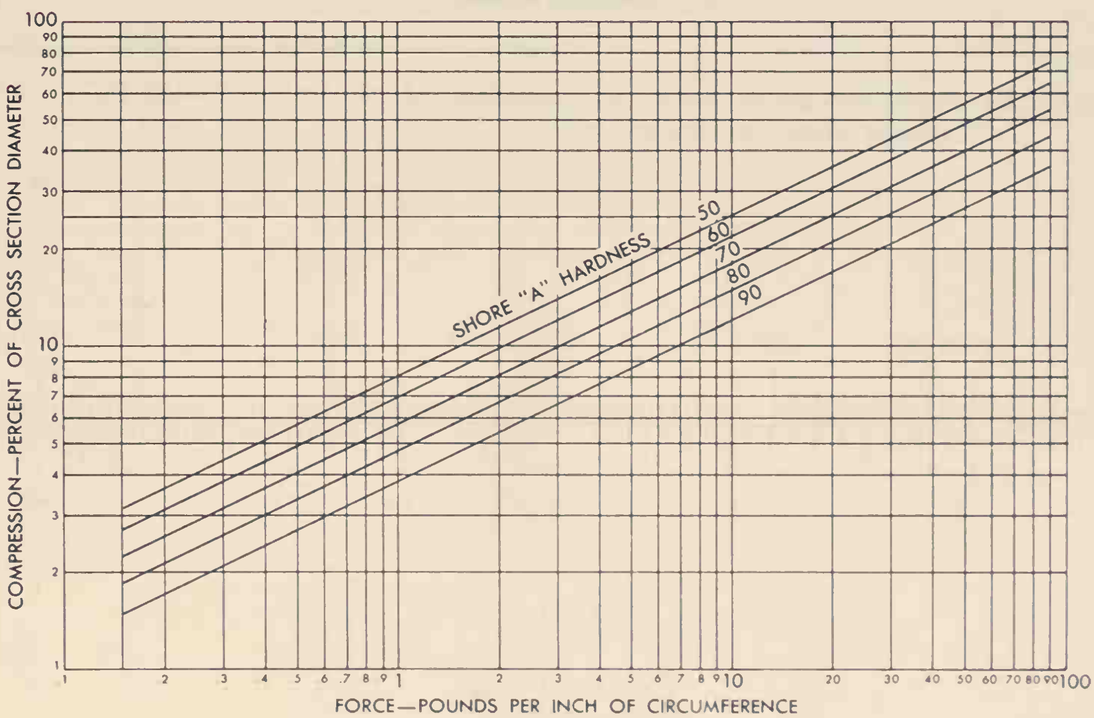


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Figure 23-12A Logarithmic graph: O-ring compression (*Courtesy Parker Seal*)

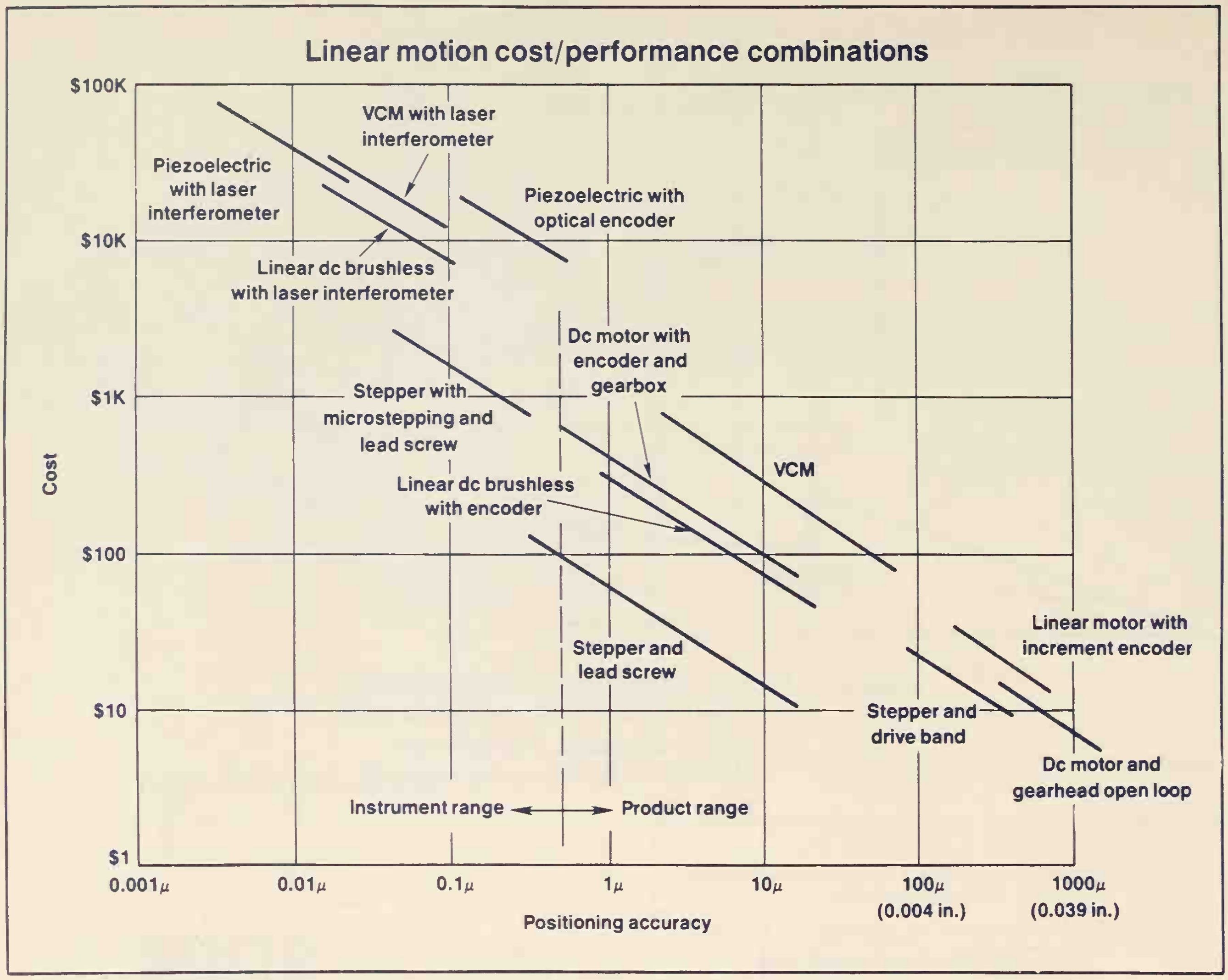
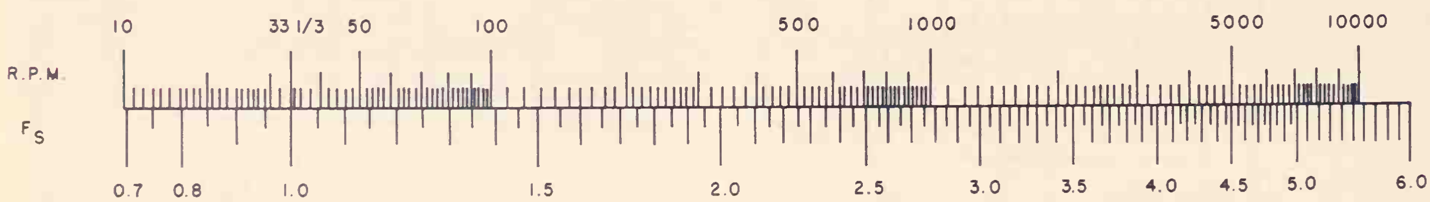


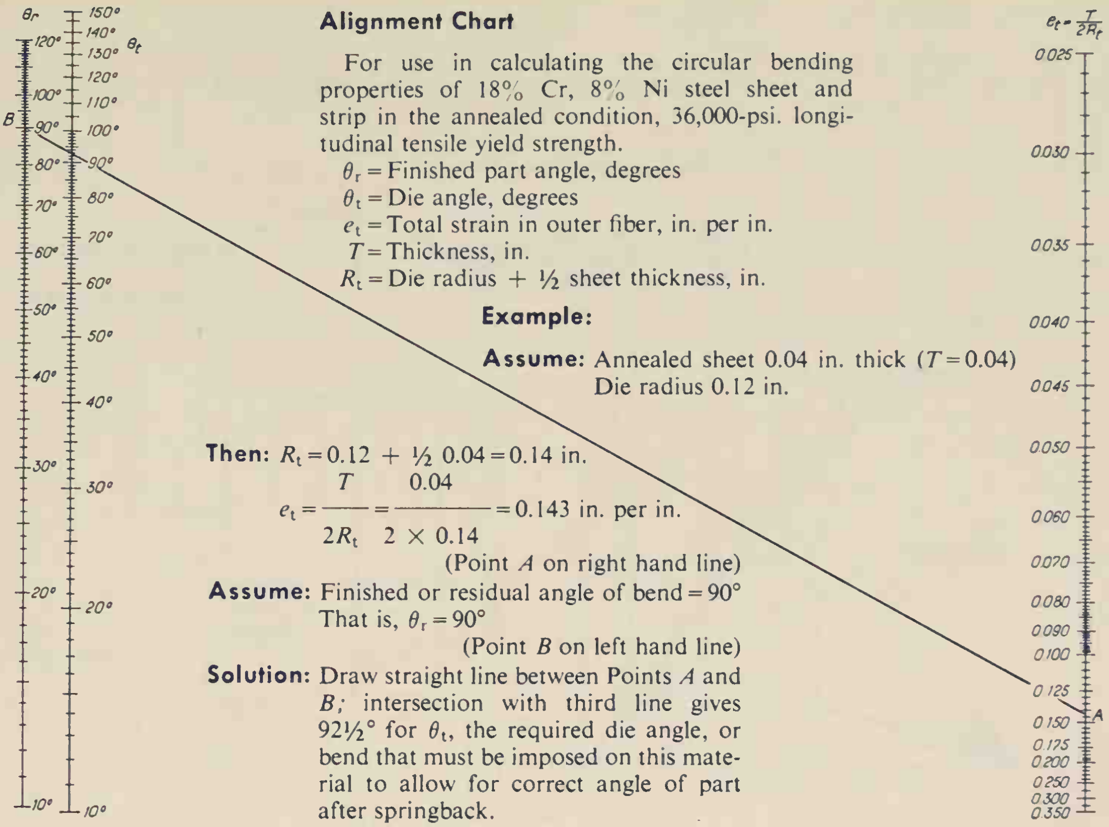
Figure 23-12B Logarithmic graph: cost vs. accuracy (*Reprinted from* Machine Design, *Oct.* 27, 1987. *Copyright Penton Publishing Inc.*, 1987.)



$$F_S = \left(\frac{N}{33\frac{1}{3}}\right)^{.3}$$

F_S = Speed factor
N = R.P.M.

Figure 23-13A Adjacent alignment chart (*Courtesy McGill Manufacturing Company, Inc.*)



Circular bends on annealed 18-8.

Figure 23-13B Parallel alignment chart: three variables (*Courtesy Allegheny Ludlum Corporation*)

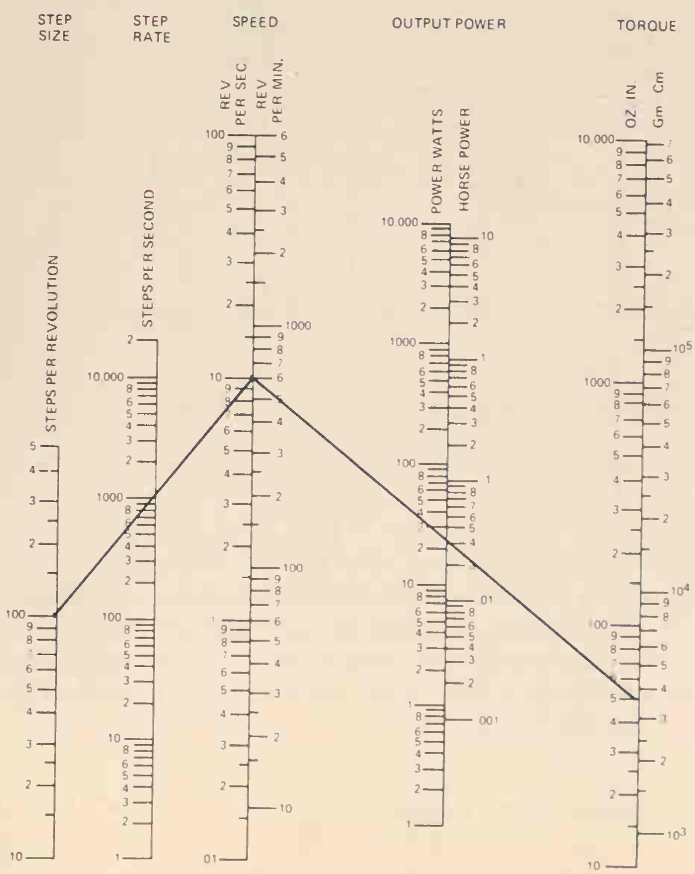


Figure 23-13C Parallel alignment chart: four variables (*Courtesy Pacific Scientific*)

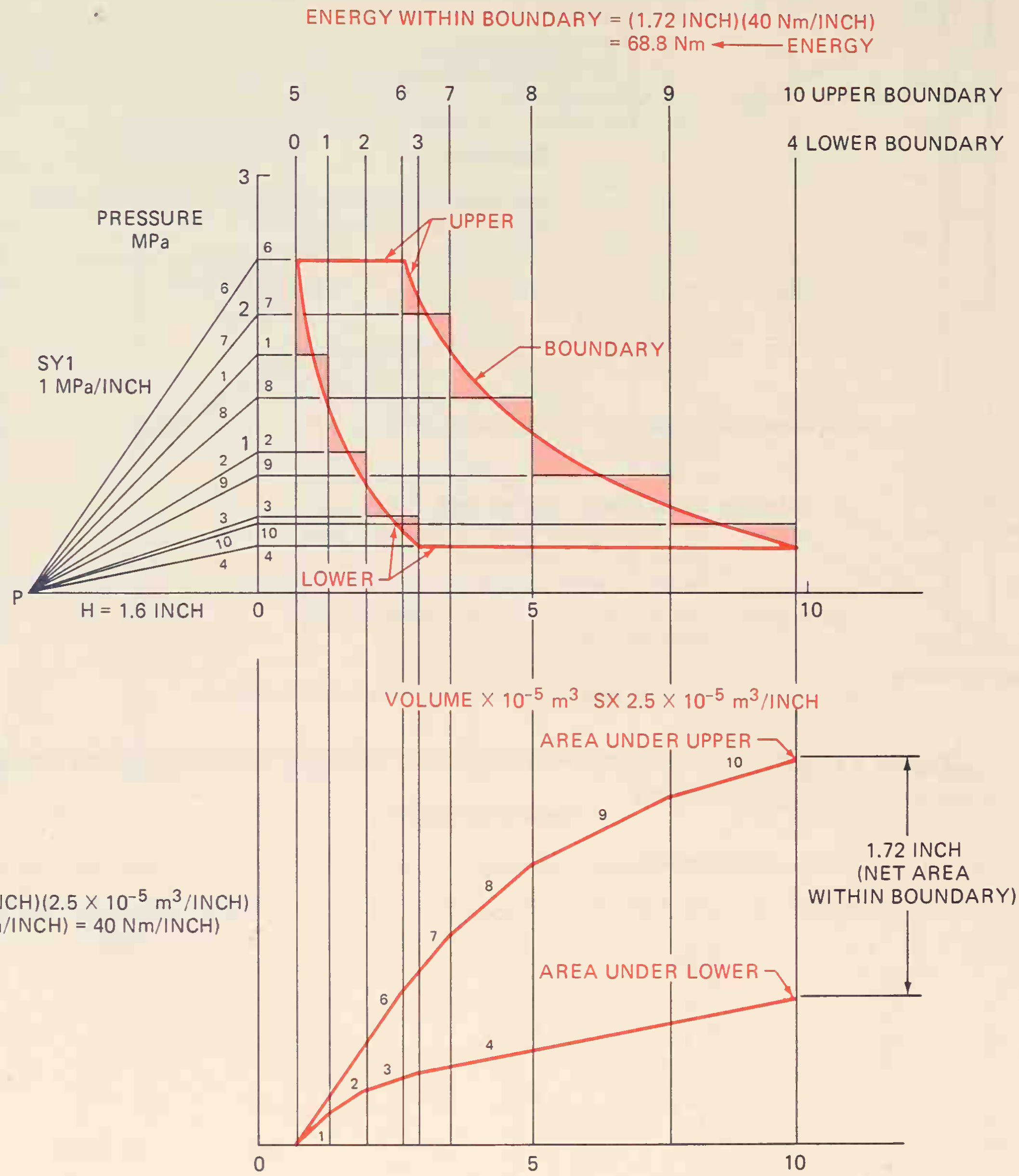


Figure 23-14 Graphical calculus: integration

Graphical Calculus: Integration. Graphical integration provides designers with a visual, reasonably accurate, approach to integration. Analytical, mechanical, and computer techniques for integrating are also available; however, the graphical approach helps the designer to "see" the results. The application, shown in Figure 23-14, generates the energy within a pressure-volume plot. The technique is discussed later in this chapter.

Graphical Calculus: Differentiation. The technique for doing graphical differentation, and the advantages to a designer are similar to graphical integration; however, obtaining reasonably accurate results requires more skill than integrating graphically. Figure 23-15.

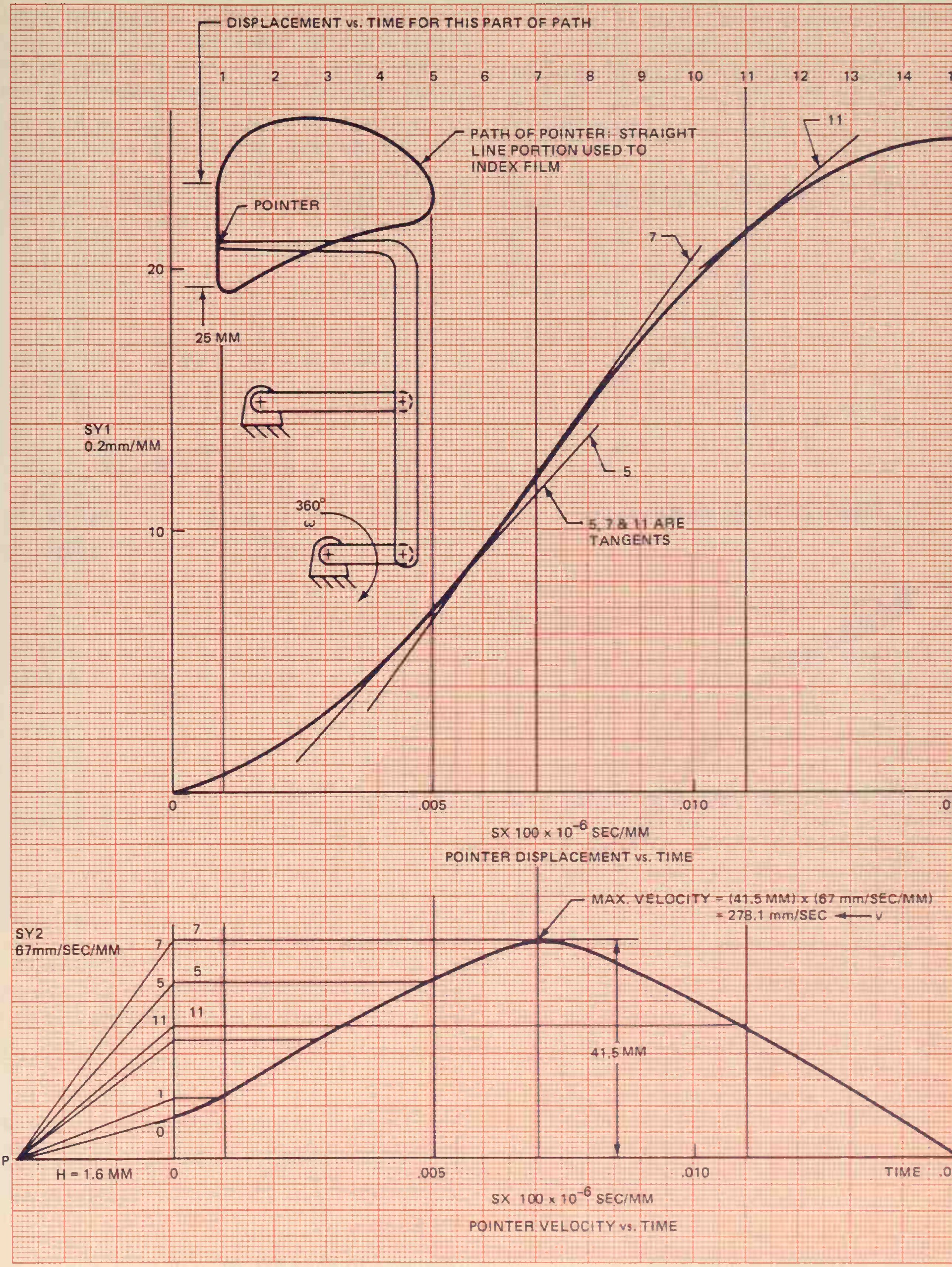


Figure 23-15 Graphical calculus: differentiation

Timing Graphs. Timing graphs aid designers in coordinating electrical and electronics components in a system driven by clock pulses, Figure 23-16.

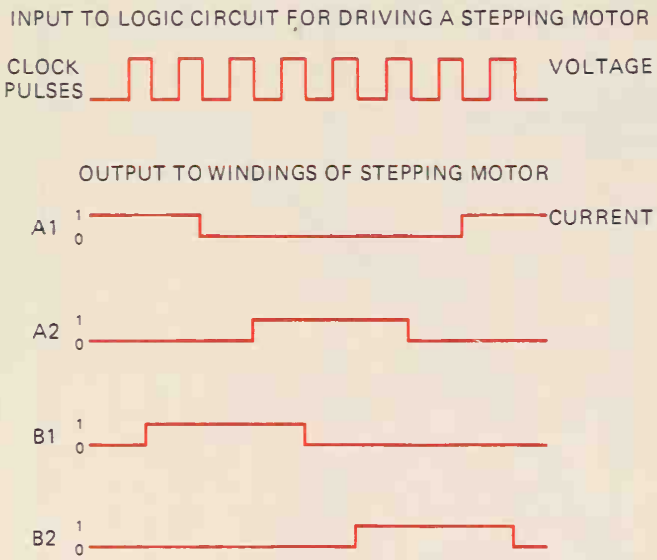


Figure 23-16 Timing graphs

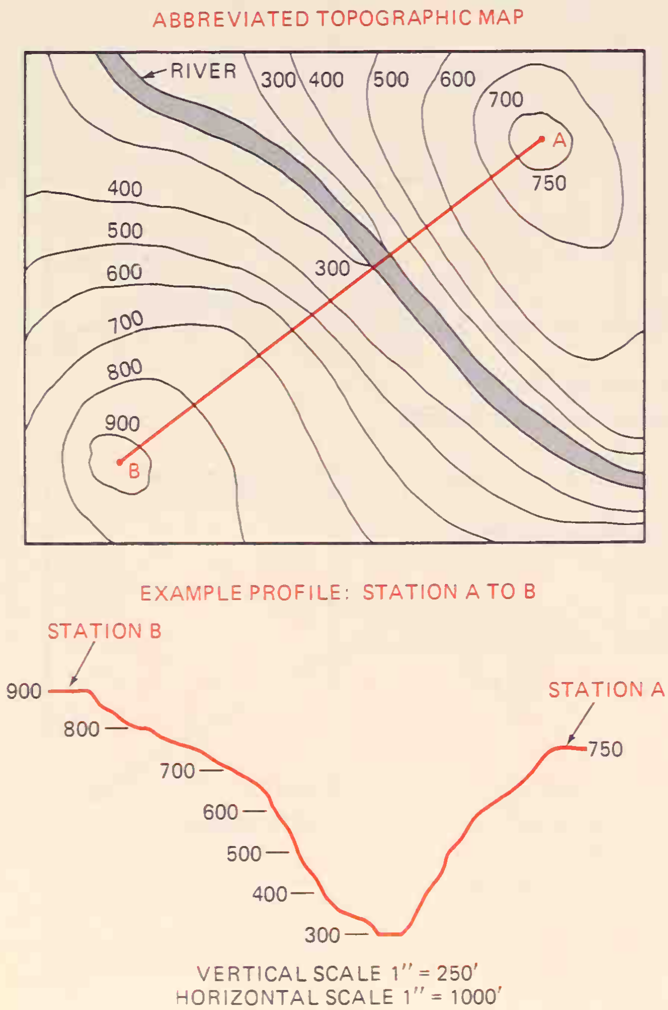


Figure 23-17 Topographic map

Topographic Maps (Charts). These speak for themselves, Figure 23-17. The pilots of space, air, land, sea, and undersea vehicles use maps and sophisticated devices to locate their positions. Civil, agricultural, mining, and petroleum engineers generate information for their use and explorations from maps.

Force Maps. Force polygons drawn on force maps (same scale in all directions) are included here because of their utility in science and technology courses, Figure 23-18. Force polygons are discussed later in reference to an elementary structures design.

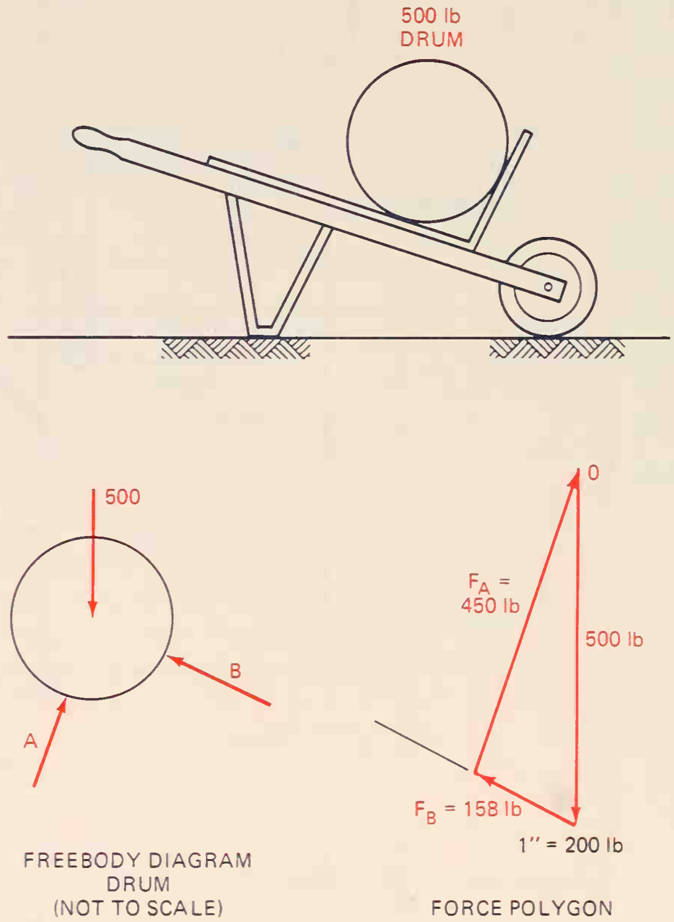


Figure 23-18 Force maps

Beam Diagrams. Beams of varying shapes, materials, and sizes occur in so many designs that a brief introduction to beam diagrams in this chapter seems appropriate, Figure 23-19. These diagrams are discussed later.

Knowing the major functions of these graphs and charts, and having the skill and knowledge to prepare them, will enhance your ability to read and use them in courses and in industry.

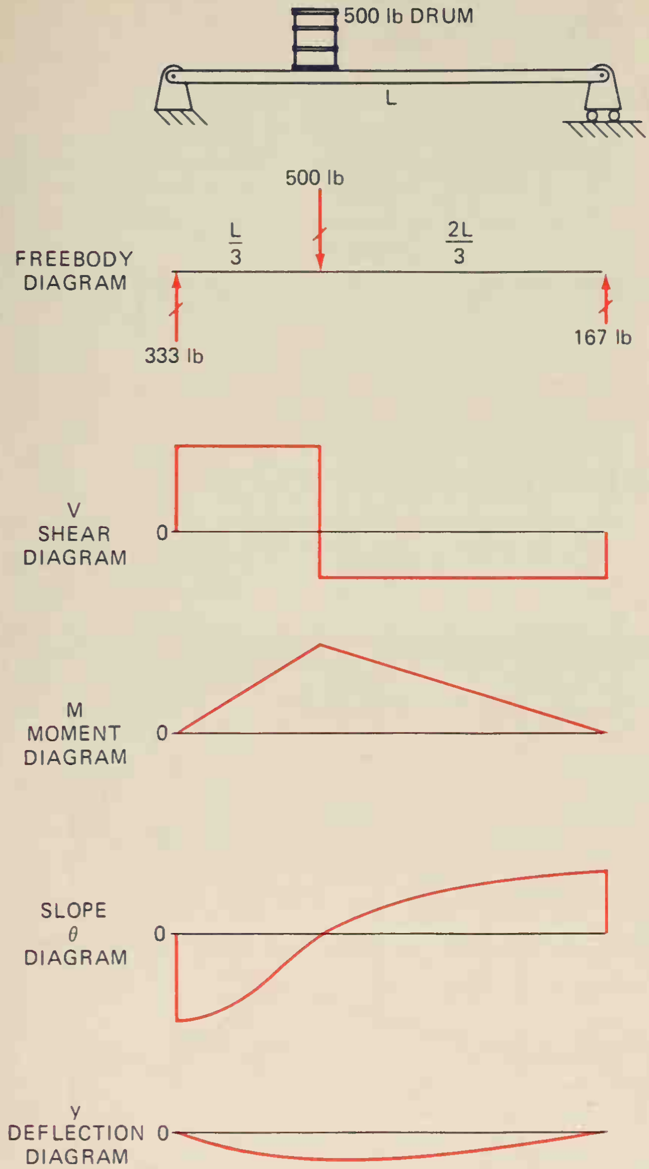


Figure 23-19 Beam diagrams

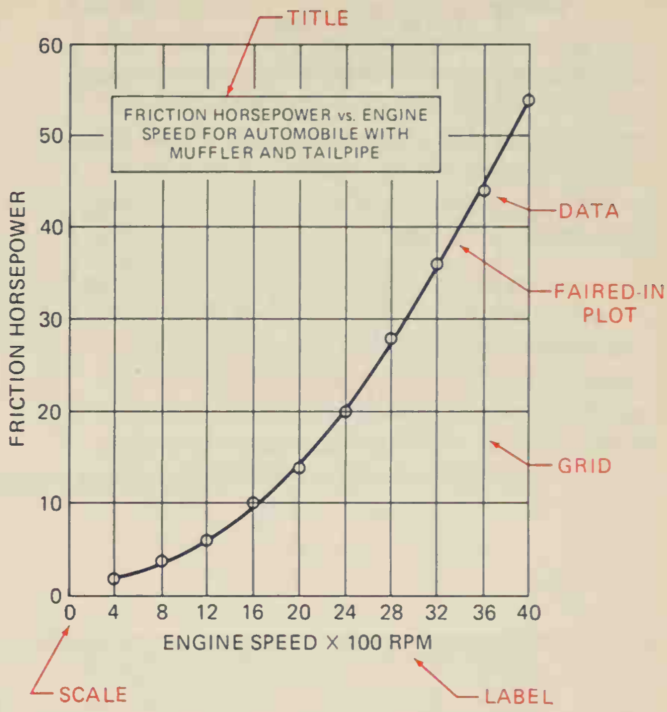


Figure 23-20 Basic components

Five Basic Components

First, consider the five basic components of almost all charts and graphs.

1. The grid
2. The scales
3. The scales' labels
4. The plot
5. The title

These are identified in Figure 23-20. Diligently including all five components will make your instructor extremely happy! Selecting and developing all five requires a number of steps that act as a checklist to ensure professional charts and graphs.

The Steps

Assuming that the data to be plotted has been collected, and that the function of the chart or graph has been decided, do the following:

1. Examine the data to determine the ranges to be plotted.
2. Use scales to present the data for optimum communication or generation of information, Figure 23-21. To help users interpolate between scale numbers, use scales that are multiples of 1, 2, 5, or 10 (unless the intervals are topical, such as days, weeks, months, years, or geographical locations), Figure 23-22. Use horizontal scales for independent variables, and vertical scales for dependent variables.
3. Select commercial grid sheets to save time. Grids familiar to readers save them time. Moreover, commercial grids were developed for specific, frequently needed, functions. Your experiences and observations will help you to select the best formats for presenting data.
4. Plots usually start at the lower left unless the points are negative or the function of the chart or graph requires a different format. Figure 23-20 shows a typical plot. Figure 23-23 shows a different format.

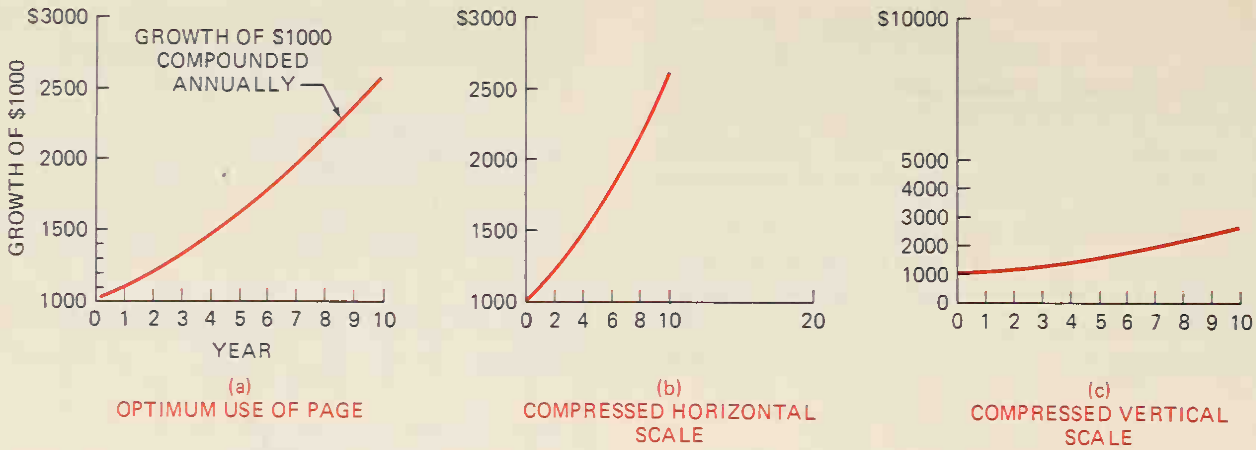


Figure 23-21 Optimum use of page area

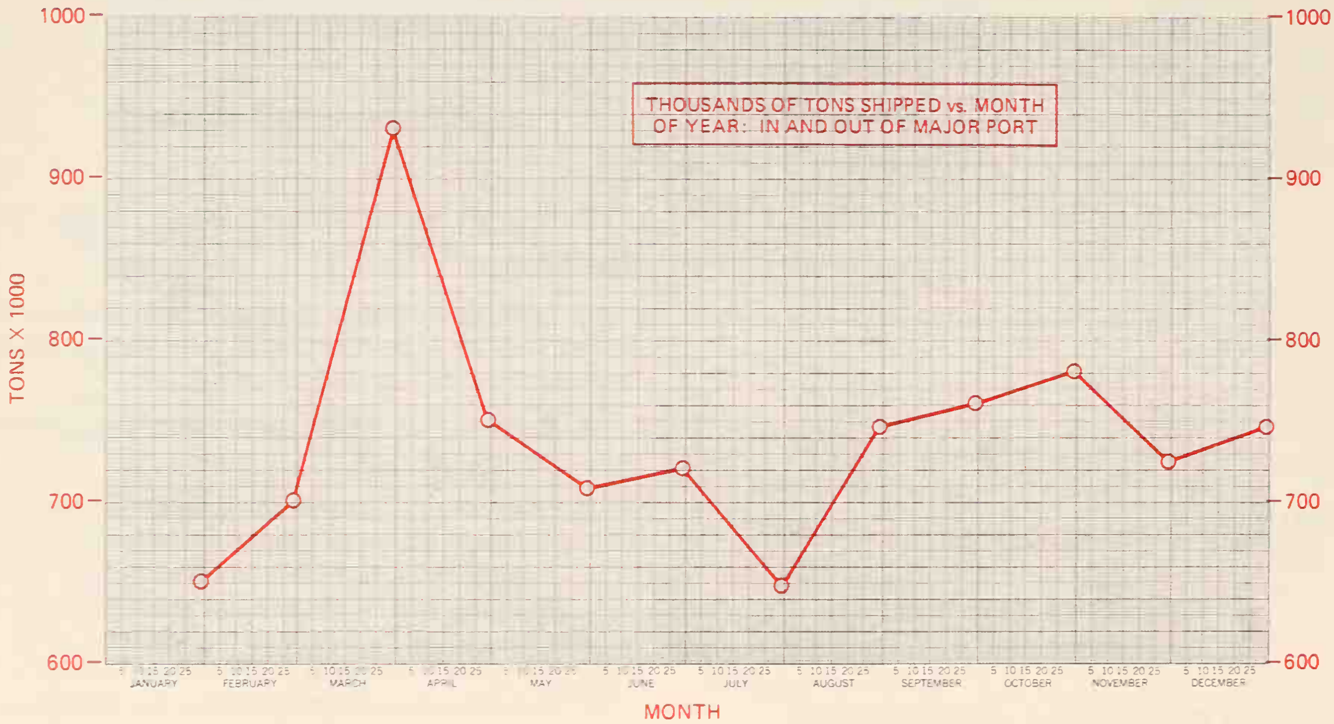


Figure 23-22 Topical scales

5. Use symbols for specific points when plotting data from laboratory experiments. Circles, squares, and triangles are common. Curves do not go through the symbols. See Figure 23-20.

6. Draw all curves lightly before finally darkening them in. Use smooth curves, without symbols, for equations. "Best" fit curves through points (symbols) for experimental data may miss some of the points. See Figure 23-20. Employ line segments for connecting discontinuous data, Figure 23-24. Note: curves representing changing physical phenomena (mechanical, electrical, and chemical) usually appear as smooth plots.

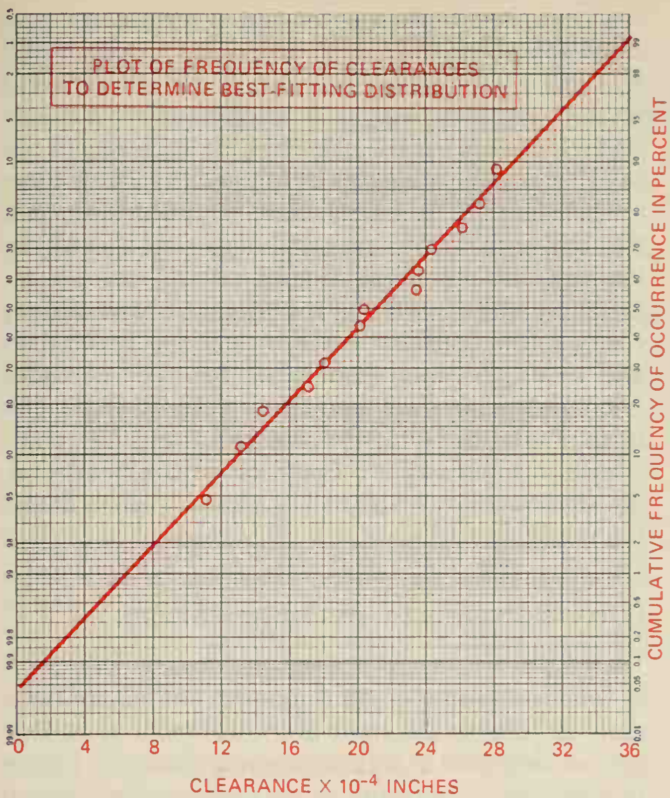


Figure 23-23 Different format

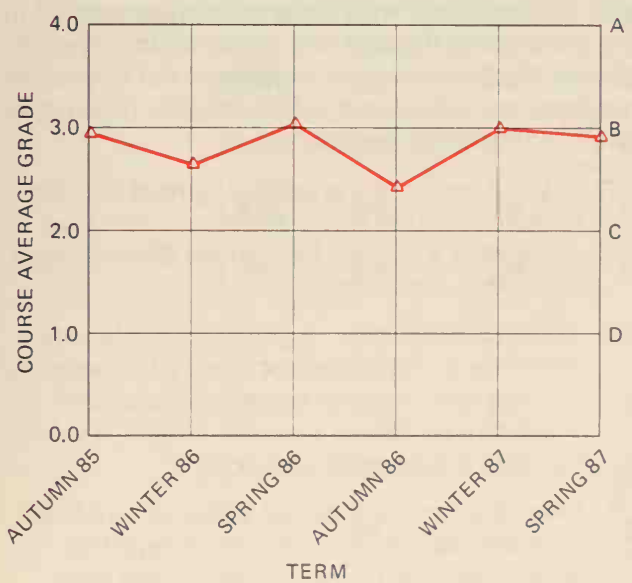


Figure 23-24 Discontinuous data

7. Clearly identify multiple plots on the same grid by labels and by a variety of different lines, Figure 23-25.

8. Label each axis by describing the variable and the unit of measurement. See Figure 23-20.

9. As a minimum, include in the title the dependent variable as a function of the independent variable. Also include the source of the data, the date, and your name. Arrange all labels, titles, and notes to be read either parallel to the bottom of the page or from the right side. Use a cleared space for the title if it appears in the grid area. Titles may be placed outside the grid area.

10. Step back and ask if the final form of the chart or graph communicates effectively or assists in generating the intended information. Successful charts and graphs are three orders of magnitude (10**3 = 1000) better at conveying information than words!

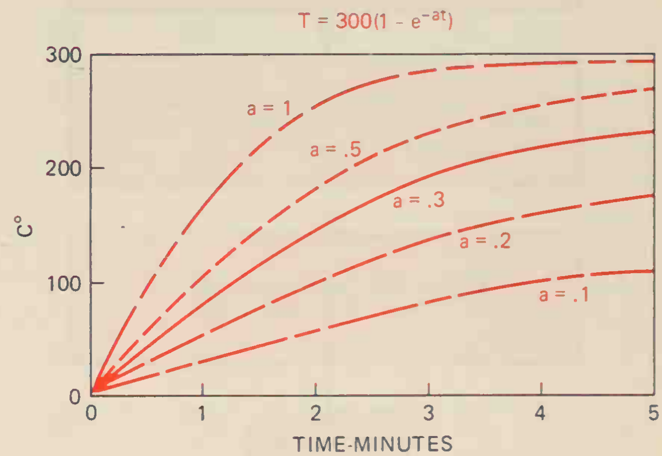


Figure 23-25 Variety of lines

The preceding discussion on preparing graphs and charts is summarized in the flow chart in Figure 23-26.

Further examples of uses and instructions for preparing specific charts and graphs constitute the remainder of the chapter. The examples illustrate student activities, classroom assignments in technical courses, and industrial applications.

Specific Charts and Graphs

In the preceding overview of the functions and formats of charts and graphs, six types were designated for further discussions.

- Pie Charts and Bar Charts: generated from a spreadsheet in a personal computer.
- Force Polygons: used in an optimization investigation.

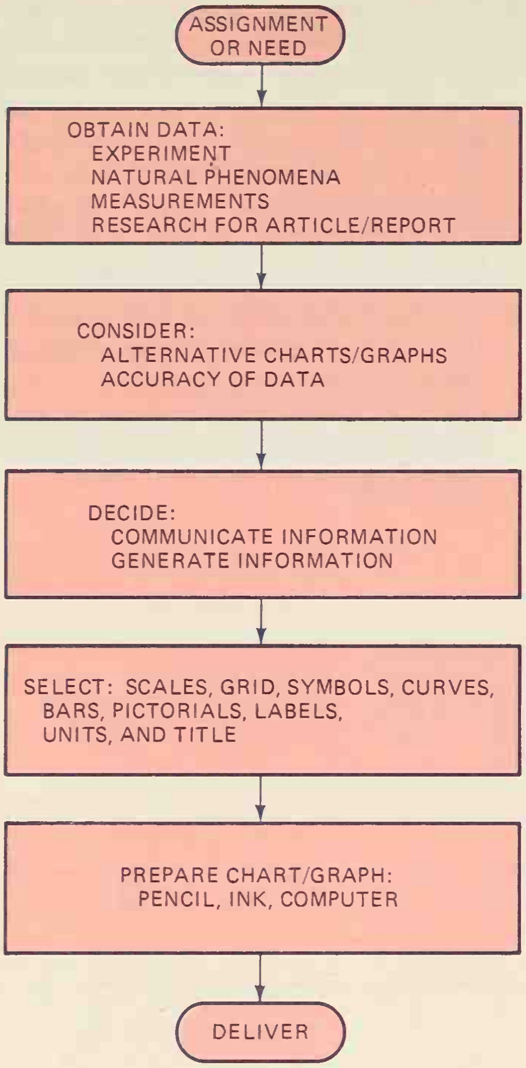


Figure 23-26 Design procedure: charts and graphs

- Nomograms: several alignment charts and concurrency charts to graphically represent equations.
- Empirical Equations: y = mx + b, y = b (e**mx), and y = b (x**m) for matching equations to data.
- Graphical Integration and Differentiation: Pole and Ray method.
- Beam Diagrams: free-body, shear, moment, slope, and deflection diagrams.

Pie Charts and Bar Charts from a Spreadsheet

Assume that a student in an orientation-to-higher-education class has prepared a weekly activity schedule for the first term as shown in Figure 23-27. The student's anticipated schedule of eating, sleeping, playing, attending class, studying, and everything else has been typed into a spreadsheet format in a personal computer. The format resembles "pigeon holes" for stuffing information into, arranged in columns and rows. One column lists each of the twenty-four hours; seven columns list the activities for each day of the week, coded in categories as follows: (ST) study time, (CL) class time, (SL) sleep time, (PL) playtime, (EA) eating time, and (MI) miscellaneous—transportation, laundry, club meetings, and church.

A program generated by the student, or one already contained in software, sorts through the seven days and totals the number of hours for each category. Then, instructions are typed or selected from a menu to generate and plot the pie chart and bar chart shown in Figure 23-28. Later, or for the next term, the student can, with a push of a button, easily adjust the schedule and have new plots made.

Force Polygons in an Optimization Investigation

Force polygons, vector diagrams, and vector polygons all refer to the same graphical technique. *Force polygons* are used in this discussion. However, before proceeding to the optimization investigation, several assumptions and definitions need to be stated. This discussion assumes that the reader has had a brief introduction to forces and vectors but will appreciate a condensed review of some basic concepts. Only solid bodies at rest with coplanar, concurrent (all in one plane going through one point) vectors are considered. Furthermore, the weights of the bodies, or members, are considered to be negligible (zero) compared to the forces applied.

1. *Vector*: A vector is a graphical symbol that represents direction by means of an arrowhead at one end of a straight line whose scaled length represents a *magnitude*.
2. *Physical Simplifications*: A physical simplification describes the essentials of a real phenomenon. For example, a vector is a graphical model which can represent a weight, a force, a velocity, or an acceleration of a body.
3. *Force*: A force is a directed action of one body on a second one that tends to change the state of motion, or rest, of the second body; therefore, a force is a vector quantity.
4. *Equilibrium*: The sum of forces acting on a solid body, in any direction, add to zero on a body in equilibrium that is either at rest or moving at a constant velocity. The following equation of mechanics states this principle succinctly: $\Sigma F = 0$.
5. *Two-Force Members*: The majority of two-force members are found in structures, frames,

HOUR	SUN	MON	TUE	WED	THU	FRI	SAT
0000	SL	SL	SL	SL	SL	SL	SL
0100	SL	SL	SL	SL	SL	SL	SL
0200	SL	SL	SL	SL	SL	SL	SL
0300	SL	SL	SL	SL	SL	SL	SL
0400	SL	SL	SL	SL	SL	SL	SL
0500	SL	SL	SL	SL	SL	SL	SL
0600	SL	SL	SL	SL	SL	SL	SL
0700	SL	MI	MI	MI	MI	MI	SL
0800	SL	EA	EA	EA	EA	EA	SL
0900	MI	CL	CL	CL	CL	CL	MI
1000	EA	CL	MI	CL	MI	CL	EA
1100	MI	CL	CL	CL	CL	CL	ST
1200	MI	EA	EA	EA	EA	EA	ST
1300	EA	ST	CL	ST	CL	MI	EA
1400	ST	ST	CL	ST	CL	MI	PL
1500	ST	ST	CL	ST	CL	PL	PL
1600	ST	ST	MI	ST	MI	PL	PL
1700	ST	MI	MI	MI	MI	PL	PL
1800	EA	EA	EA	EA	EA	EA	PL
1900	EA	MI	ST	MI	ST	PL	EA
2000	PL	ST	ST	ST	ST	PL	PL
2100	ST	ST	ST	ST	ST	PL	PL
2200	ST	ST	ST	ST	ST	PL	PL
2300	ST	SL	SL	SL	SL	PL	PL

Figure 23-27 Week activities: spreadsheet

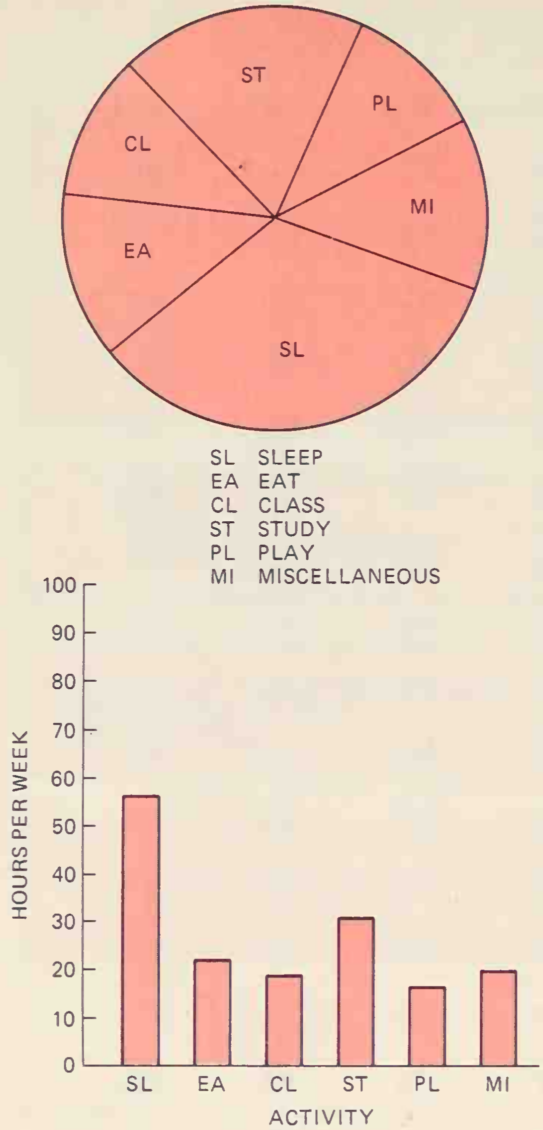


Figure 23-28 Pie and bar charts from spreadsheet

trusses, and flexible members in tension. The two forces are equal and opposite in direction, colinear, and applied at the ends of the member. See Figure 23-29 for two examples, one in tension and one in compression.

6. *Vector Addition and Subtraction*: Two vectors that are not parallel and not colinear but are acting on the same body and going through the same point may be added by the parallelogram-law technique. Refer to Figure 23-30 for an example showing the addition of two vectors A and B to obtain a single vector R, which is equivalent to the effect of the two vectors and is called a *resultant*. Figure 23-30 also shows the subtraction of vector B from vector A. A vector labeled *equilibrant* is the reaction to the resultant vector R and is equal and opposite to R, and its line of action goes through the same

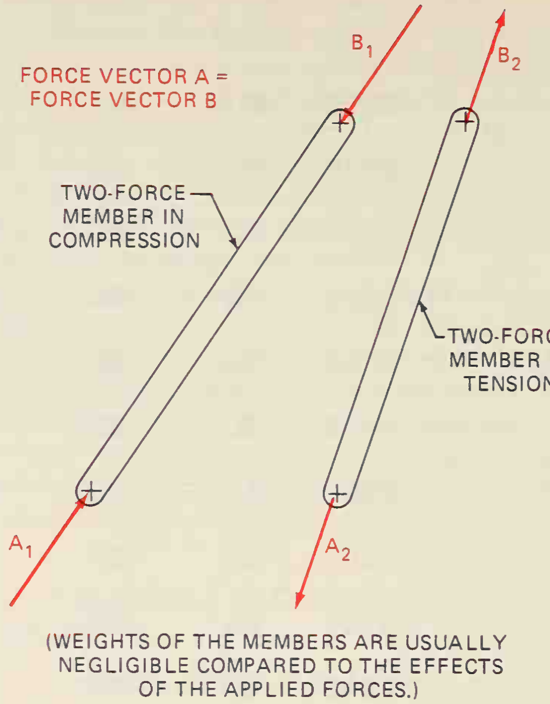


Figure 23-29 Two-force members

point. Of course, the sum of the resultant R and the equilibrant equals zero. (Note: the term "equilibrant" is used mostly in definitions, but not much in actual problems in mechanics.)

More than two vectors—such as A, B, and C—acting on a body and going through a common point add, "tail to head," in any order to create a resultant and an equilibrant. Figure 23-31. Figure 23-31 also illustrates that the sum of vectors A, B, and C plus the equilibrant equals zero. Moreover, when all the force vectors (three or more) acting through a common point on a body that is in equilibrium are added "tail to head," the sum must equal zero.

7. *Free-Body Diagrams* (FBD): A body in equilibrium, free from its supports, or a portion of the body shown separately, is a free-body diagram when all the forces acting on the body are shown. Figure 23-32 shows a complete body in equilibrium, and it is drawn as an FBD. The isolated pinned joint at B is also drawn as an FBD. Isolating joints saves space and time and allows for both external forces and internal forces to be shown.

The forces on the isolated joint B are assumed to go through the "pin" at the joint. Joints in trusses and frames are usually considered to be pinned even though the joint

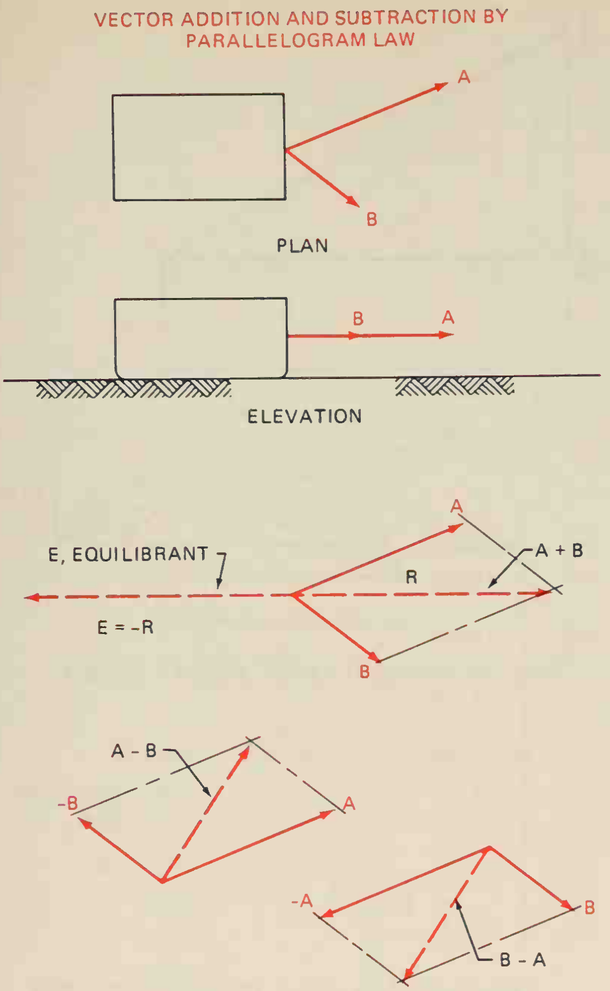


Figure 23-30 Parallelogram law: vector addition and subtraction

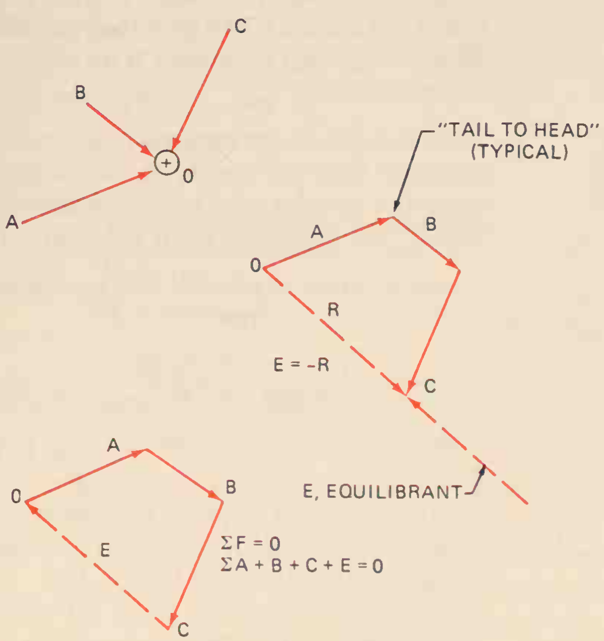


Figure 23-31 Addition: three or more vectors

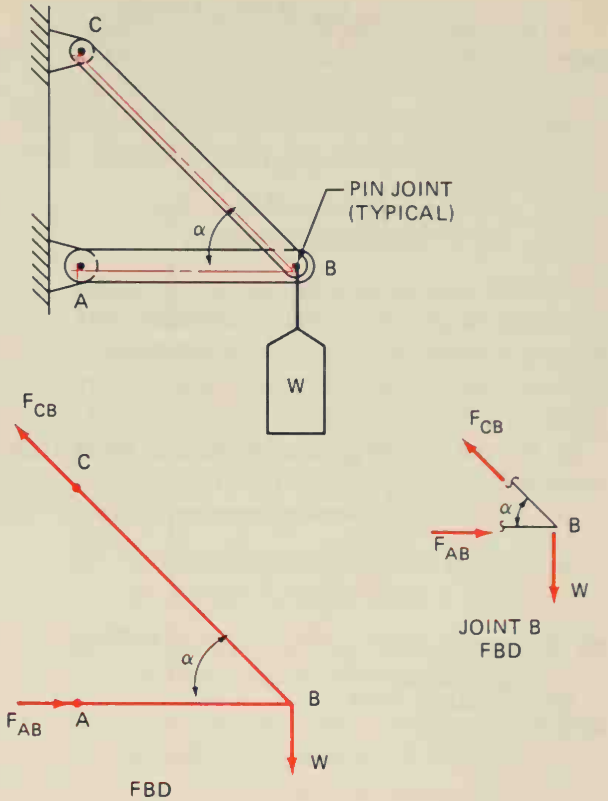


Figure 23-32 FBD (freebody diagrams)

may be welded, riveted, or bolted. This practice is a simplification in mechanics to facilitate joint analyses with FBD's.

Having the skill to draw accurate Free-body diagrams will significantly increase a student's grade point average!

8. *Force Polygon for Analysis*: The force polygon in Figure 23-33 was used to determine the direction and magnitude of the forces F (CB) and F (AB) for the isolated joint B in Figure 23-32. Assuming that the boom AB and the strut CB have been drawn to scale, the steps in the procedure are as follows:

   a. Start at reference point O and construct to scale the force vector W pointing vertically downward.

   b. Since the two remaining forces F(CB) and F(AB) must add on to W and finally end at the starting point O, one light line through the head of W is drawn parallel to the strut CB. A second line is drawn through point O parallel to boom AB. The intersection point of the two lines determines the magnitudes of F(CB) and F(AB); also, the "tail to head" pattern determines their directions. (Only two unknown forces may be determined using this technique in coplanar problems).

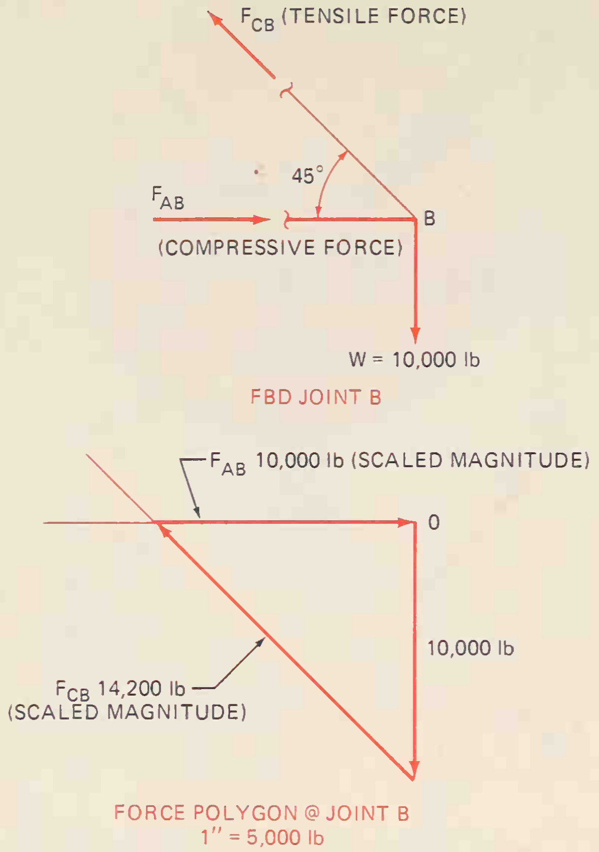


Figure 23-33 Force polygon application

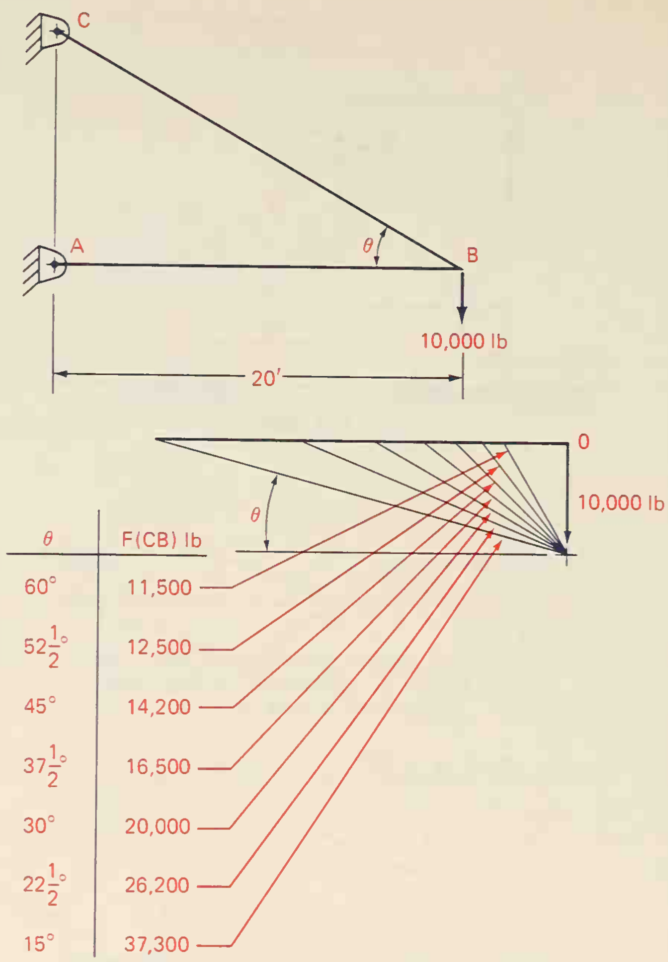


Figure 23-34A Force polygons for F(BC)

c. The direction of F(CB) is "away" from the joint B; therefore, F(CB) is a tensile force. The direction of F(AB) "into" the joint indicates a compressive force. W is an externally applied force, so it is neither tensile nor compressive. F(AB) could have been considered first in step b and the results would be identical. Now that definitions and assumptions have been stated, the optimization investigation utilizing force polygons comes next.

9. *Optimization Investigation Using Force Polygons*: Optimizing a design usually entails finding maximum performance or minimum cost or both. The objective in this elementary example is to determine the angle theta between the boom AB and the strut CB that will give the minimum cost for the member CB, with CB still supporting the 10,000-pound load safely. Refer to Figure 23-34A.

a. Member CB is to be an equal leg, structural angle made of mild steel. Boom AB is 20 feet long and is assumed to be satisfactory for any angle theta between 15° and 60°. Weights of the members are negligible.

b. Force polygons shown in Figure 23-34A determine the tensile forces F(CB) in member CB for different angle thetas. Space diagrams (same linear scale in all directions) in Figure 23-34B give the required lengths L(CB) for member CB for the same angles.

c. Next, the forces are entered in a stress equation from the theory of mechanics of materials to select the equal leg structural angles. The equation S = (F)/(A) states that:

$$\text{normal stress in pounds per square inch (psi)} = \frac{\text{pounds Force}}{\text{cross-sectional area in square inches}}$$

The *force* is assumed to be normal to the cross-sectional area, and each fiber in the entire member is stressed the same. One type of steel used for structural members has a *yield strength* of 36,000 psi. This means that the member could withstand tensile forces, in a linear manner (see Figure 23-35), without excessive yielding

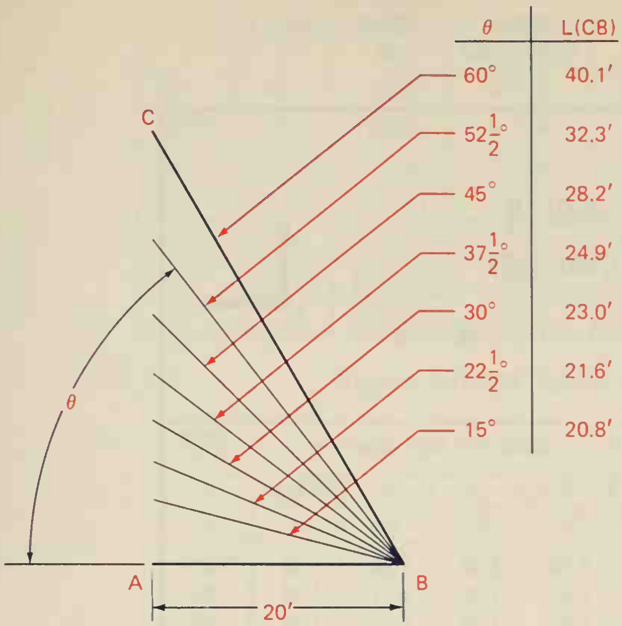


Figure 23-34B Space diagrams for L(BC)

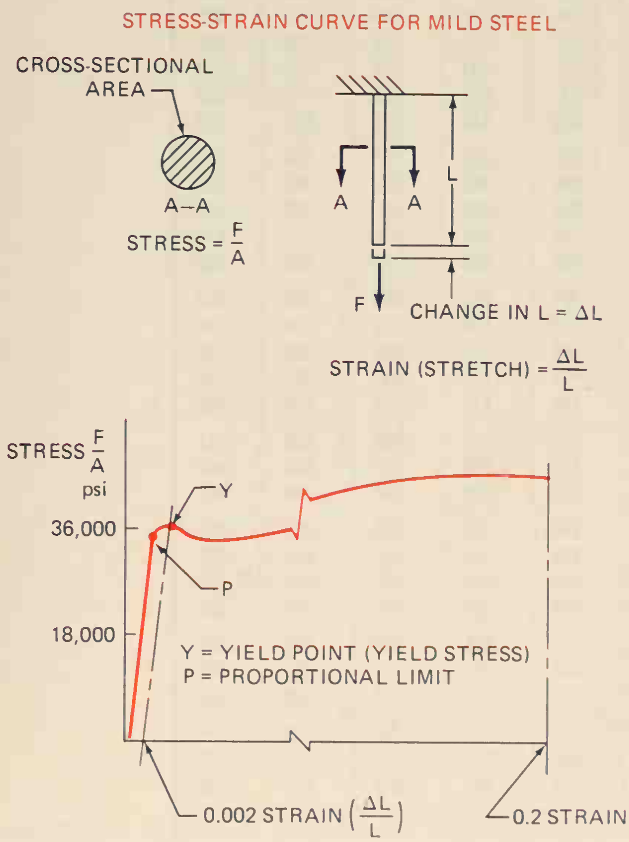


Figure 23-35 Stress vs. strain

(stretching), up to 36,000 psi. Therefore, a designer would divide the yield stress by a *factor of safety* to obtain an *allowable* or *working stress* and specify that the stress in the member must not exceed it. A typical factor of safety for this application would be 2.0, so the allowable stress would be 18,000 psi; that is, halfway down the linear plot in Figure 23-35. This allowable stress is used in the stress equation.

The stress equation may now be rearranged to solve for area, the third unknown.

Cross-sectional Area =
pounds force/18,000 psi

d. Figure 23-36 contains an excerpt from an AISC Handbook which lists equal leg structural angles, cross-sectional areas in square inches, and weight per foot of each angle. The following example-calculation for an angle theta of 30° summarizes several of the steps already described and adds several more steps to arrive at cost.

(i) L(CB) is found in a space diagram to be 23 feet long for theta = 30°.

(ii) F(CB) is found in a force polygon to be 20,000 pounds for theta = 30°.

(iii) A(CB), the required cross-sectional area to limit the stress to 18,000 psi, is found from the equation:

$$A(CB) = \frac{F(CB)}{18{,}000} = \frac{20{,}000}{18{,}000}$$
$= 1.111$ square inches.

(iv) From the AISC Handbook data, the nearest angle with a cross-sectional area of 1.111 or more is Angle 2-½ × 2-½ × ¼ with an area of 1.19 and a weight of 4.1 pounds/foot. Select the lightest member of a group in the handbook, because they are usually the ones readily available in warehouses.

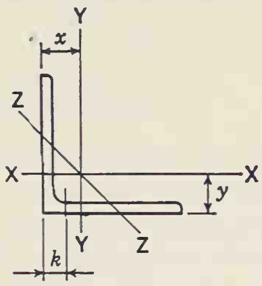
(v) Finally, assuming that the cost is $2.00 per pound, this angle would cost: (23 feet)(4.1 pounds/foot)(2.00/pound) = to the nearest dollar, $189.00.

(vi) The rest of the structural angles were selected in a similar manner and tabulated in Figure 23-37A.

(vii) Figure 23-37B shows three curves, each a function of angle theta. The optimizing curve, $(CB) vs. theta, shows the lowest (optimum) cost at approximately 48°; therefore, the best angle to specify is angle 2 × 2 × 3/16 × 3 feet long.

Nomograms: Alignment Charts and Concurrency Charts

Nomograms represent equations graphically as shown in Figure 23-13. *Alignment Charts*, one class of



ANGLES
Equal legs
Properties for designing

Size and Thickness	k	Weight per Foot	Area	AXIS X-X AND AXIS Y-Y				AXIS Z-Z
				I	S	r	x or y	r
In.	In.	Lb.	$In.^2$	$In.^4$	$In.^3$	In.	In.	In.
L 3½ × 3½ × ½	7/8	11.1	3.25	3.64	1.49	1.06	1.06	.683
7/16	13/16	9.8	2.87	3.26	1.32	1.07	1.04	.684
3/8	3/4	8.5	2.48	2.87	1.15	1.07	1.01	.687
5/16	11/16	7.2	2.09	2.45	.976	1.08	.990	.690
1/4	5/8	5.8	1.69	2.01	.794	1.09	.968	.694
L 3 × 3 × ½	13/16	9.4	2.75	2.22	1.07	.898	.932	.584
7/16	3/4	8.3	2.43	1.99	.954	.905	.910	.585
3/8	11/16	7.2	2.11	1.76	.833	.913	.888	.587
5/16	5/8	6.1	1.78	1.51	.707	.922	.865	.589
1/4	9/16	4.9	1.44	1.24	.577	.930	.842	.592
3/16	1/2	3.71	1.09	.962	.441	.939	.820	.596
L 2½ × 2½ × ½	13/16	7.7	2.25	1.23	.724	.739	.806	.487
3/8	11/16	5.9	1.73	.984	.566	.753	.762	.487
5/16	5/8	5.0	1.46	.849	.482	.761	.740	.489
1/4	9/16	4.1	1.19	.703	.394	.769	.717	.491
3/16	1/2	3.07	.902	.547	.303	.778	.694	.495
L 2 × 2 × 3/8	11/16	4.7	1.36	.479	.351	.594	.636	.389
5/16	5/8	3.92	1.15	.416	.300	.601	.614	.390
1/4	9/16	3.19	.938	.348	.247	.609	.592	.391
3/16	1/2	2.44	.715	.272	.190	.617	.569	.394
1/8	7/16	1.65	.484	.190	.131	.626	.546	.398
L 1¾ × 1¾ × ¼	1/2	2.77	.813	.227	.186	.529	.529	.341
3/16	7/16	2.12	.621	.179	.144	.537	.506	.343
1/8	3/8	1.44	.422	.126	.099	.546	.484	.347
L 1½ × 1½ × ¼	7/16	2.34	.688	.139	.134	.449	.466	.292
3/16	3/8	1.80	.527	.110	.104	.457	.444	.293
5/32	3/8	1.52	.444	.094	.088	.461	.433	.295
1/8	5/16	1.23	.359	.078	.072	.465	.421	.296
L 1¼ × 1¼ × ¼	7/16	1.92	.563	.077	.091	.369	.403	.243
3/16	3/8	1.48	.434	.061	.071	.377	.381	.244
1/8	5/16	1.01	.297	.044	.049	.385	.359	.246
L 1 × 1 × ¼	3/8	1.49	.438	.037	.056	.290	.339	.196
3/16	5/16	1.16	.340	.030	.044	.297	.318	.195
1/8	1/4	.80	.234	.022	.031	.304	.296	.196

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Figure 23-36 Equal leg structural angles (*Courtesy American Institute of Steel Construction*)

θ	L(CB) ft	F(CB) lb	A(CB) Calculated	Angle ∠	A(CB) Handbook	lb/ft	Wt(CB) lb	$(CB)
60°	40.1	11,500	0.639	2×2×3/16	0.715	2.44	97.8	196
52½°	32.3	12,500	0.694	2×2×3/16	0.715	2.44	78.8	158
45°	28.2	14,200	0.789	2½×2½×3/16	0.902	3.07	86.6	173
37½°	24.9	16,500	0.917	3×3×3/16	1.09	3.71	92.4	184
30°	23.0	20,000	1.111	2½×2½×¼	1.19	4.1	94.3	189
22½°	21.6	26,200	1.456	2½×2½×5/16	1.46	5.0	108.0	216
15°	20.8	37,200	2.067	3½×3½×5/16	2.09	7.2	149.8	300

Figure 23-37A Table: optimization investigation

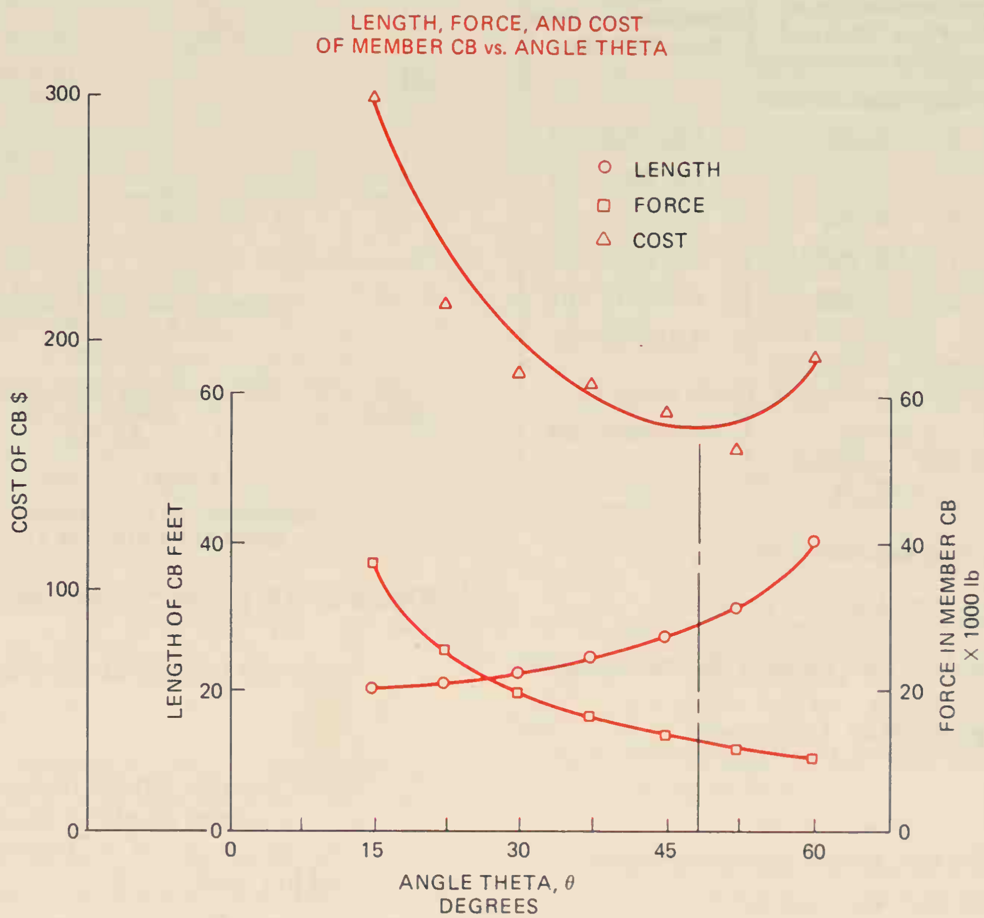


Figure 23-37B Graphs: optimization investigation

nomograms, appear in periodicals, vendor catalogs, and textbooks. These charts are designed to help the reader visualize the information to be generated, and to obtain the information quickly and accurate enough for most design calculations. As a further aid for the reader, the charts contain an example or two showing how to use them. Thus, designers can use the charts easily without having to know how the chart was constructed.

However, if designers know the theory and how to construct alignment charts, they will use them more effectively and confidently. Moreover, these designers will be able to decide whether the effort and time to prepare alignment charts will ultimately save time for themselves or their colleagues. Some may need to make alignment charts for reports and manuals.

First, consider a few reminders regarding mathematics, followed by a few definitions; then, a number of charts.

1. *Common Logarithm.* A common logarithm is an exponent of the base number 10, so that when 10 is raised to that exponent a specific number is generated. For example, the common logarithm of the number 25, written log 25, is equal to 1.397940; that is, 10**1.397940 = 25. The table in Figure 23-38 shows an interesting comparison of "the old way" of obtaining logs and the current source, hand calculators.

N Number	Log N Characteristic from Five-Place Table and Mantissa by observation	Log N Complete Log from Hand Calculator
	mantissa+characteristic	
1	0. .00000	0.000000 00
7560	3. .87852	3.878522 00
756	2. .87852	2.878522 00
75.6	1. .87852	1.878522 00
7.56	0. .87852	8.875218 −01
.756	7.56/10 0.87852 − 1.00000 = −.12148	−1.214782 −01
.0756	7.56/100 0.87852 − 2.00000 = −1.12148	−1.121478 00

Note:
(a) logarithms obey exponent laws:

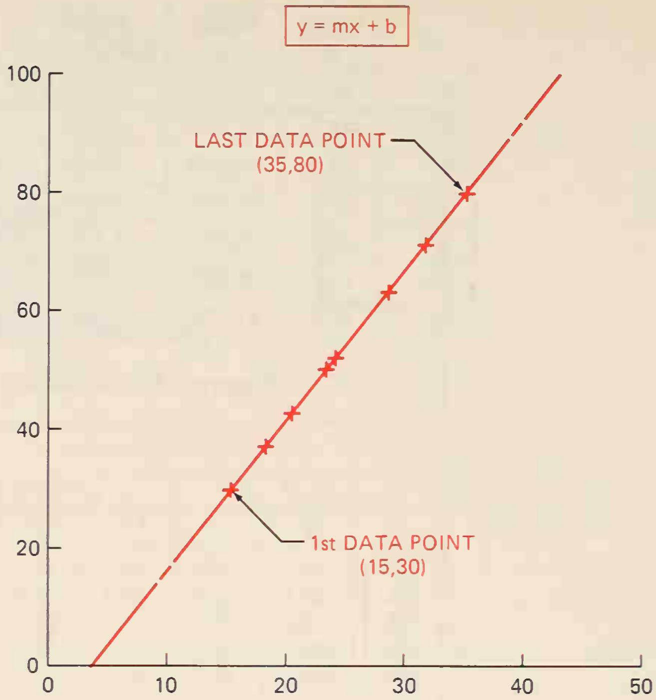
$$\frac{10^m}{10^n} = 10^{m-n} \text{ AND } 10^m \cdot 10^n = 10^{m+n}$$

(b) mantissa: one less than number of digits before decimal

Figure 23-38 Logarithms

2. *Function of a Variable: $y = f(x)$.* In the equation $y = x^{**}2 + 3x + 10$, y is a function of the variable x, written in short form as $y = f(x)$. Occasionally, in alignment chart derivations a single variable, such as u, that may have a range of numerical values is written as $f(u) = u$.

3. *Straight-Line Equation $y = mx + b$.* The straight-line equation, $y = mx + b$, specifies that a dependent variable y is a function of an independent variable x, m is the slope of the straight line, and b is the intercept along the vertical axis. Assume that the coordinate axes follow a traditional pattern: y is plotted in the vertical direction (ordinate axis) and x is plotted in the horizontal direction (abscissa), as shown in Figure 23-39.



$$\text{SLOPE } m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{80 - 30}{35 - 15} = \frac{50}{20} = 2.5$$

$\therefore y = 2.5x + b$

USE ONE DATA POINT TO FIND b.
$30 = 2.5(15) + b$
$b = -7.5$

FINALLY $y = 2.5x - 7.5$

(HOWEVER, THE EQUATION IS GOOD ONLY OVER THE RANGE OF THE DATA.)

Figure 23-39 $y = mx + b$: straight-line equation

4. *Similar Triangles.* Similar triangles form the basis of almost all alignment chart designs. Some properties of the triangles are summarized in Figure 23-40.

5. *Alignment Chart.* An *alignment chart* is a graphical representation of the relationship of two or more variables, such as $y = \log X$, $u + v = w$, $uv = w$, and $u = v/w$.

6. *Scale Equation $L = mf(x)$.* The *scale equation* fits functions to the page area. In the equation: $L = m\,[f(X_n) - f(X_0)]$, L = the distance between the final value X_n and the initial value X_0. Designers select distance L, arbitrarily: m = scale modulus which makes the scale fit the page. The quantity $f(X_n)$ = the value of the function of X (when X_n is the largest number of the given range of numbers) and $f(X_0)$ = the lowest value of the function of X.

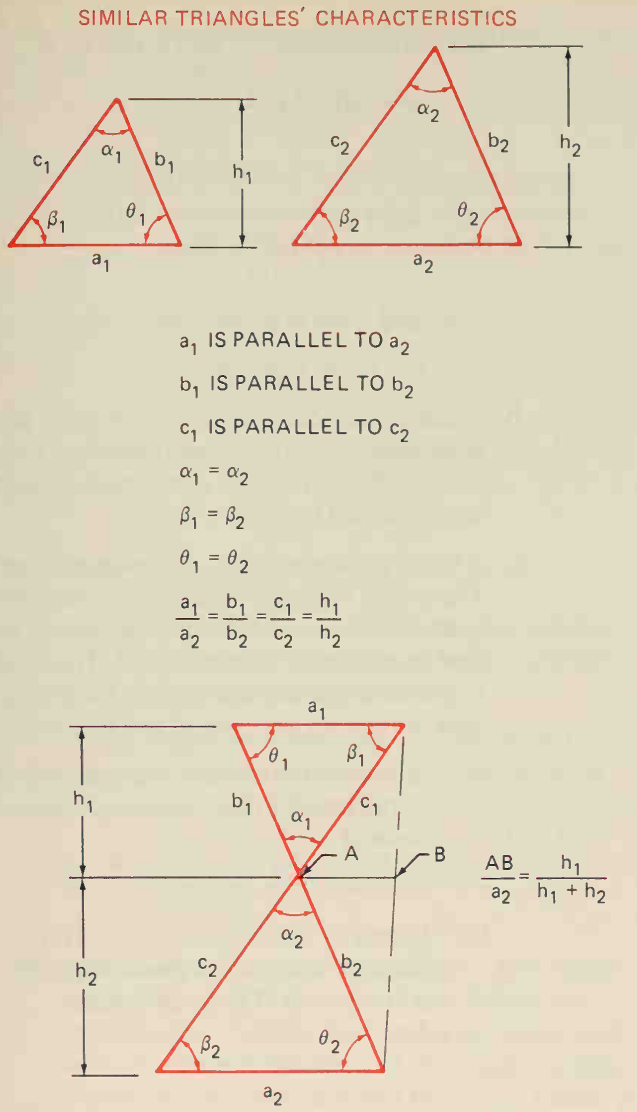


Figure 23-40 Similar triangles

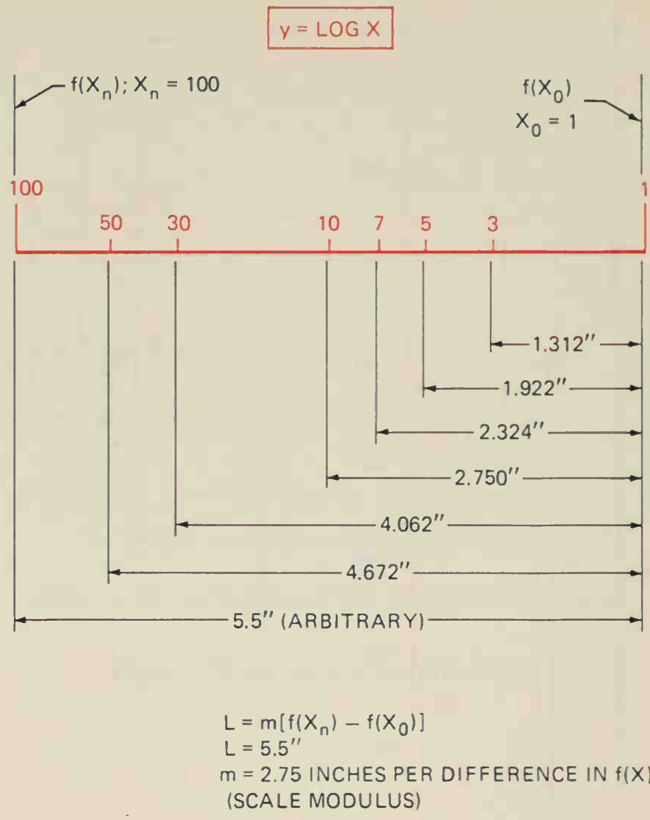


Figure 23-41 Functional scales: $y = f(x)$

7. *Functional Scale for* $y = f(X)$. A *functional scale* is a line graduated and labeled according to a functional relationship. Distances to the labels are calculated using the scale equation, but the distances are not shown on the scale.

   The functional scale in Figure 23-41 is labeled for the function $y = \log X$. The distances to the labels were calculated using the following steps:

   a. Since X ranges from $X = 1$ to $X = 100$, and 5.5 inches was arbitrarily selected to fit the scale on the page, the scale modulus was calculated.

   $$L = m[f(X_n) - f(X_0)]$$
   $$5.5 = m[\log 100 - \log 1]$$
   $$m = \frac{5.5}{(2 - 0)}$$
   $$= 2.75 \text{ inches per difference in } f(X).$$

   b. Next, distances to each label were calculated; for example, when $X = 30$:

   $$L = (2.75)(\log 30 - \log 1) = 4.062''$$

   This distance and several others are shown in Figure 23-41.

8. *Adjacent Alignment Chart for* $f(u) = f(v)$

   a. Two related variables plotted along the same line, but on opposite sides, make up an adjacent alignment chart. A temperature conversion chart for relating degrees Celsius to degrees Fahrenheit is an excellent example. Assume that 8 inches is arbitrarily designated as the scale length and do the following to create the conversion scale shown in Figure 23-42:

   (i) $L(\text{Celcius}) = L(C) = m(C)(100 - 0)$
   $8 = m(C)(100)$
   $m(C) = 0.08$ inches per difference in degrees Celsius

   thus, $L(C) = 0.08C$ is the scale equation.

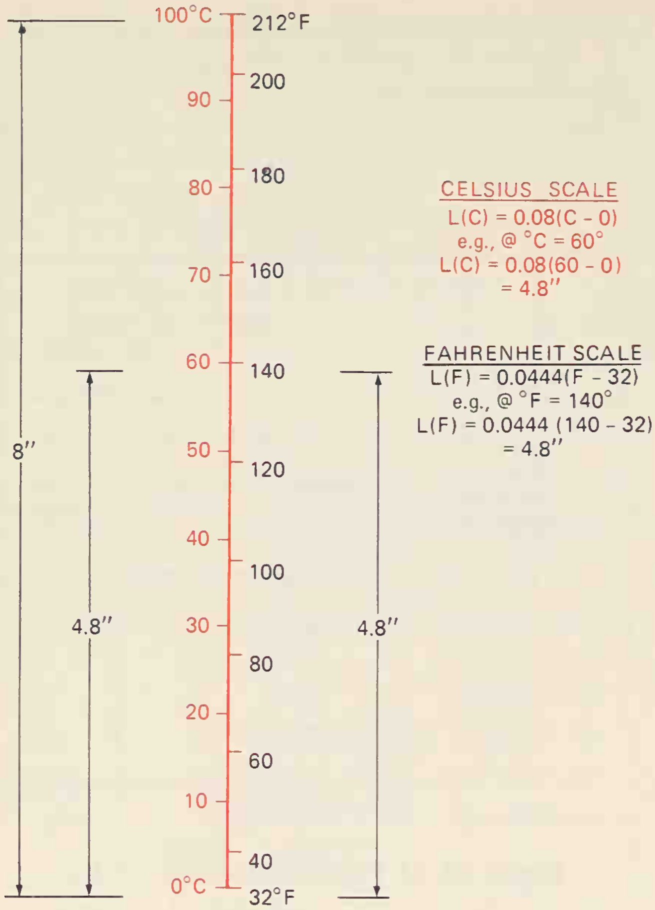


Figure 23-42 Adjacent alignment chart: f(u) = f(v)

(ii) $L(\text{Fahrenheit}) = L(F) = m(F)\,\frac{5}{9}(F - 32)$

$8 = m(F)\,\frac{5}{9}(F - 32)$

when F = 212 degrees

$$m(F) = \frac{8}{\frac{5}{9}(212 - 32)} = 0.08$$

and $L(F) = (0.08)\,\frac{5}{9}(F - 32)$,

the scale equation.

b. Another adjacent alignment chart is the speedometer in most automobiles which have MPH and kmPH graduated along the same curved line.

c. A third example solves a designer's needs. The stress equation used in the *Force Polygons* discussion can be plotted along one line, as shown in Figure 23-43. The steps to produce the adjacent plots for the equation "stress = Force/Area" are as follows:

(i) Assume an arbitrary scale length of 6 inches and the equation restated to read

Area = Force/18,000

(ii) L(area) = m(A) [(F/18,000) − (0)]
Assume that the largest value of F will be 45,000 pounds force.

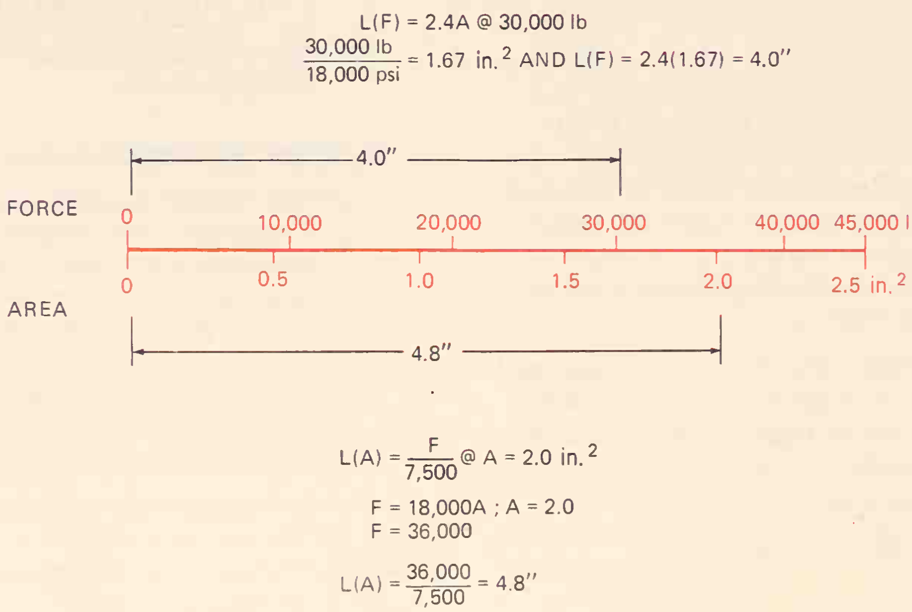


Figure 23-43 Adjacent alignment chart: stress = (force)/(area)

Then m(A) = 6/|(45,000/18,000) − (0)|
m(A) = 2.4
L(A) = 2.4|(F/18,000) − (0)|
L(A) = (F/7500 − 0)

(iii) Since F was found from the force polygons and used in the equation, rewrite the stress equation for F to be F = 18,000A

Then L(F) = m(F)(18,000A)
The maximum value of A is
A = 45,000/18,000 = 2.5

$$\text{Thus, } m(F) = \frac{6}{(18{,}000)(2.5)} = \frac{1}{7500}$$

$$L(F) = \frac{1}{7500}(18{,}000A)$$

Finally, L(F) = 2.4A

(iv) Calculate and plot distances L(A) for a number of values of force between 0 and 45,000 pounds.

(v) Calculate and plot distances L(F) for a number of values of area between 0 and 2.5. Compare several values of area opposite forces, from the chart with the tabulated values in Figure 23-37A.

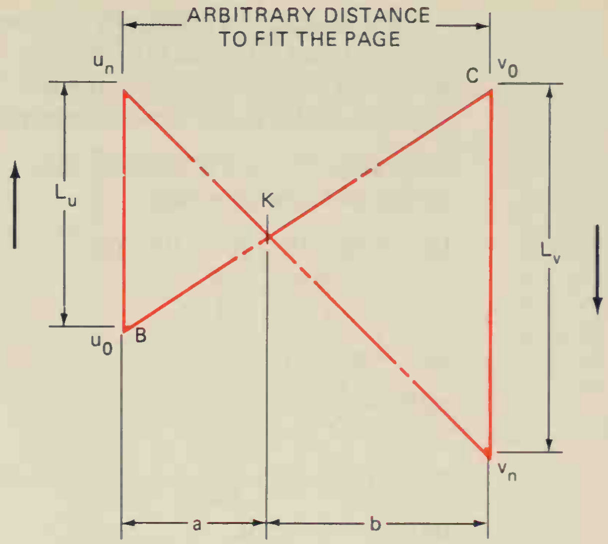


Figure 23-44 Non-adjacent scales

9. *Non-Adjacent Alignment Chart for f(u) = f(v).* Refer to the adjacent alignment chart discussion and visualize that the two scales are separated by a convenient distance to fit a page. Rotate one scale 180° and connect the lower value end of each with a straight line. All that remains to do to create a non-adjacent alignment chart is to locate a pivot point K to "hinge" straight lines called "isopleths." "Isopleths" are the lines used to locate values in a nomogram.

a. The steps for deriving the technique for preparing nonadjacent alignment charts are as follows:

(i) Locate two parallel lines at an arbitrary distance apart to fit the page. Select L(u) and L(v) as convenient lengths also to fit the page. Construct the similar triangles as shown in Figure 23-44 and label intersections of the lines. Assume that the initial values of u and v are equal to zero— to facilitate the derivation.

(ii) From similar triangles

$$\frac{L(u)}{L(v)} = \frac{BK}{KC} = \frac{a}{b}$$

From the scale equation

$$\frac{L(u)}{L(v)} = \frac{m(u)\,f(u)}{m(v)\,f(v)} = \frac{a}{b}$$

And since f(u) = f(v)

$$\frac{m(u)}{m(v)} = \frac{a}{b}$$

(iii) Determine m(u) and m(v) so the ratio a/b can be found, which is used as a guide to divide the arbitrary distance between the scales in proportion to a and b. Point K locates the division and also acts as the pivot point for isopleths.

b. Use these steps to prepare a non-adjacent alignment chart for the equation C = 2πR where circumference is a function of radius R, or f(C) = f(R). R varies from 0 to 20 inches, and L(R) is arbitrarily set at 4 inches. See Figure 23-45.

(i) Determine m(R) from
L(R) = m(R)|f(20) − f(O)|

$$m(R)\,\frac{4}{20} = 0.2$$

Thus, L(R) = 0.2R

(ii) Assume that L(C) is arbitrarily 6 inches long and that L(C) and L(R) are separated by 4 inches, (L(R) on the left side), to fit the page. Now determine:

m(C) using $R = C/2\pi$ because the values of R are specified.

$$L(C) = m(C)\,[f(C(20) - f(C(O))]$$
$$= m(C)\,\frac{2\pi 20}{2\pi} - \frac{2\pi}{\pi}$$
$$L(C) = m(C)\,(20)$$
$$m(C) = \frac{6}{20} = 0.3$$

Thus, $L(C) = 0.3\,\frac{C}{2\pi}$

or $L(C) = 0.0478C$

(iii) Locate point K from

$$\frac{m(R)}{m(C)} = \frac{0.2}{0.3} = \frac{2}{3}$$

Divide line R(O) − C(O) into five parts and locate K a distance of 2 parts from R(O).

(iv) Graduate the two scales, L(R) and L(C), using scale equations. A helpful graphical technique for dividing lines is shown in the Figure 23-45.

(v) Use several isopleths to verify the chart, e.g., when R = 10, C should equal 62.8 inches.

10. *Parallel Alignment Chart for f(r) + f(t) = f(s)*

a. The procedure for preparing a set of three parallel scales for a three-variable equation, r + t = s, or more generally f(r) + f(t) = f(s), is derived using similar triangles and scale equations. The derivation aims at obtaining relationships from two of the scales so that the third can be located and graduated.

b. The following steps in the derivation are illustrated in Figure 23-46.

(i) Preliminary construction requirements and assumptions are summarized in the Figure 23-46.

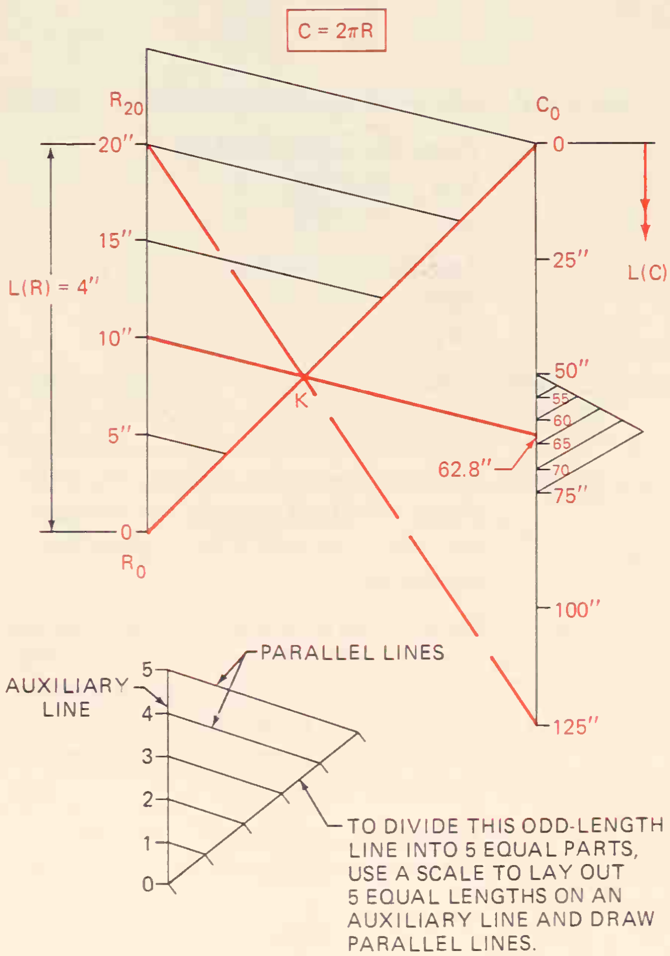


Figure 23-45 C = 2(3.14)R

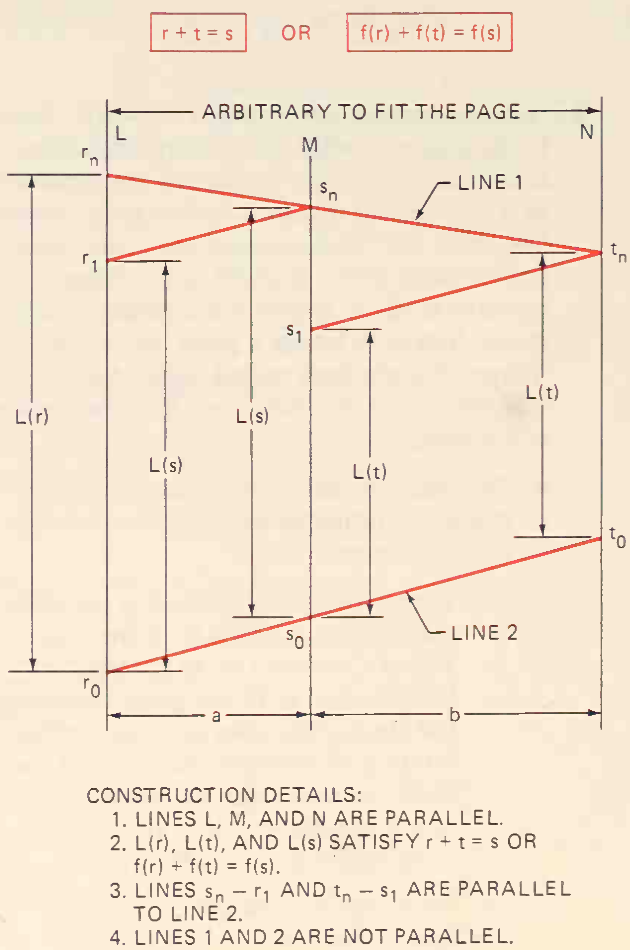


Figure 23-46 Parallel alignment chart: f(r) + f(t) = f(s)

(ii) To facilitate the derivation assume that:

–Initial values of the variables are equal to zero: r(O) = t(O) = s(O) = 0

–The scales L(r) and L(t) have been graduated and that m(r) and m(t) are known.

$L(r) = m(r)\, f(r)$
$L(t) = m(t)\, f(t)$

To be determined:

$L(s) = m(s)\, f(s)$

(iii) From similar triangles:

$$\frac{L(r) - L(s)}{a} = \frac{L(s) - L(t)}{b}$$

Substitute scale equations:

$$\frac{m(r)\, f(r) - m(s)\, f(s)}{a} = \frac{m(s)\, f(s) - m(t)\, f(t)}{b}$$

Cross multiply, collect terms and get m(r) f(r) + a/b m(t) f(t) = (a + b)/b m(s) f(s). Then since f(r) + f(t) = f(s), the coefficients must all be equal; that is, m(r) = a/b m(t) = (a + b)/b m(s). From step (iii): m(r)/m(t) = a/b which is used to locate the third scale, L(s).

Also from step (iii):

$$m(r) = \frac{a + b}{b}\, m(s) = (1 + \frac{a}{b})\, m(s)$$

Since $\frac{a}{b} = \frac{m(r)}{m(t)}$

$$m(r) = (1 + \frac{m(r)}{m(t)})\, m(s)$$

Finally, $m(s) = \frac{m(r)\, m(t)}{m(r) + m(t)}$

which is the scale modulus for L(s).

11. *Example Parallel Alignment Chart for r + t = s.* Figure 23-47 shows the chart for the equation r + t = s where r = 0 to 20 and t = 0 to 50. Do the following to construct the chart:

a. Draw the parallel scales for r and t to fit the page and leave room between them for scale s. Arbitrarily select L(r) = 4 inches, L(t) = 5 inches. Locate their zero values at the bottom. L(r) goes on the left.

b. Calculate scale moduli for m(r) and m(t).

$L(r) = m(r)\,(20 - 0)$

$$m(r) = \frac{4}{20} = 0.2$$

$L(t) = m(t)\,(50 - 0)$

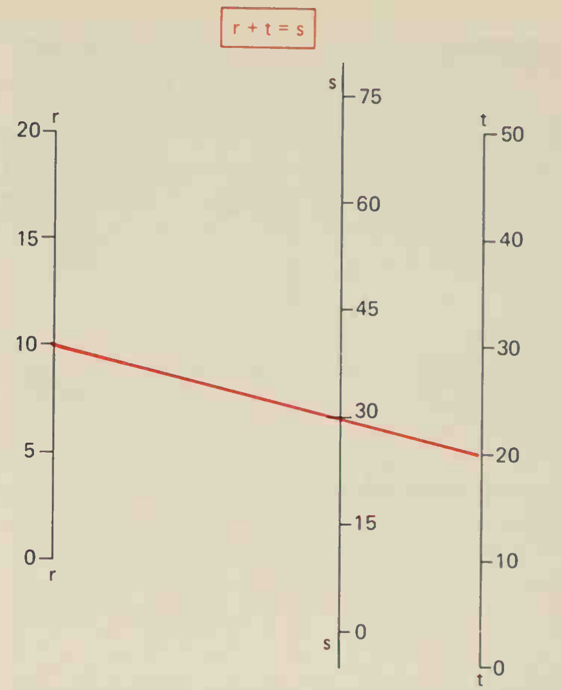


Figure 23-47 Parallel alignment chart: r + t = s

$$m(t) = \frac{5}{50} = 0.1$$

c. Locate a vertical line for the center scale, L(s), from

$$\frac{a}{b} = \frac{m(r)}{m(t)} = \frac{0.2}{0.1} = \frac{2}{1}$$

which places L(s) two-thirds of the distance between L(r) and L(t), from L(r)

d. Locate one value on L(s) by constructing an isopleth between any two values of r and t, e.g., r = 10 and t = 20, which of course gives s = 30. The remainder of L(s) can be completed using the scale equation L(s) = m(s) f(s), where s varies from 0 to 70.

e. Determine m(s) from

$$m(s) = \frac{m(r)\, m(t)}{m(r) + m(t)} = \frac{(.2)(.1)}{(.2 + .1)}$$

$m(s) = 0.067$

Thus, L(s) = 0.067f(s) for graduating scale s.

12. *Parallel Alignment Chart for f(r) • f(t) = f(s).* This second example is typical of an equation a designer would use. Assume that a nomogram is desired for E = IR. The equations can be rewritten as log E = log I + log R, which is in the form of f(r) + f(t) = f(s), which was derived earlier.

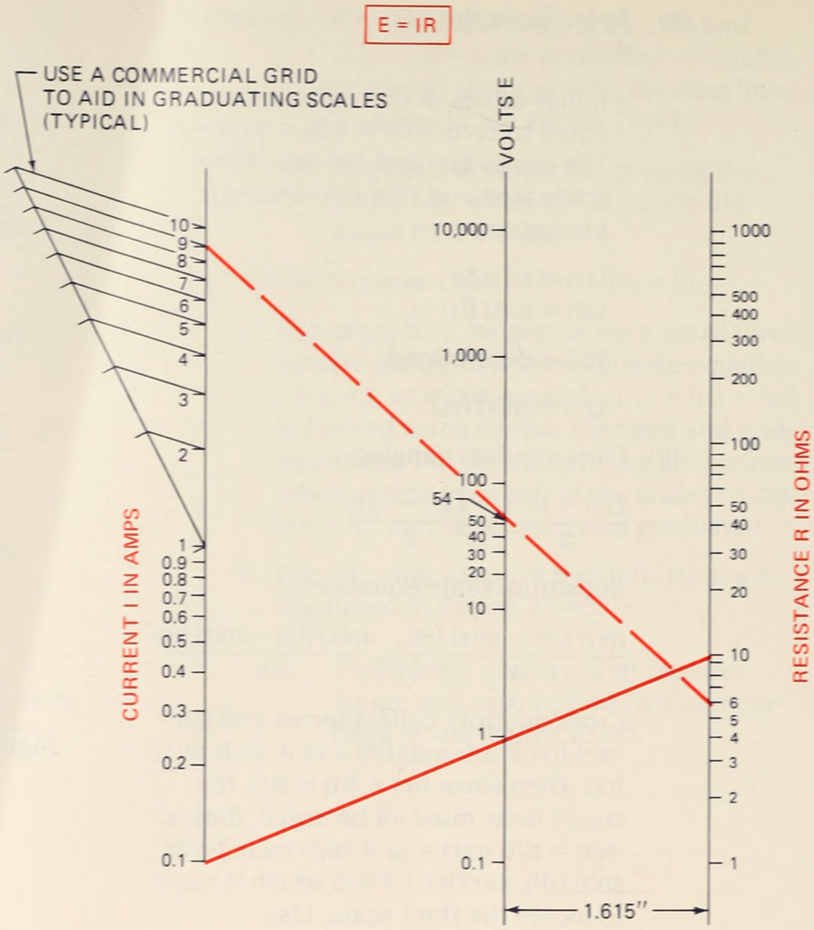


Figure 23-48 E = IR

To construct the nomogram for this basic equation, (volts) = (amps) (ohms), follow the steps below and refer to Figure 23-48.

a. Assume the ranges for the variables I and R: I = 0.1 to 10 amps and R = 1 to 1000 ohms. Select L(I) = 5 inches and L(R) = 5 inches: place them 4 inches apart, vertical, parallel, and with the smaller values at the bottom. Locate L(I) on the left side. Graduate them using the scale equations:

$L(I) = m(I) \bullet f(I)$ and $L(R) = m(R) \bullet f(R)$.

The y = log X scale in Figure 23-41 is a useful graphical aid in graduating logarithmic scales as illustrated in Figure 23-48.

b. Calculate scale moduli m(I) and m(R) to use in determining a/b and m(E).

$L(I) = m(I)(\log 10 - \log 0.1)$

$$m(I) = \frac{5}{(1.0 - (-1.0))} = 2.5$$

Thus, $L(I) = 2.5\, f(I)$
$L(R) = m(R)(\log 900 - \log 1)$

$$m(R) = \frac{5}{2.954243 - 0} = 1.6925$$

Thus, $L(R) = 1.6925\, f(R)$

c. $$\frac{a}{b} = \frac{m(I)}{m(R)} = \frac{2.5}{1.6925} = 1.477$$

Thus, a = 1.477 b and a + b = 4.00

and 1.477 b + b = 4.00

so, b = 1.615 inches from L(R);
a = 2.385 inches from L(I).

d. $$m(E) = \frac{m(I)\, m(R)}{m(I) + m(R)} = \frac{(2.5)(1.6925)}{(2.5 + 1.6925)}$$
$m(E) = 1.009$

Thus, $L(E) = 1.009\, f(E)$

so, $L(E) = 1.009\,(\log 9000 - \log 0.1)$
$= 1.009$ times $(3.954243 - (-1))$

$L(E) = 4.9988$ inches

e. Construct an isopleth for any value of E from IR, e.g., (0.1 amps) × (10 ohms) = 1 volt, which locates the scale L(E).

f. Graduate L(E) using the scale equation and the graphical aid, y = log x.

13. *Short Method for a Parallel Alignment Chart for* E = IR. After constructing a number of alignment charts and learning the theories plus graphical techniques, users will appreciate more practical, faster methods. One method is shown in Figure 23-49 for the steps below.

a. On a sheet of commercial 3-cycle, log-linear (semi-logarithmic) grid paper:

Locate I = 0.1, 1.0, and 10 amps on the left side of the sheet. Locate R = 1, 10, 100, and 1,000 ohms in a similar manner at a convenient distance to the right; say 5 or 6 inches.

b. Do two different calculations for E, but make $E_1 = E_2$, e.g.,

$E_1 = (10)(10) = 100$ volts
$E_2 = (1)(100) = 100$ volts

c. Connect the I and R values, respectively, with isopleths to locate the E scale where the two isopleths intersect. Label the intersection, 100.

d. Finish the E scale as before.

14. *Concurrency Charts for f(r) + f(t) = f(s).* Concurrency charts provide designers with an additional graphical format to visualize equations with three or more variables, and to generate information. The basic format is the familiar horizontal and vertical cartesian coordinate system. This first concurrency chart example has two objectives: one is to illustrate the format, and the other is to point out that designers may have a number of choices of formats for any one equation.

Note that the equation form r + t = s, or f(r) + f(t) = f(s), has been discussed earlier for parallel alignment charts.

Assume that the variables have values: r = 0 to 12, and t = 0 to 10. Figure 23-50 shows the concurrency chart for finding the third variable, s. Follow the steps used to prepare the chart:

a. Observe that the equation s = r + t is a straight-line equation, where s is y, r is x, and t is b in the general straight-line equation y = mx + b. The slope m = 1.

b. Divide the horizontal axis in equal segments for the variable r, 0 to 12.

c. Graduate the vertical axis to account for the minimum and maximum values of s, 0 to 22.

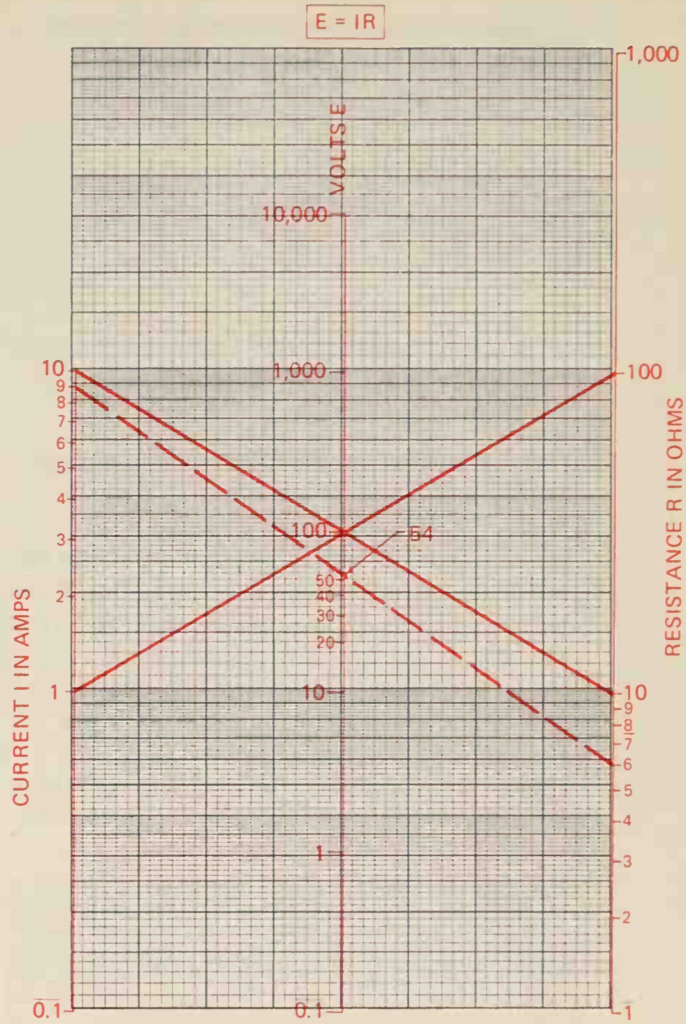


Figure 23-49 Shortcut: parallel alignment chart

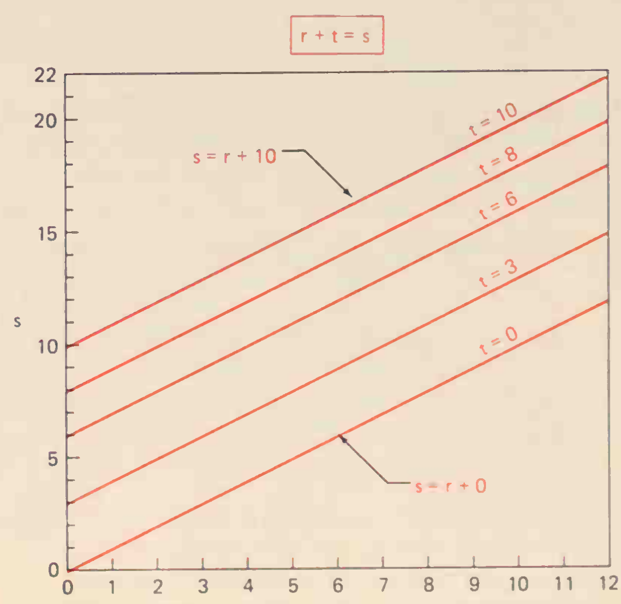


Figure 23-50 Concurrency chart: f(r) + f(t) = f(s)

d. Write equations to account for the intercept t in $s = (1)\,r + t$. For example,

When $t = 0,\ s = r$
$t = 1,\ s = r + 1$
$t = 2,\ s = r + 2$
○
○
○
$t = 10,\ s = r + 10$

e. Plot the equations which all have the same slope of 1, and label them with their appropriate t value.

15. *Concurrency Charts for f(r) • f(t) = f(s).* A second example of a concurrency chart, shown in Figure 23-51, is for the equation $E = IR$, which was used earlier. The equation can be rewritten in the form $\log E = \log I + \log R$, as before. This equation, also, is patterned after the familiar straight-line equation, because log E is y, log I is x, and log R is b. The slope $m = 1$. The steps to prepare the chart are similar to those for the preceding chart, except that the horizontal and vertical scales are graduated in the logarithmic format. The

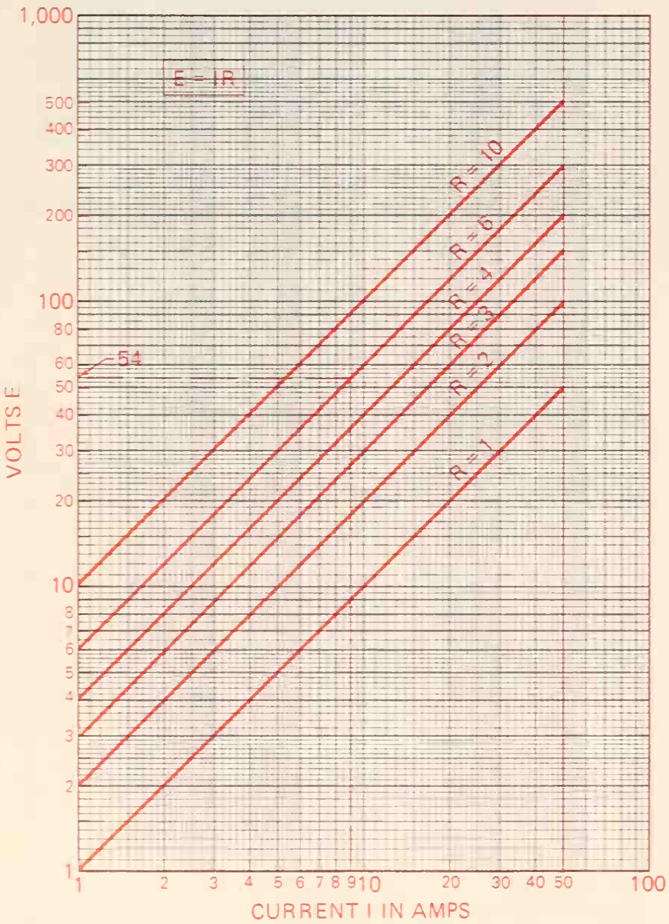


Figure 23-51 Concurrency chart: f(r) • f(t) = f(s)

variables I and R have the following ranges for this example:

$I = 0$ to 50 amps and $R = 1$ to 10 ohms.
E, then will be 0 to 500 volts.

a. Straight-line equations can be written to account for the intercept log R, as follows:

When $R = 1$
$\log E = \log I + \log 1$
and $E = I$

When $R = 10$
$\log E = \log I + \log 10$
and $E = 10\,I$

b. Finally, the curves are drawn with a slope of 1, as shown in Figure 23-51.

16. *Concurrency Charts for f(r) • f(t) = f(s).* This chart is an alternative format to the preceding discussion. The same equation, $E = IR$, is used but the steps are different and the chart is different, as seen in Figure 23-52. Do the following for this alternative:

a. Observe that $E = IR$ can be compared to the straight-line equations in a slightly different way. In the equations $y = mx + b$ and $E = RI$:

E is y, I is x, and R is the slope of the line.

b. Let the two variables have the same ranges as before, $I = 0$ to 50 amps and $R = 1$ to 10 ohms. Next, the following equations can be written:

When $R = 1$
$E = I$

When $R = 2$
$E = 2I$
○
○
○
When $R = 10$
$E = 10I$

c. Graduate the horizontal and vertical scales in a linear manner for I and E, respectively.

The foregoing definitions and discussions of alignment charts and concurrency charts, plus the steps to prepare them, provide sufficient theory and construction guidelines to help designers use these charts effectively to obtain information or to prepare their own. However, further discussions and instructions are available for those who need them. An excellent reference was written by A.S. Levens, NOMOGRAPHY, 1959, John Wiley and Sons, Inc.

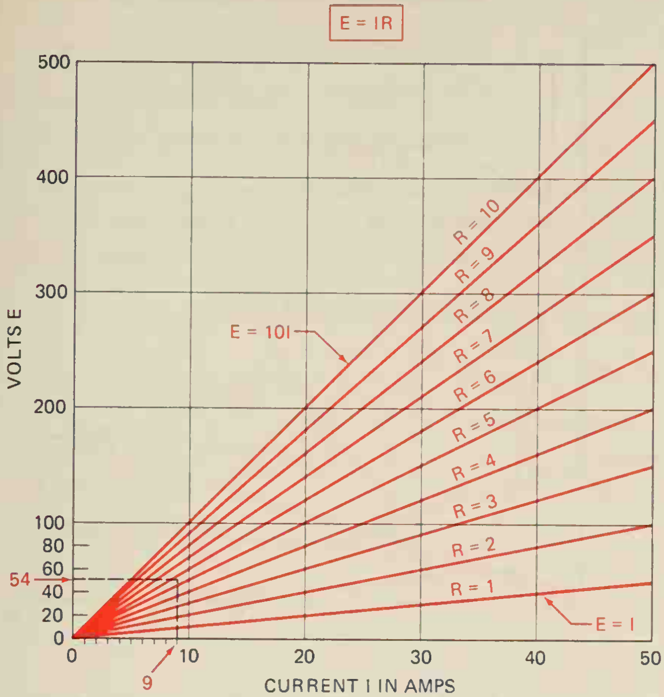


Figure 23-52 Concurrency chart: f(r) • f(t) = f(s)

Empirical Equations: y = mx + b, y = b(e**mx) and y = b(x**m): and Other Curve Matching Techniques

Consider two problems involving the need to analytically describe curves, either plotted from data in an experiment or developed during the design of a surface.

1. *Data Problem.* Data involving two changing variables, one independent and the other dependent, has been recorded for an experiment in a lab course. An equation is required to describe the relationship of the two variables so additional data points can be calculated within the range of the data already recorded. What steps should be taken next? How can an equation be generated?

2. *Curve Problem.* This problem differs slightly from the preceding one because the data points are to be part of a design development to generate curved lines for an automobile body surface. Equations of the lines involve the use of a personal computer; however, the problem is still graphical. What steps should be taken? How are the curves generated? Equations?

The Data Problem will be discussed first, primarily from a graphics approach. Then the *curve problem* will be considered from a more analytical basis and involving personal computers. Both problems use physical and graphical illustrations and explanations.

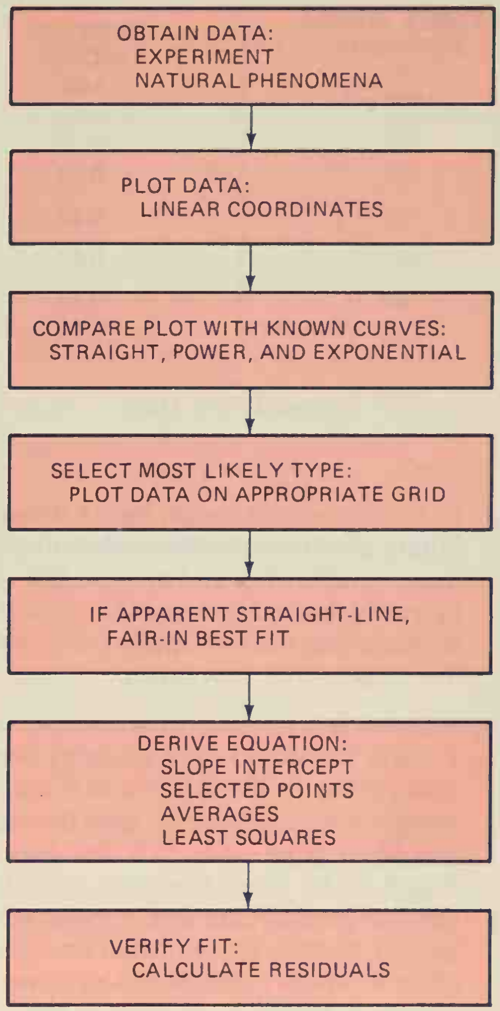


Figure 23-53 Empirical equations: procedure

Data Problem. Empirical Equations for Experimental Data. The flow chart in Figure 23-53 depicts the overall approach for deriving and verifying empirical equations. The steps contained in the chart are followed while considering three sets of data.

First Set of Data

1. Assume that the data tabulated in Figure 23-54 has been collected during a lab assignment involving surface factors for various steels, and that the next task is to plot the data on linear coordinate graph paper.

2. Before plotting the data, consider the three types of curves that are generally produced from experiments or from observing natural phenomena: (a) Straight-Line, (b) Power, and (c) Exponential.

ULTIMATE TENSILE STRENGTH S × 1000 psi	SURFACE FACTOR k(a)
100	0.53
120	0.50
140	0.46
160	0.43
180	0.38
200	0.36

Figure 23-54 Data

a. Data plotting in a *straight line* on linear coordinate paper would obviously indicate a linear relationship and an equation would be easily derived; however, be certain to indicate that the line applies only within the range of the data taken.

b. Plots of data tending toward a *power curve* y = B (x**m) would show patterns similar to those in Figure 23-55. When m = 1, a unique straight line results which goes through zero and has a slope equal to B. See curve 1 in Figure 23-55. When m equals a positive number greater than one, curve 2 would be typical. Positive m's less than one look like curve 3, which continues in an upward direction. Negative values of m give the hyperbolic shape of curve 4. Curves 1, 2, and 3 go through zero when x = 0.

c. *Exponential curves*, in general, look like those in Figure 23-56. When m = 0 in the equation y = B(e**mx), the plot is the horizontal line 1 parallel to the x axis. Positive values of m give curve 2, which intercepts the y axis at the value of B and continues upward. Curve 3 starts downward from B on the y axis and asymptotically approaches the x-axis. Curve 3 is repeated in Figure 23-57, because 3 and 4 are the most common types. These two represent phenomena where the rate of change in a variable is proportional to the variable itself. For example, curve 3 illustrates the decay of a radioactive substance N. The equation N(at any time t) = N(originally) (e** − at) can be derived from data. The constant, a, represents 0.693/half life. Curve 4 illustrates the change in temperature of an object being heated. The temperature approaches a maximum value asymptotically as described by T(actual at time t) = T(max) (1 − e** − mt).

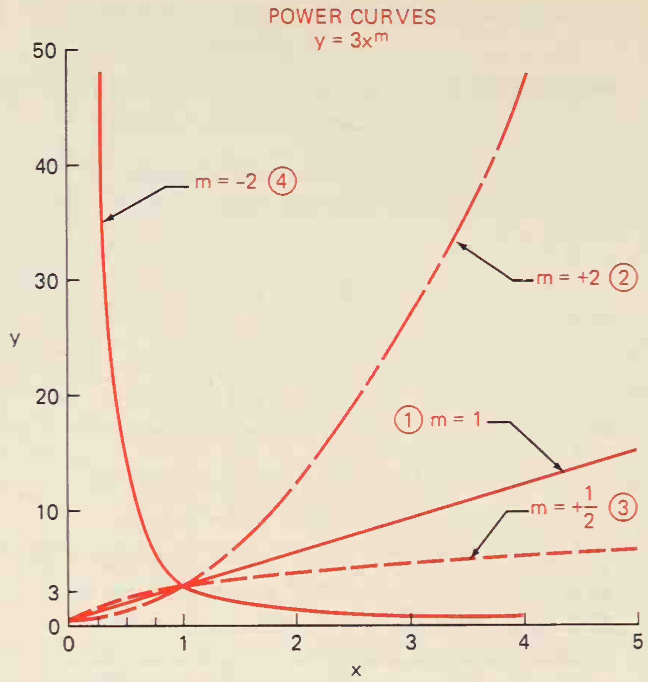


Figure 23-55 Power curves on linear coordinates

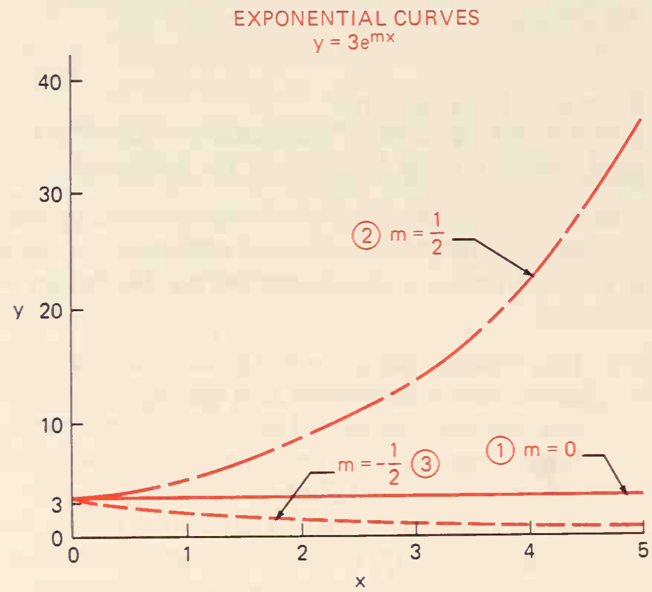


Figure 23-56 Exponential curves on linear coordinates

3. This first set of data plots almost as a straight line of the form y = mx + b on linear coordinate axes, as shown in Figure 23-58. A "best" fit straight line is drawn "by eye" through most of the points; that is, a straight line has been "faired-in."

4. Next, derive an equation of the form y = mx + b. Of the many approaches available, the four listed here are the ones most often found in graphics texts. In increasing order of difficulty and time involvement, they are:

a. Method of Slope-Intercept

b. Method of Selected Points

c. Method of Averages

d. Method of Least Squares

All four methods are used for this first set of data, and the curve from each method is verified (checked) by the method of residuals.

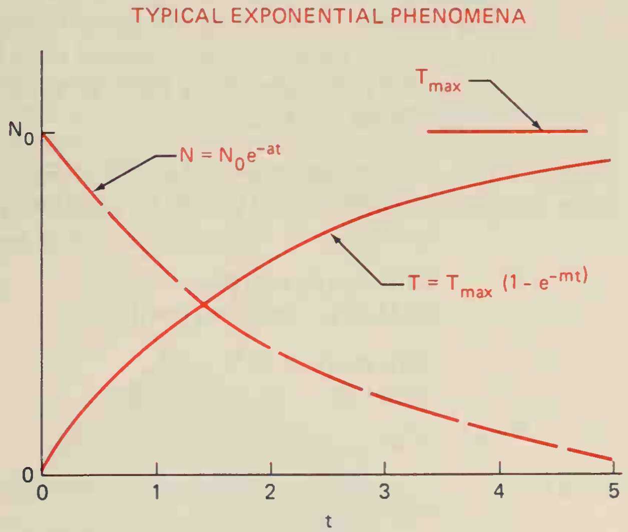


Figure 23-57 Exponential curves on linear coordinates

5. The methods.

a. Slope-Intercept Method

(i) Select two points, e.g., A and B in Figure 23-58.

(ii) Graphically, determine m, negative because of the downward slope, using the distance AC divided by CB. The slope must be compatible with the equation; therefore AC = 0.088 surface factor units, BC = 50 kpsi, and AC/BC = m = −.088/50 = −.00176 surface factor units/kpsi.

(iii) Thus, the equation is k(a) = −.00176 S + b. Next, graphically determine the intercept b, but note that the S values only go down to 100 kpsi. The intercept must be found when S = O. The graphical method for finding b when the independent variable range does not include zero, is to simply project backward to zero, as shown with line PQ and QR in Figure 23-58. The intercept is found to be 0.71.

(iv) Finally the equation is k(a) = −.00176 S + 0.71. The 0.71 value is the intercept

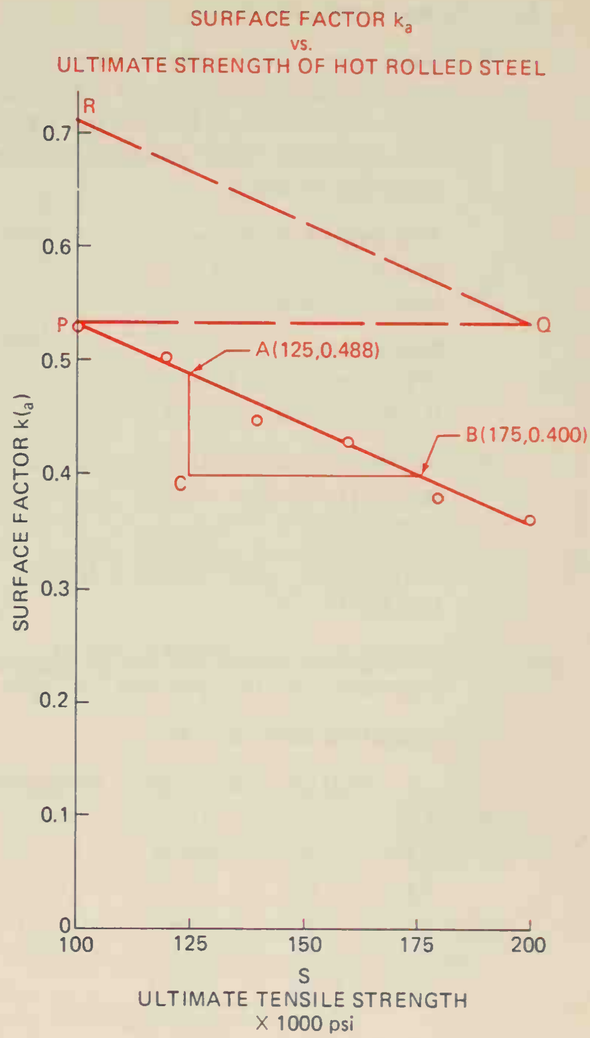


Figure 23-58 Data on linear coordinates

at S = O; however, remember to state that the equation is good only between S = 100 kpsi and S = 200 kpsi.

(v) Calculate and sum the residuals, which are equal to observed values of k(a) − calculated values of k(a), using the derived equation, at the six values of S.

S	k(a) obs.	k(a) calc.	Residuals R
100	0.53	0.528	+.002
120	0.50	0.493	+.007
140	0.46	0.458	+.002
160	0.43	0.422	+.008
180	0.38	0.387	−.007
200	0.36	0.352	+.008
		SUM R =	+.020

A positive sum indicates that the curve could be moved upward slightly for a better fit.

b. Selected Points Method

(i) Select two pairs of coordinate points from the "best" fit line and substitute them into the basic form of the straight-line equation. Then solve simultaneously for m and b.

The pair of points are:
k(a) = 0.5, S = 120
k(a) = 0.36, S = 200

Substitute:
0.50 = m(120) + b (q)
0.36 = m(200) + b (p)

(ii) Solve simultaneously for m and b.
(p) − (q) = −.14 + m(80)
m = −.00175

and 0.36 = −.00175(200) + b
b = 0.71

(iii) Finally, k(a) = −.00175 S + 0.71 between S = 100 kpsi and 200 kpsi

(iv) Calculate Residuals R

S	k(a) obs.	k(a) calc.	Residuals R
100	0.53	0.530	+.005
120	0.50	0.496	0
140	0.46	0.462	−.005
160	0.43	0.428	0
180	0.38	0.394	−.015
200	0.36	0.360	0
		SUM R =	−.015

c. Averages Method

This method doesn't require the direct use of the graphical plot; however, the data must be plotted to decide which type of curve the data points more closely match.

The expression SUM(y − mx − b) = 0 says that for the best fit line, the differences between the observed values of y and the calculated values of mx + b add to zero.

(i) Divide the data into two equal groups, substitute the data into equations y − mx − b = 0, and add them.

.53 − 100m − b
.50 − 120m − b
.46 − 140m − b
1.49 − 360m − 3b = 0 (r)

.43 − 160m − b
.38 − 180m − b
.36 − 200m − b
1.17 − 540m − 3b = 0 (s)

Solve (r) and (s) simultaneously and find m = −.00178 and b = 0.71

(ii) The equation of the line becomes k(a) = −.00178 S + 0.71 for S from 100 kpsi to 200 kpsi.

(iii) Calculate the Residuals in the same way as before and find that SUM R = +.003

d. Least Squares Method

This method consumes the most time, but it gives the best accuracy of the four methods. The expression $SUM(y - mx - b)^2 = a\ minimum$ says that for the best fit, the differences between the observed data for y and the calculated data mx + b, squared, should be a minimum.

(i) Set the derivatives of $SUM(y - mx - b)^2$ with respect to m and to b, equal to zero:

With respect to m:
SUM [2(y − mx − b)(−x)] = 0

With respect to b:
SUM [2(y − mx − b)(−1)] = 0

(ii) Multiply and rewrite to obtain:

SUM (x)(y) = b SUM(x) + m SUM(x**2)
SUM (y) = b SUM(number of observations) + m SUM(x)

(x)(y)	(b)(x)	M(x**2)
100 (.53)	= b100	+ m(100)**2
120 (.50)	= b120	+ m(120)**2
140 (.46)	= b140	+ m(140)**2
160 (.43)	= b160	+ m(160)**2
180 (.38)	= b180	+ m(180)**2
200 (.36)	= b200	+ m(200)**2
386.6	= b900	+ m142,000 (t)

Y	b	mx
.53	= b	+ m100
.50	= b	+ m120
.46	= b	+ m140
.43	= b	+ m160
.38	= b	+ m180
.36	= b	+ m200
2.66	= 6b	+ m900 (w)

(iv) Solve (t) and (w) simultaneously and find

m = −.00177
b = 0.709

so, k(a) = −.00177S + 0.709

(v) Calculate Residuals R and get SUM R = −.001, which is the best fit of the four methods summarized here.

a. Slope-Intercept SUM = +0.014

b. Selected Points SUM = −0.015
c. Averages SUM = +.003
d. Least Squares SUM = −.001

Second Set of Data. To calibrate a Weir, the following data was taken:

H (feet)	2.	3.	4.	5.	6.
Q (cu. ft/min)	14.2	41.5	80.0	135.2	225.3
H (feet)	7.	8.	9.	10.	
Q (cu. ft/min)	330.5	445.5	620.5	790.	

A Weir is a rigid plate used to measure the flow of water in open channels (e.g., irrigation channels). The rigid plate goes crosswise in the channel, as shown in Figure 23-59, so the water must spill over it. Height of the water, H, above the bottom of the notch indicates the rate of flow, Q.

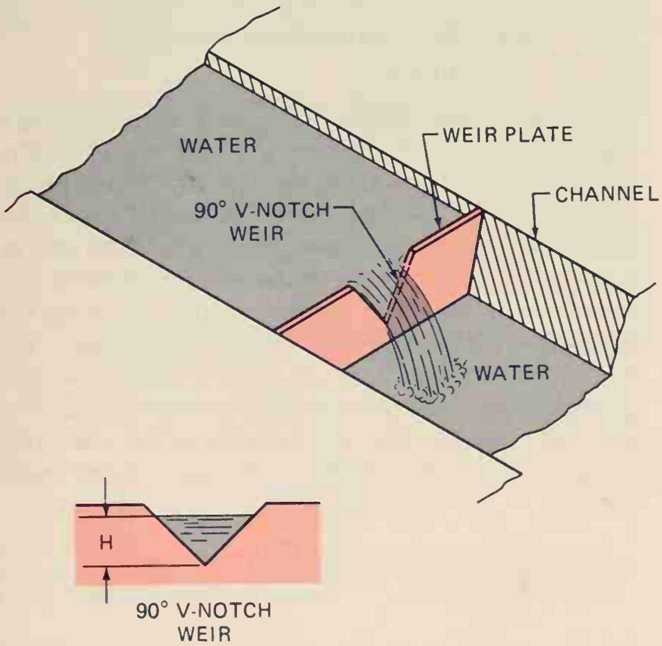


Figure 23-59 Weir

1. Follow the general empirical-equations approach depicted in Figure 23-53 and plot the Weir data on linear coordinate paper to ascertain the type of curve—straight, power, or exponential. The plot of the Weir data in Figure 23-60 appears similar to the one in Figure 23-55, which seems to be increasing upward as H gets larger. Also, the plot of Q would go through zero for H = O. Thus, a power type curve is indicated.

2. Try a logarithmic 2 × 2 cycle commercial grid for obtaining a straight line. Figure 23-61 indeed shows that the data forms a linear relationship and will fit the logarithmic form of the general power equation, log y = log B + m log x.

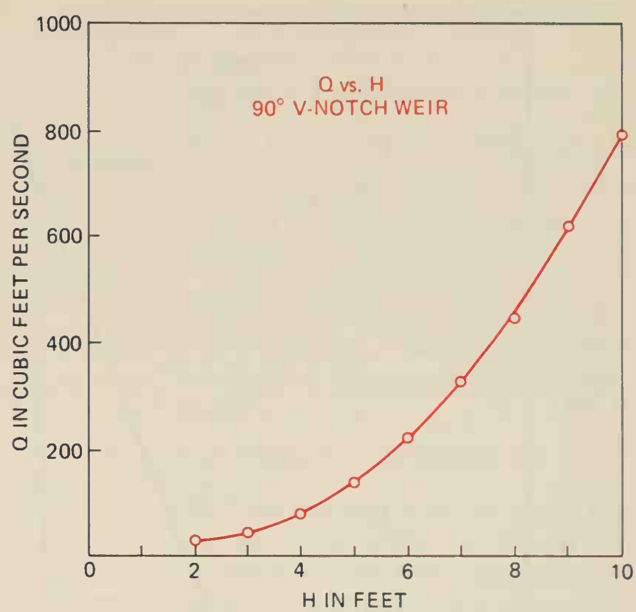


Figure 23-60 Weir data on linear coordinates

3. Fair-in a best fit straight line and prepare to derive a power equation from log Q = log B + m log H.

4. The Slope-Intercept and Selected Points methods are used for this set of data.

   a. Slope-Intercept Method

      (i) Select two points on the best fit line, A and D in Figure 23-61.

      (ii) Determine slope m from

      m = (log A − log C)/(log C − log D);

      (log 450 − log 80) = 0.7501

      and (log 8 − log 4) = .301

      so m = +(.7501)/(.301)
      = 2.492 cubic feet per second per foot.

      (iii) The logarithmic equation changes to log Q = log B + 2.492 log H. Next, graphically determine the slope-intercept. Use an offset technique to find an intercept for H = 0, as shown in Figure 23-61. Upward from P to R and then parallel to the original line from R to B, in effect adds an additional cycle so the intercept can be found: it is B = 2.5. Finally the equation can be written as Q = 2.5(H**2.492) for values of H between 2 feet and 10 feet only. Further measurements should be taken below 2 feet.

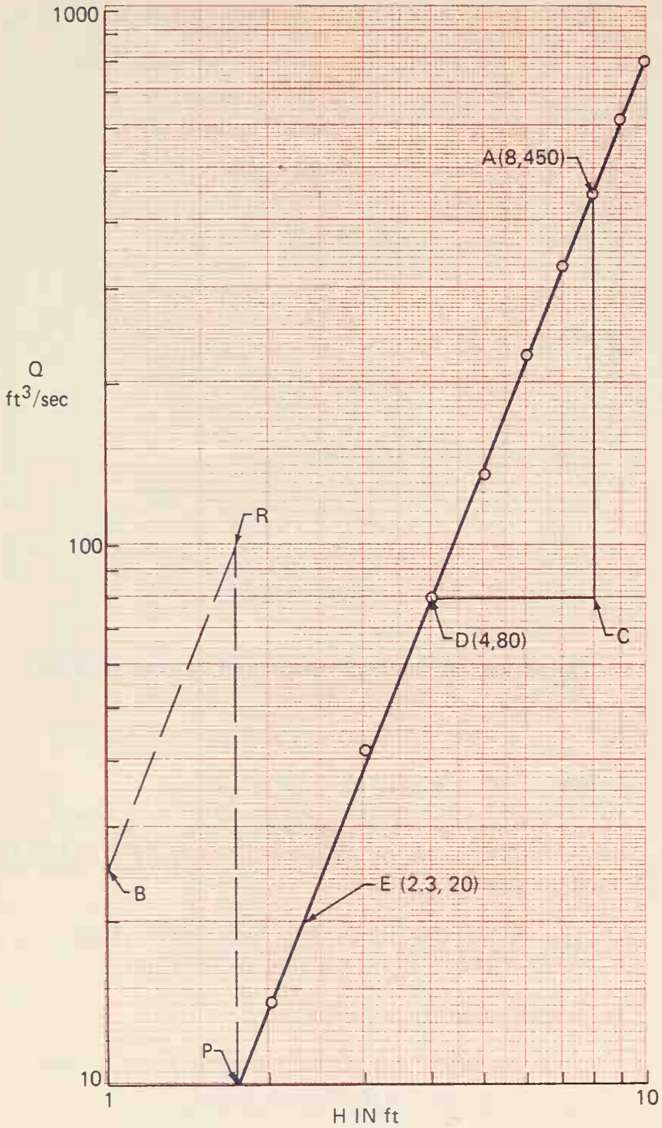


Figure 23-61 Weir data on logarithmic grid

(iv) Calculate and SUM the residuals.

H	Q (Observed)	Q (Calculated)	Residual R
2	14.2	14.06	+0.14
3	41.5	38.63	+2.87
4	80.0	79.12	+0.88
5	135.2	137.97	−2.77
6	225.3	217.32	+7.98
7	330.5	319.10	+11.40
8	445.5	445.08	+0.42
9	620.5	596.92	+23.50
10	790.6	776.14	+14.46
		SUM R =	+58.88

The positive sum indicates that the faired-in straight line should be moved slightly upward for a better fit.

b. Selected Points Method

(i) Select two pairs of coordinates from the best fit line and substitute them into the equation log Q = log B + m log H. From the line, obtain A(450, 8) and E(20, 2.3) to write log 450 = log B + m log 8 and log 20 = log B + m log 2.3

(ii) Solve simultaneously:

log 450 − log 20 = m(log 8 − log 2, 3)
m = 2.498

and then, log 450 = log B + 2.498 log 8,

so B = 2.496.

(iii) The equation finally is:

log Q = log 2.496 + 2.498 log H

and Q = 2.496 (H**2.498)

(iv) Calculate residuals to verify the equation

Third Set of Data. Picture a researcher operating a remote device used to place small canisters containing material into a nuclear reactor used for research. The material is lowered into a flux of neutrons to be irradiated. The material absorbs the neutron energy, but later gives up the energy by emitting gamma rays hundreds of times per second. A graph showing the material's pattern of energy change, E vs. time t, is in Figure 23-62. The detention period starting at time T1 helps the researcher obtain gamma ray data to be used to determine the half-life of the irradiated material. The data recorded from a gamma ray detector was:

N (counts per second)	2000	210	40	7
t (time in seconds)	0	900	1640	2450

For this set of data, the researcher knew that the decay rate (gamma rays emitted) would be directly

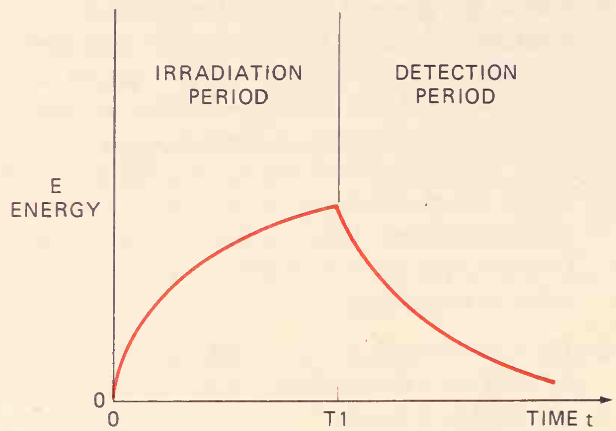


Figure 23-62 Irradiation of sample: energy level

proportional to the energy level of the irradiated material. Physical phenomena of this type behave exponentially as y = B(e**mx), so a log-linear grid was selected without bothering to check the data on linear coordinate paper.

1. Follow the general approach in Figure 23-53, starting at the straight-line plotting on a log-linear grid. Use a commercial grid, semi-logarithmic, 4 cycles. Figure 23-63 shows the plot plus a faired-in best fit straight line. The form of the equation of this line is log y = log B + m log e x, where the coefficient of x is m log e.

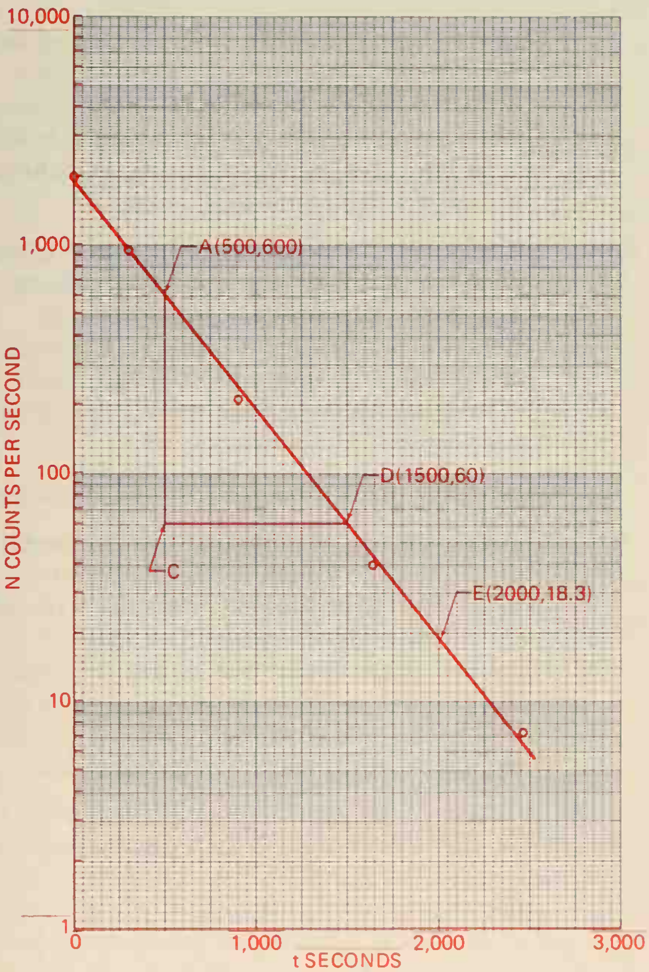


Figure 23-63 Irradiation data on semilogarithmic grid

2. Use the Slope-Intercept and Selected Points method for matching an equation to the plot of the data. The straight-line equation for the variables N and t is log N = log B + m log e t.

a. Slope-Intercept Method

(i) Select points A (500, 600) and D(1500, 60) on the best fit line.

(ii) Determine the slope m from

m log e =
(log 600 − log 60)/(500 − 1500)

m(.4343) = (2.77815 − 1.77815)/(−1000)

m = −(1)/((1000)(.4343))
= −.002303 counts per second per second.

(iii) Then the equation is log N = log B − .002303 (log e)t. The B intercept from the graph is 1900, so the final equation is

N = 1900(e** − .002303 t).

(iv) The time elapsed to arrive at the half-life t(HL) value of the counts can now be calculated by noting that one-half of the initial count equals one-half of 1900; therefore,

1900/(2) = 1900 e** − .002303t(HL)

and ½ = e** − .002303 t(HL).

Thus, log 1 − log 2 =
−.002303(log e)t (HL)

and t(HL) = 300.9 seconds.

The straight-line plot confirms this value of 950 counts per second at approximately 300 seconds.

(v) Calculate and sum the residuals.

t seconds	N observed	N calculated	Residuals R
0	2000	1900	+100
900	210	239.1	−29.1
1640	40	53.5	−3.7
2450	7	6.7	+.3
		SUM R =	67.5

b. Selected Points Method

(i) Two pairs of coordinate points from the best fit line are A(500, 600) and E(2000, 18.3).

(ii) Substitute them in log N = 1900 − .002303(.4343)t and solve simultaneously:

log 600 = log B + m (.4343)(500)
log 18.3 = log B + m (.4343)(2000)

so m = −.00233 counts per second per second.

Then, to solve for B:
log 600 = log B − .00233 (log e) 500.
B = 1923.6 counts per second

(iii) Finally

log N = log 1923.6 − .00233 (log e) t

so N = 1923.6(e** − .00233t)

(iv) Calculate Residuals next to verify the derived equation.

Note how the straight-line equation formed the basis for handling all three sets of data. Additional plotting techniques and analytical approaches are discussed next.

Curve Problem. The goal in the Data Problem was to find an equation to fit all of the data of an experiment, over the range of the data. The equations that were derived showed the relationships of dependent to independent variables such as k(a) = −.00176S + .71, Q = 2.5(H**2.492), and N = 1900(e** − .002303t) —linear, power, and exponential equations, respectively. Finding the proper coordinate grids so that the data plotted in approximately a straight line was the key to deriving the equations.

A number of additional approaches may be used to match equations to curves. One is similar to the Selected Points technique already discussed, but the basic equation could be third order, such as y = ax**3 + bx**2 + cx + d, which requires four sets of "selected points." Sometimes the entire curve may be described by a number of equations, piecewise, in series. Still another method describes a curve that may touch the first and last points, but only goes near the others. These types of curves are introduced in this section for three main reasons.

1. They require graphical-physical explanations to visualize the concepts.
2. Personal computers make it possible for students and designers to do this type of curve matching and curve generating in a relatively short time.
3. The trend in one type of manufacturing uses these approaches to generate curved surfaces and the related equations, which are then used to program numerically controlled milling machines to cut the surfaces.

Two physical models help to visualize the following curve types.

1. Splines

   a. Figure 23-64 shows the technique traditionally used by ship builders (before computers) to draw smooth contour lines through a series of points. The "ducks" shown in the figure weigh about 5 pounds, are cast iron with felt glued to their bottoms, and are used to apply pressure at specified points along a thin metal strip called a *spline*. These pressure points are placed over the points that define a contour line of a ship. Because of the stiffness of the spline, the curve going into a point is exactly in-line with the curve leaving the point. Distances between points are called spans.

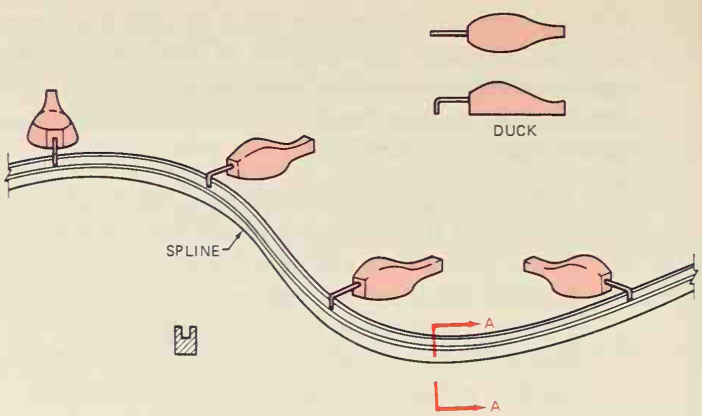


Figure 23-64 Spline

   b. *Cubic splines* can be generated which in effect take the place of the metal spline. These equations, one for each span, not only describe the curve over the span but ensure that the span segments are "in line." Software is available to generate cubic splines on personal computers.

2. Bezier (pronounced bay-zee-ay) and B-Splines

   a. Bezier Curves: Assume that the thin metal strip shown in Figure 23-65 is magnetic and without the "ducks." The strip is placed on a flat surface between a number of "point" magnets that pull on the strip but never touch it. The strip is anchored to the end points of a series of points: all points except the ends are the magnets. At the

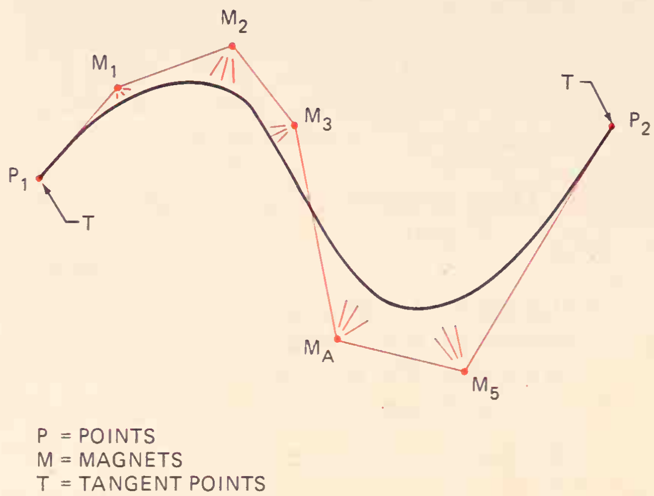


Figure 23-65 "B-spline" type curve

ends, the strip is tangent to a line from the end point to the nearest point. Also, if one magnet along the strip moves, the whole strip may move slightly.

Designers use BEZIER curves in conjunction with a computer screen to generate pleasing curves for the design of automobile bodies. Once the curve satisfies the designer, an equation is automatically generated to match the curve. Ultimately surfaces are generated using curves in horizontal and vertical planes.

One disadvantage of the BEZIER curve generating procedure is that when one point moves, the entire curve can be affected. Usually all but a portion of a curve is OK, and just changing a single portion is desirable.

b. B-Splines: The B-Spline curve-making technique allows a single portion of a Bezier-type curve to be modified without affecting the entire curve. Therefore, automobile body designers find that the B-Spline technique saves considerable time in designing contour lines and surfaces. Software is also available for generating B-Splines on personal computers.

One application of these curve-generating techniques illustrates a trend in some machining operations. Shoe "lasts" (full scale models of the left and right feet for a given shoe size) are completely described by spline-type equations. The equations are automatically coded into language that instructs numerically controlled machines to cut the lasts. Thus, no drawings are needed to communicate the information from the designer to the machine.

Conclusion. This curve problem discussion was included in empirical equations to emphasize that the computer is not only affecting the process of making drawings, in CADD systems, but is also being used to assist designers to generate graphical curves, surfaces, and models.

The next section contains discussions on graphical calculus, integrating, and differentiating that is also useful to designers.

Graphical Integration and Differentiation: Pole and Ray Method

The advantages of knowing how to do graphical calculus, integrating, and differentiating are twofold: (a) they enhance insight and understanding of analytical integrating and differentiating, and (b) they provide a means of handling data and some equations, which would be too difficult and expensive to do analytically. Furthermore, graphical calculus, as do other graphical techniques, provides designers with relatively rapid visual techniques for designing, analyzing, and checking. Therefore, this section focuses on the graphical techniques for integrating and differentiating using the *Pole* and *Ray* method.

1. First, consider two fundamental ideas, one for integrating, the other for differentiating.

   a. Figure 23-66 illustrates a graphical explanation of the process of integrating and the resulting integral curve.

      (i) The area between the curve and the horizontal axis in the Y1 vs. X graph is divided into segments by vertical division lines 1 and 2.

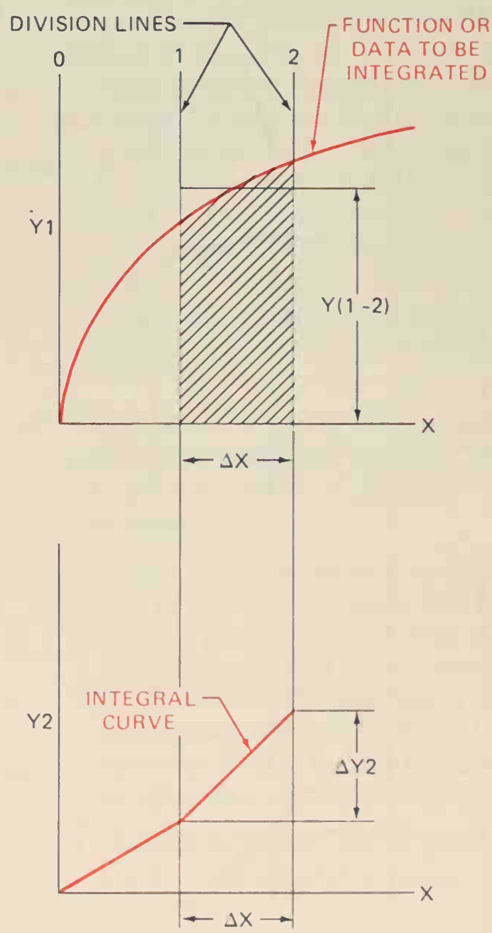


Figure 23-66 Graphical integration: fundamentals

      (ii) The cross-hatched area between the division lines 1 and 2 represents the change of the integral curve in the vertical direction between the same two division lines. The area shown is above the x axis, so it is positive: therefore, the change in the integral curve is upward between the same two division lines.

(iii) Items (1) and (2) above restated in the symbols shown would be: the average height of the area, Y(1 − 2), times the distance between division lines 1 and 2, Δx, equals $\Delta Y2$ of the integral curve between the same two division lines in the Y2 and X graph.

(iv) Vertical scales Y1 and Y2 are different, but in-line: both horizontal scales are identical.

b. Figure 23-67 shows a graphical explanation of differentiation and the resulting derived curve.

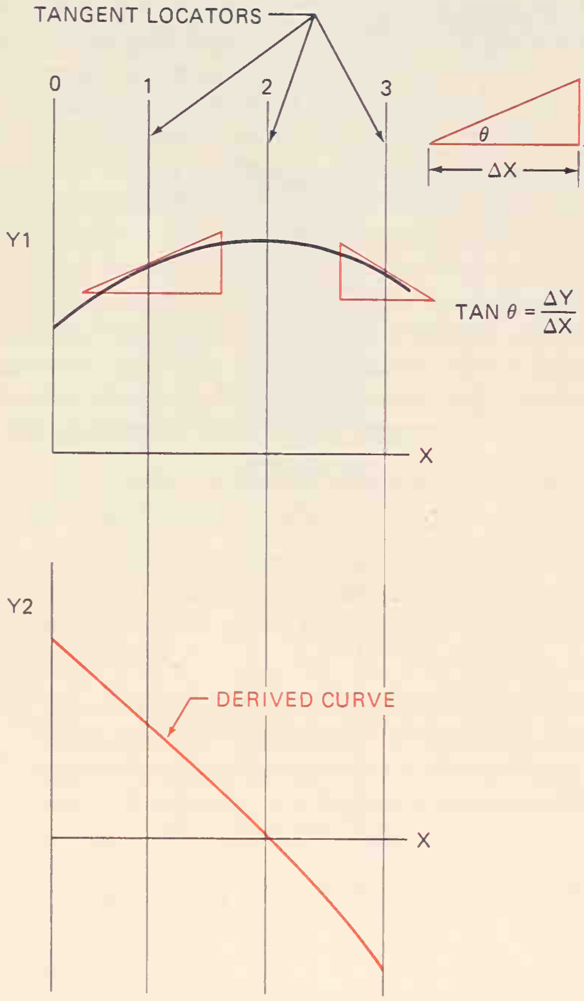


Figure 23-67 Graphical differentiation: fundamentals

(i) Tangents to the curve in the Y1 vs. X graph are constructed "by eye" at the three tangent locator points, and the slope of the tangents are determined by a $\Delta Y/\Delta X$ calculation.

(ii) The positive, zero, and negative slopes from points 1,2, and 3, respectively, are plotted in the Y2 vs. X graph.

(iii) Items (1) and (2) restated in the symbols shown would be: the slopes $\Delta Y/\Delta X$ at specific points in the Y1 curve are represented by proportionate vertical distances in the Y2 vs. X graph.

(iv) Vertical scales Y1 and Y2 are different but in line: the horizontal scales are identical.

2. Graphical Integration. The overall procedure to do graphical integration follows the flow chart in Figure 23-68. Most of the procedure entails graphical construction steps: the last step, deriving a scale, is both analytical and graphical.

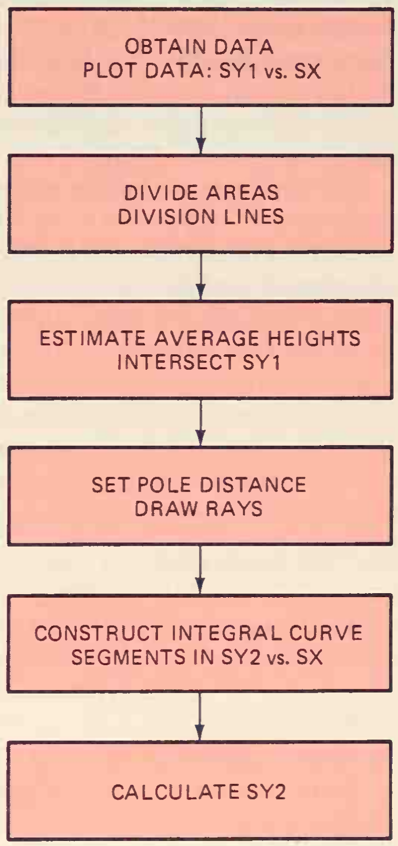


Figure 23-68 Graphical integration: procedures

a. Refer to Figure 23-69 and follow the steps to do the graphical construction. (Note: (i) is the circled number 1 in the figure, etc.)

(i) Plan space for two sets of axes, the upper space for SY1 vs. SX and the lower for SY2 vs. SX. For illustration purposes, data from an aircraft launch is used. The following data for acceleration in g's vs. time t, during the launching cycle for an airplane from an aircraft carrier was recorded in a control center in the carrier.

g's Meters, per sec./per sec.	t seconds
0.00	0.0
0.50	0.2
1.00	0.3
2.55	0.5
4.60	0.6
5.20	0.7
5.40	0.8
5.26	1.0
4.95	1.3
4.60	1.6
4.00	2.0

(ii) Plot the data on a commercial grid 10 × 10 to the inch, and fair-in a best fit curve. Use vertical scale SY1 equal to 2 g's/inch, and the horizontal scale SX equal to 0.5 seconds/INCH. (The capital letters, INCH, represent the basic unit of distance on the grid.)

(iii) Use division lines to divide the area between the curve and the horizontal axis. Use more lines during curving portions of the curve for better accuracy. Label the lines 1, 2, 3, 4, 5, and 6, for this plot.

(iv) Estimate "by eye" the average height of each division of area. Sketch A in Figure 23-69 shows that a line for average height is approximated when the negative area is about equal to the positive area. Extend a line to the SY1 axis for each average height, and label each extension.

(v) Set the *Pole* distance H equal to 1.5 INCHES as an extension of the horizontal axis SX, to the left, to point P. The distance H affects the slope of the derived curve: short *Pole* distances cause the curve to be steep; long distances, flat.

(vi) Construct *Rays* from the extension-lines intersections on axis SY1 to the *Pole* point P.

(vii) Construct and label the second set of axes, SY2 vs. SX, so SY2 is aligned with SY1. The calculation for SY2 is discussed after the steps for the graphical construction.

(viii) Start at point T on the SY2 vs. SX axes and construct a line TK parallel to the *Ray* associated with the area between the SY1 axis and division line 1. The height of point K above the horizontal axis represents the area between the SY1 axis and division line 1. From K draw a line KJ parallel to the *Ray* associated with the area between division lines 1 and 2. Continue similarly for the remaining *Rays* to point W. Finally, the distance WZ times the scale SY2 represents the total area between the SY1 axis and division line 6.

(ix) To establish a workable *Pole* distance, the following approach works. Construct a trial H distance, say to P1, shown in Figure 23-69. Estimate the average height of the entire area between the SY1 axis and division line 6, which would be line RQ. Draw *Ray* R-P1 and construct a line TU parallel to R-P1 and construct a line TU parallel to R-P1 in the SY2 vs. SX graph. Point U indicates the approximate location of where the integral curve will probably terminate; that is, where point W will be.

(x) Calculate the scale SY2 for the integral curve graph using the equation SY2 = (H)(SX)(SY1), which is derived as follows:

- Figure 23-70 shows SY1 vs. SX, with SY2 vs. SX directly below. The first curve is plotted and the area is divided by division lines 1 and 2. FD represents the average height of the area between the SY1 axis and division line 1. FP is the *Ray* associated with the area. H is the *Pole* distance.
- Line OK in the SY2 vs. SX graph is constructed parallel to ray FP, and KJ = ΔY.
- The desired result of this graphical integration construction is that (ΔY)(SY2) = (FD)(SY1)(ΔX)(SX), which says generally that the area between any two division lines represents the change in height of the integral curve between the same two division lines. Note how the scales must be used in the equation to obtain the correct values.

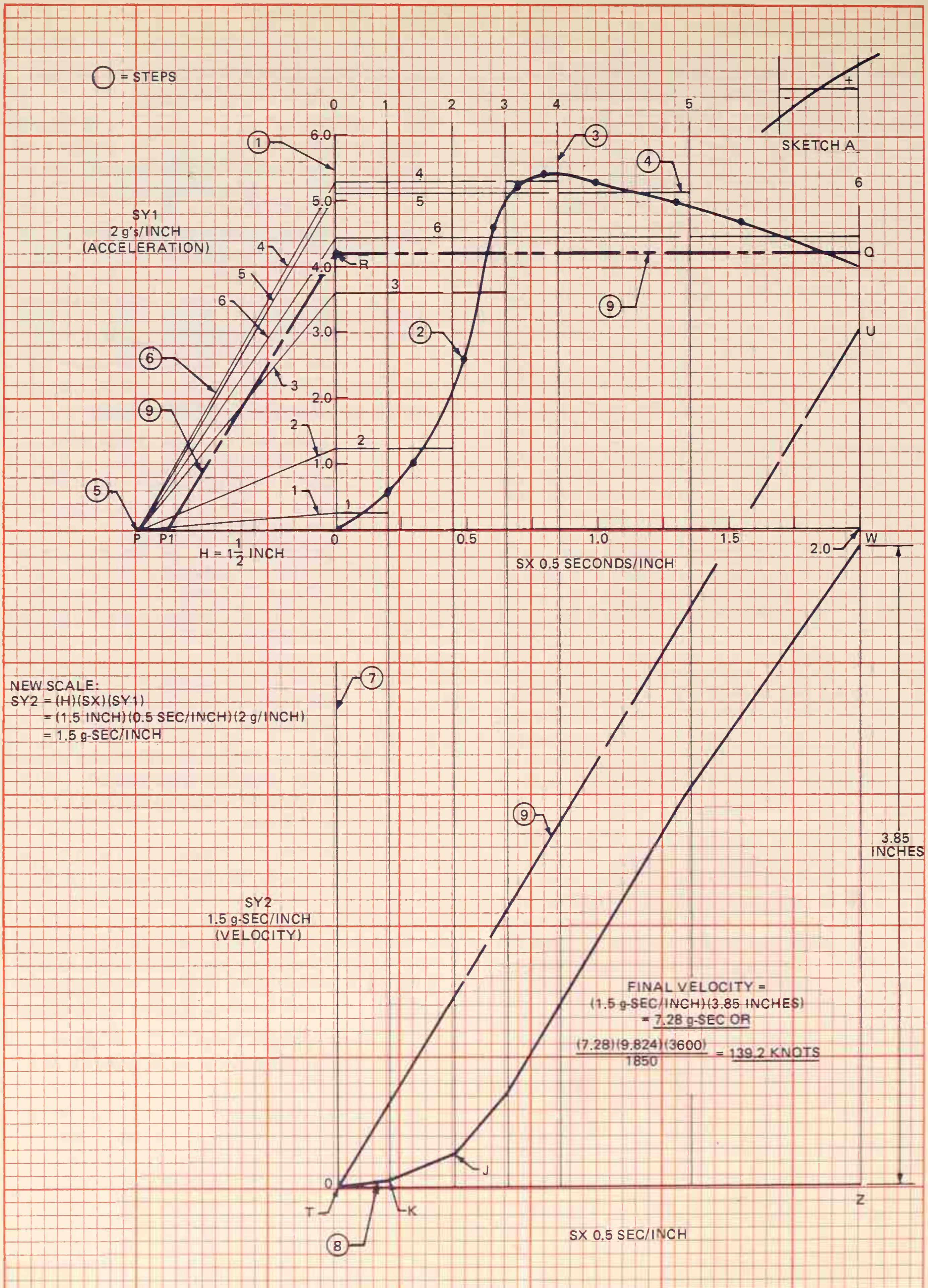


Figure 23-69 Graphical integration: steps

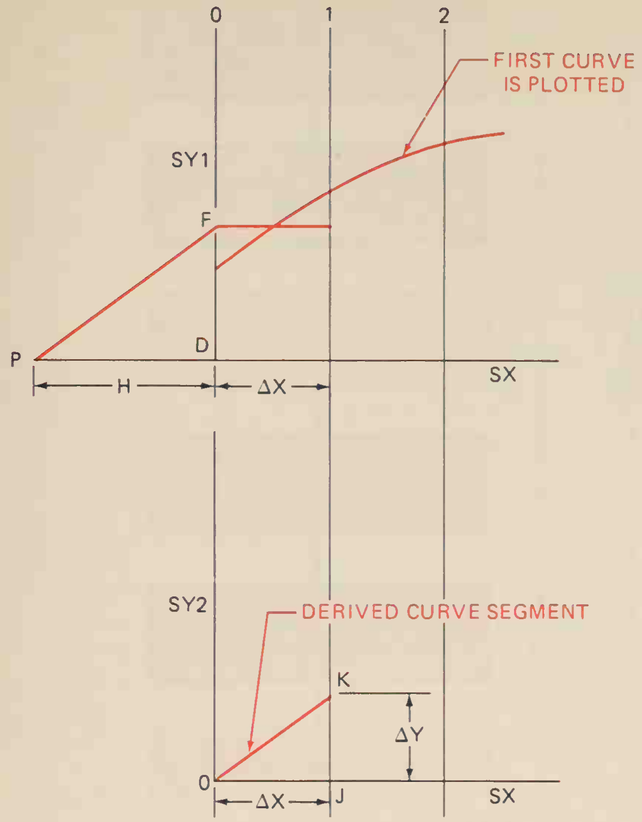


Figure 23-70 Graphical integration: scale derivation

- Geometrically from similar triangles:

$$\frac{FD}{PD} = \frac{KJ}{OJ} = \frac{\Delta Y}{\Delta X} \text{ and } PD = H$$

$$\text{so, } \frac{FD}{H} = \frac{\Delta Y}{\Delta X}\text{; then } \Delta Y = \frac{(\Delta X)(FD)}{H}$$

Substitute ΔY in the equation from the preceding step to get

$$\frac{(\Delta X)(FD)}{H} \bullet (SY2) =$$

$$(FD)(SY1)(\Delta X)(SX)$$

Cancel like quantities and obtain $SY2 = (H)(SX)(SY1)$

b. An additional capability of graphical integration is to divide odd-shaped areas and volumes into equal portions. The following example demonstrates this capability.

(i) A right-circular-cone shaped water tank is used for this example to convince the reader that the method works, since the graphical results can be checked analytically. After following this example it should be easy to imagine an odd-shaped fuel tank nestled in a wing section of an airplane and how the tank could be graduated into equal volumes.

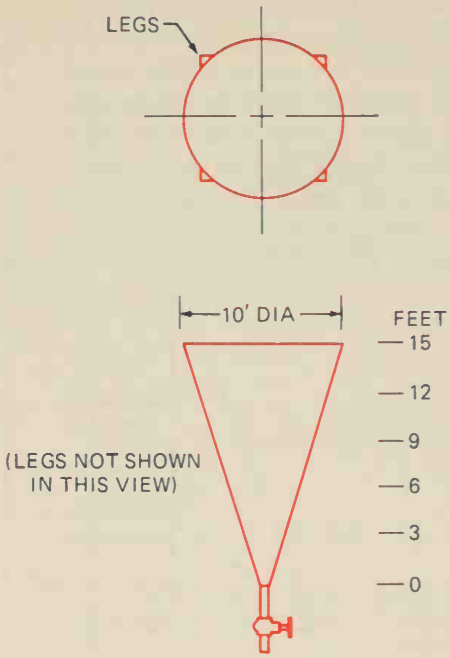


Figure 23-71 Water tank

(ii) Figure 23-71 shows the water tank that needs to be graduated and marked at ¾, ½, and ¼ FULL.

(iii) Cross-sectional areas of the 15-foot tall, 10-foot diameter tank were calculated at 3-foot intervals and recorded here:

Station S in Feet	0.	3.	6.	9.	12.	15.
Area A (square feet)	0.	3.14	12.6	28.3	50.2	78.5

(iv) Figure 23-72 shows how the steps to do graphical integration were followed to plot the data to scale, divide the areas with division lines, estimate the average heights, and transfer those heights to the vertical axis, locate the pole point, draw the rays, and generate the integral curve.

(v) Distance WZ times SY2 scale of 125 cubic feet/INCH equals 390 cubic feet.

(vi) To obtain the graduations, WZ was divided into four equal lengths: the divisions were then transferred horizontally to the integral curve and, finally, these intersections were projected vertically down to the horizontal axis.

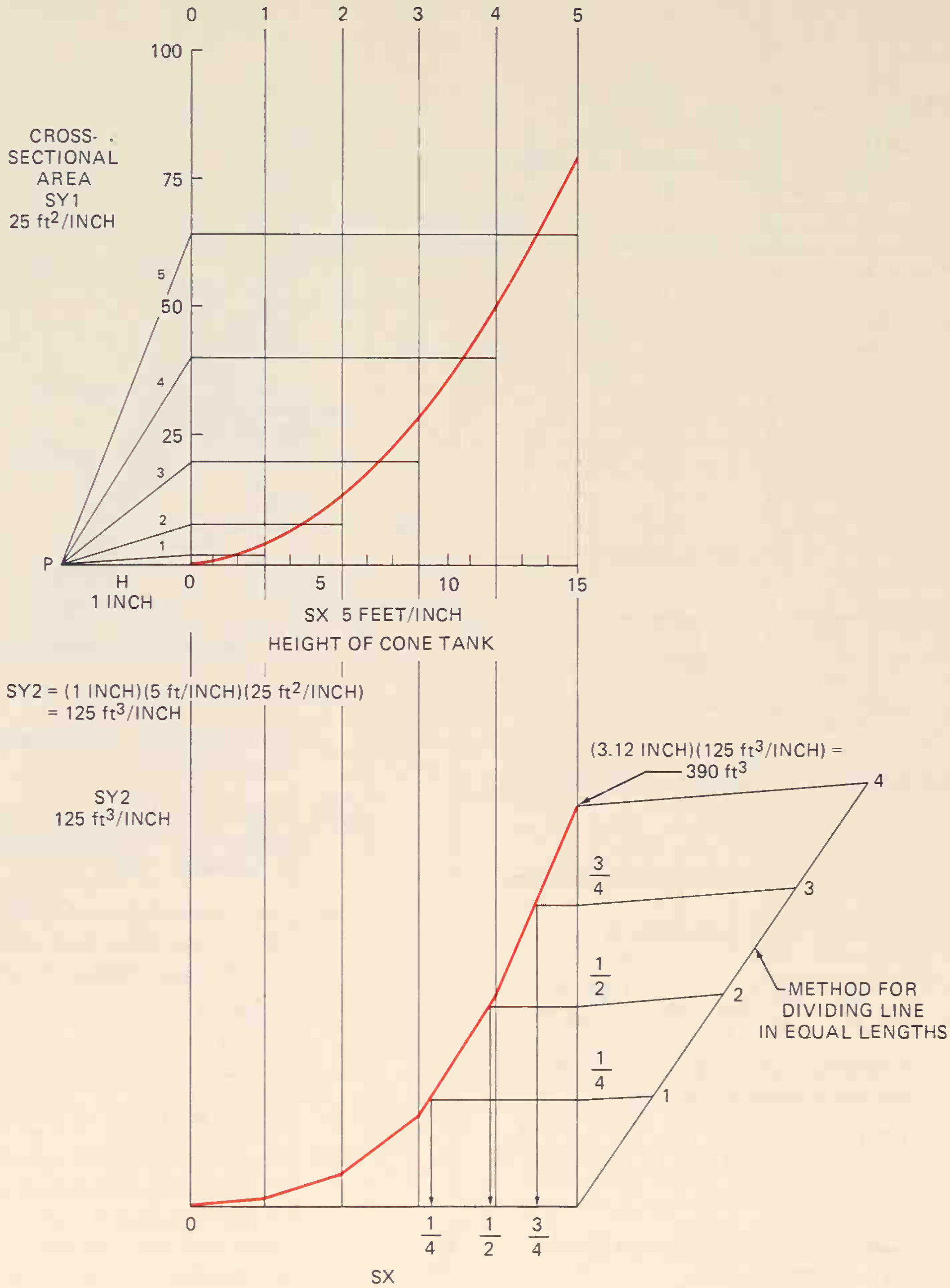


Figure 23-72 Graduating volumes

The intercepts on the horizontal axis represent the location along the tank height to mark the ¼, ½, and ¾ FULL, 9.5', 12.2', and 13.5', respectively. Now the following comparison can be made with the analytical solution.

	¼	½	¾	FULL
GRAPHICAL	9.5'	12.2'	13.5'	15'
ANALYTICAL	9.45'	11.91'	13.63'	15'

The close correlation demonstrates the efficacy of this technique to graduate areas or volumes using graphical integration.

3. Graphical Differentiation. Graphical differentiation uses slopes at selected points in a curve instead of adding the areas under the curve as was done in graphical integration. Use the steps in the flow chart shown in Figure 23-73

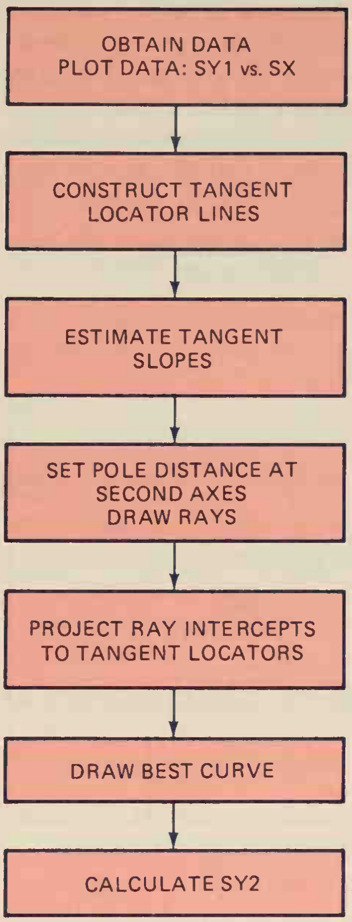


Figure 23-73 Graphical differentiation: procedure

as a guide for following the graphical differentiation example discussed next.

a. The cam shown in Figure 23-74 provides an excellent example of the application of graphical differentiation to visualize the operation of the cam and follower, and to check the cam's operation. Cams convert rotary motion of a cam shaft to reciprocating motion for the follower. If the cam profile changes too rapidly, the follower may separate from the cam surface because of excessive acceleration—an undesirable condition. Therefore, designers need to check their cam profile designs for accelerations problems. Refer to Figure 23-74 for the steps to do a graphical differentiation of the proposed displacement of the follower vs. angular positions of the cam. The first differentiation will generate a curve showing the velocity of the follower at any time during the first half of one rotation: the second half is to be a mirror image of the first half. Differentiation of the velocity curve produces an acceleration curve for the follower.

(i) Prepare space on a commercial metric grid for three sets of axes, the first set in the upper space, for follower displacement vs. time. Follower displacement was calculated at every 15° rotation of the cam, which rotated at a constant speed of one revolution every 4 seconds. The time elapsed at each 15° was also calculated. The results were as follows:

Vertical Displacement S in mm	0	.35	1.39	3.13	5.56	8.68
Time in fractions of a second	0	1/6	1/3	1/2	2/3	5/6

12.5	16.32	19.44	21.87	23.60	24.65	25
1	1-1/6	1-1/3	1-1/2	1-2/3	1-5/6	2

(ii) Plot the results and fair-in a best fit curve. Use a vertical scale SY1 equal to 0.5 mm/MM, and a horizontal scale SX equal to 1/60 second/MM. (The capital letters MM represent the basic unit of distance on the metric grid.)

(iii) Use tangent locators, vertical lines, to intersect the plotted curve at selected points: place more locators where the curve changes rapidly, for better accuracy. Label them 1, 2, 3, 4, 5, and 6, for this example.

(iv) Estimate "by eye" the slope of the curve, a tangent, at each locator intersection. Label the tangents, also.

(v) Set a *Pole* distance H = 30 MM as an extension of the horizontal axis SX of the second set of axes. The distance H affects the height of the derived curve: longer *Pole* distances cause higher curves: shorter distances, lower curves.

(vi) Construct *Rays* parallel to each tangent, from point P to the vertical axis SY2. Label the *Rays*.

(vii) Extend the tangent locators into the area of SY2 vs. SX. Then, extend horizontal lines from the *Ray* intercepts on the SY2 axis, to intersect the related tangent locator.

(viii) Fair-in a best fit curve, or line, through the intersections on the tangent locators.

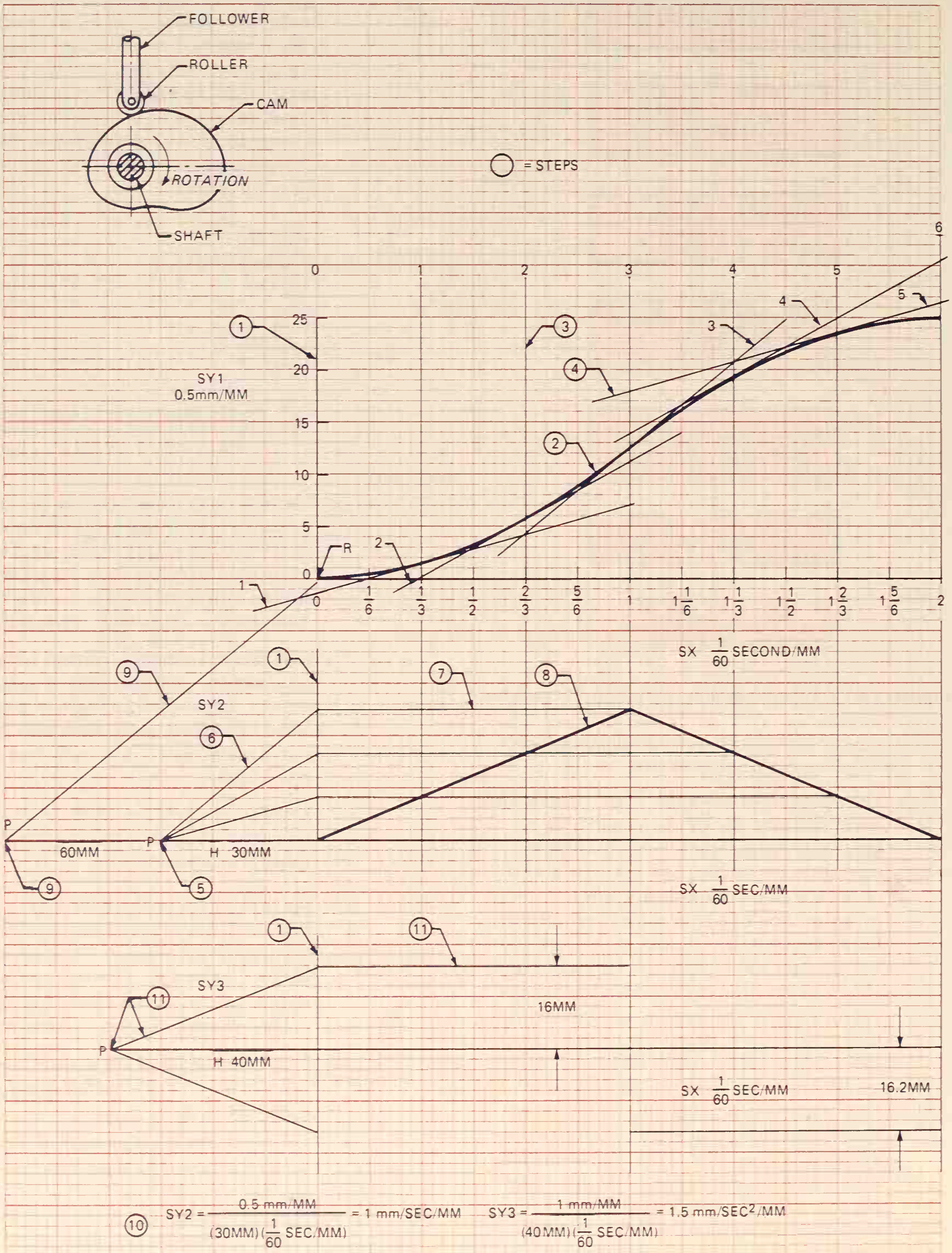


Figure 23-74 Graphical differentiation: steps

(ix) To help establish a workable *Pole* distance, try the following. Determine the steepest slope of the curve being differentiated, and use the *Ray* parallel to it to set a *Pole* distance. Tangent 3 is the steepest in this example. A trial *Pole* location of H = 60 MM causes the *Ray* PR to go too high. A second trial H = 30 MM was workable.

(x) Calculate the SY2 scale using the equation

$$SY2 = \frac{SY1}{(H)(SX)}$$

which is derived as follows:

- Figure 23-75 shows SY1 vs. SX, with SY2 vs. SX directly below. The curve is plotted on axes SY1 vs. SX, and then vertical, tangent locators are drawn.
- The slope, tangent to the curve, at location 1 is calculated by $\Delta Y/\Delta X$ from the triangle shown.
- *Ray* PF is drawn parallel to the slope at locator 1, and a horizontal line is drawn from F to locator 1, point G.
- The desired result of this graphical-differentiation construction is that

$$(GK)(SY2) = \frac{(\Delta Y)(SY1)}{(\Delta X)(SX)}$$

From similar triangles:

$$\frac{\Delta Y}{\Delta X} = \frac{FD}{H} = \frac{GK}{H}$$

Substitute and factor.

$$(GK)(SY2) = \frac{(GK)}{(H)} \bullet \frac{(SY1)}{(SX)}$$

$$SY2 = \frac{SY1}{(H)(SX)}$$

which is the derivation of the new scale.

SY2 for this example is

$$SY2 = \frac{(.5\ mm/MM)}{(30\ MM)(1/60\ sec/MM)}$$

SY2 = 1 mm/second/MM
which is a velocity scale as expected.

(xi) To finish the example, i.e., derive the acceleration curve, repeat the procedures: set axes SY3 vs. SX, set a *Pole* distance, determine the slopes, draw *Rays* parallel to the slopes, fair-in the curve, and calculate SY3.

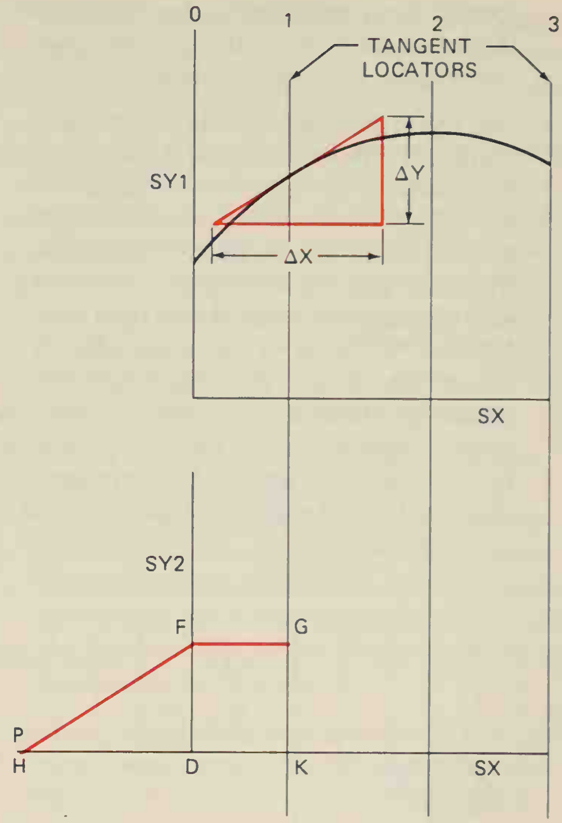


Figure 23-75 Graphical differentiation: scale derivation

$$SY3 = \frac{1mm/sec/MM}{(40\ MM)(1/60\ sec/MM)}$$

$SY3 = 1.5mm/sec^2/MM$

an acceleration as expected.

(xii) The cam profile does cause constant acceleration and deceleration, as shown in the Figure 23-75. Their magnitudes are calculated from measurements on the graph to be

acceleration =

$(16MM)(1.5mm/sec^2/MM) = 24mm/sec^2$

deceleration =

$(16.2MM)(1.5mm/sec^2/MM)$
$= 24.3mm/sec^2$

b. Graphical differentiation is more difficult to do accurately than graphical integration because of the possibility of errors in determining the slopes of curves "by eye." However, doing and understanding graphical differentiation helps to visualize that the slope of the higher-order curve at a specific locator is represented by the height from the horizontal axis to the derived lower-order curve at the same locator.

c. The conceptual relationships between graphical differentiation and integration are summarized in Figure 23-76. Curve #1 in the upper left was differentiated, and the derived curve #2 was placed just below at the lower left. Then the derived curve #2 was reproduced at the lower right and labeled #3. Curve #3 was integrated to obtain the curve in the upper right, which should be identical to curve #1. In any case, vertical distances in #2 represent the slopes in #1: sections of area in #3 represent changes in the height of #4 between the same division lines.

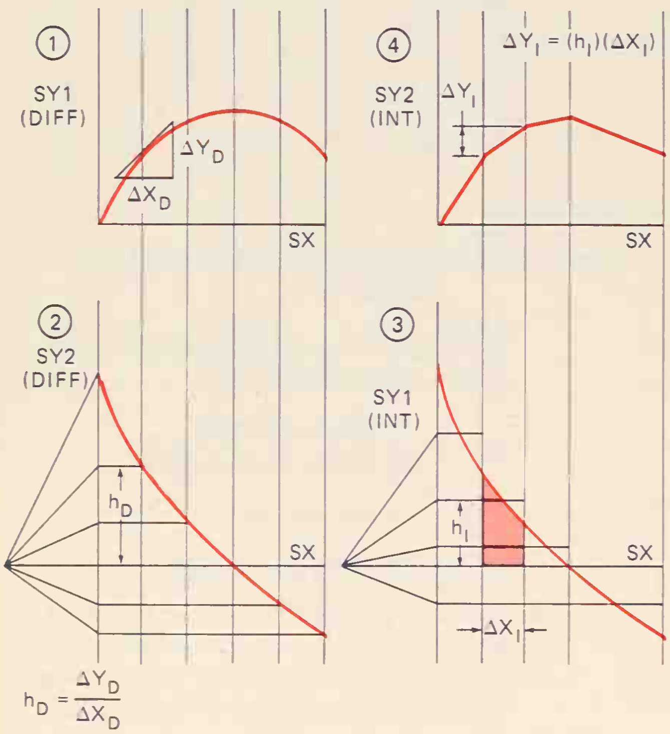


Figure 23-76 Comparison: graphical integration vs. differentiation

4. The following are concluding comments on the usefulness of graphical integration.

a. Some functions such as

$$\int_0^{\pi} \sqrt{1 + \cos^2 X}\, dx$$

that have no analytical integral can be integrated using graphical integration. Numerical methods can also be used.

b. Profiles of cuts through hilly terrains may be impractical to express analytically, so volumes of earth can be calculated. Graphical integration is used. Planimeters, mechanical integrators, are also used.

5. The concepts of graphical differentiation and integration provide a unique insight into analyzing beam diagrams, which are considered in the next section.

Beam Diagrams

Most students using *Technical Drawing and Design* will have had only a brief introduction to the mechanics of materials, so they may not have been introduced to beam diagrams. However, a brief introduction in this section to beam diagrams related to graphical differentiation and integration should help them understand beam theories in future courses. Review the graphical calculus concepts in the preceding section, particularly Figure 23-76, before perusing this section.

1. Several preliminary concepts:

a. The centrally loaded beam in Figure 23-77 (a) has supports at ends A and E. At A, a symbol shows that the beam is pinned to a support that is fixed to a rigid frame or structure. "Whiskers" represent the rigid frame or structure.

b. The FBD (free-body diagram) in Figure 23-77 (b) is drawn in the traditional simplified-model form used in beam analyses. In this example, the weight of the beam is considered negligible compared to the effect of

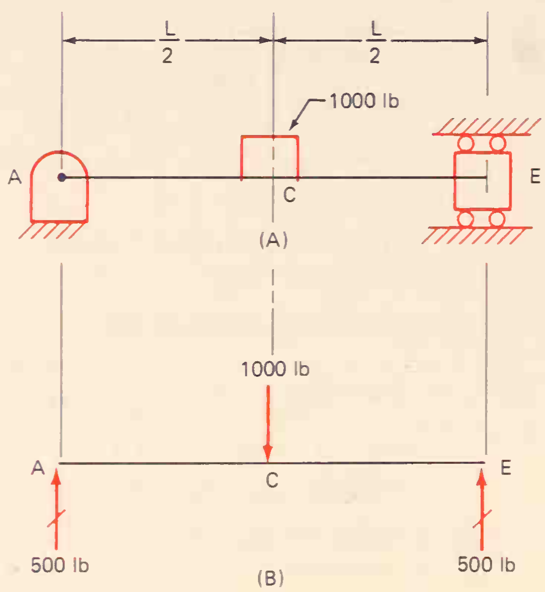


Figure 23-77 Centrally loaded beam

the applied load, 1000 pounds. Vectors representing the reactions at A and E, and the applied load at C, are all parallel: Their algebraic sum must equal zero for the beam to be in equilibrium.

2. The 1000-pound load causes the beam to deflect; the maximum deflection occurring at C is shown in Figure 23-78 (a). This deflection curve is usually the last beam diagram to be derived in beam analyses. However, the deflection diagram is considered first here to illustrate how graphical differentiation principles apply in deriving beam diagrams.

    a. Differentiate the deflection curve to obtain the slope curve shown in Figure 23-78 (b). From left to right, the slope curve indicates a large negative slope at A, less negative at B, zero at C, positive at D, and larger positive at E. The deflection anywhere along the beam is represented by the variable y; slopes are represented by dy/dx.

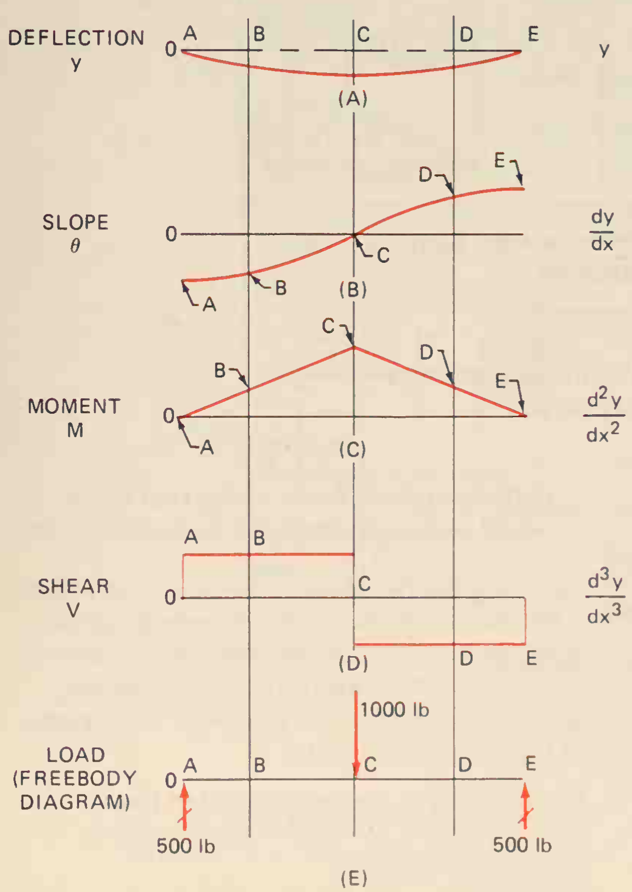


Figure 23-78 Centrally loaded beam: beam diagrams

    b. The next derived curve is called a moment diagram, Figure 23-78 (c). The moment diagram shows that the slope curve has changing positive slopes throughout, and a maximum slope at C. The maximum moment in this beam also occurs at C. A moment about a point is defined as *the force times the shortest distance from the point to the line of action of the force*. Therefore, the varying moment, zero at A and E, and increasing to the maximum at C, varies as a function of the distance from the reactions at A and E. Moment diagrams are second-order derivatives.

    c. Finally, in Figure 23-78 (d) the shear diagram appears as the derivative of the moment diagram. Since the moment diagram has two linear portions, one positive sloped and one negative, the shear diagram appears as two horizontal lines, one above the axis and one below. Shear diagrams are third-order derivatives.

3. Refer to Figure 23-76 again to review the comparisons of graphical differentiation and integration, because the beam diagrams are integrated next.

4. Follow the progression of diagrams in Figure 23-79 for the same beam; however, this time the shear diagram is considered first, which is the usual progression in beam analyses.

    a. Before constructing the shear diagram, look at the FBD. Upward forces are positive; downward, negative. Start at A and consider the beam from left to right. Figure 23-79 (b) shows the shearing tendency caused by the reaction force at A. This tendency, for this beam, remains constant along the beam until a change in loading occurs at C. From C onward, the effect of the reaction at A plus the larger downward load at C causes the tendency for shear to be downward, and constant through to E.

    b. The moment diagram in Figure 23-79 (c), going from left to right, shows the moment increasing as X increases. The conceptual sketch at right isolates a portion of the beam and shows it in equilibrium, because the 500X is balanced by the reaction force of 500 pounds times the moment arm X.

    c. Consider the order of the graphical curves compared to the analytical derivatives.

        (i) The moment diagram is the integral of the shear diagram. Since the shear diagram has a zero-order slope, the moment diagram is a first-order curve.

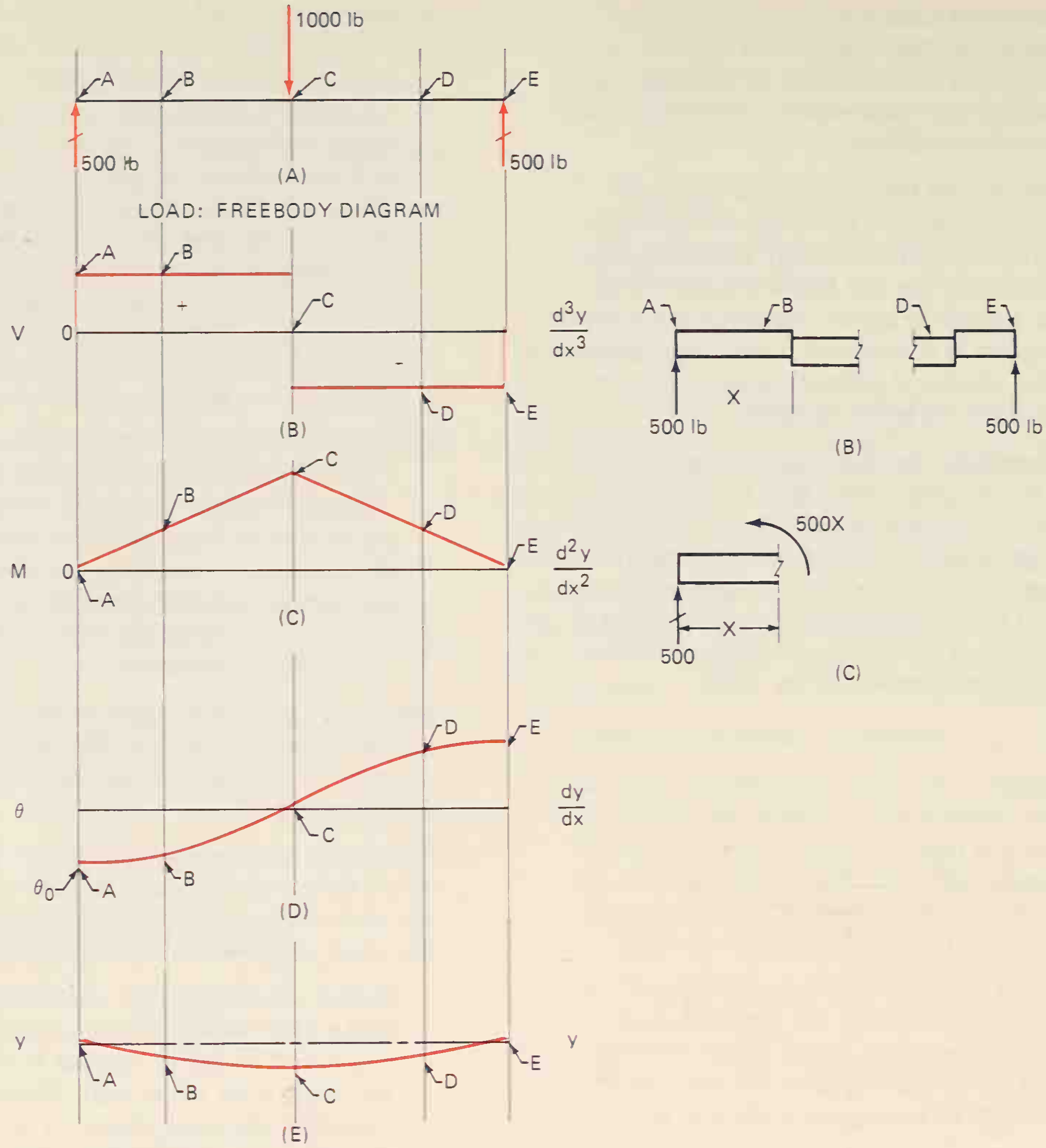


Figure 23-79 Centrally loaded beam: beam diagrams

(ii) Analytically, the shear diagram, always a third derivative, integrates to a second derivative.

d. Figure 23-79 (d) shows the slope diagram, integral of the moment diagram. The slope diagram starts with an initial value of slope at A. This value must be found either analytically or graphically. The graphical method is shown in step 6, below. Slope diagrams are first-order derivatives.

e. Finally, Figure 23-79 (e) shows the deflection curve, the integral of the slope curve. (Moment curves and deflection curves are the ones designers use most: the slope curve is just the intermediate step.) The deflection curve looks as the real beam would with a concentrated load at the center.

5. Compare the beam diagrams shown in Figures 23-80 and 23-81 with the preceding discussion. Shear and moment diagrams are shown, but deflections are given as equations only. These are typical of the diagrams that appear in handbooks and texts.

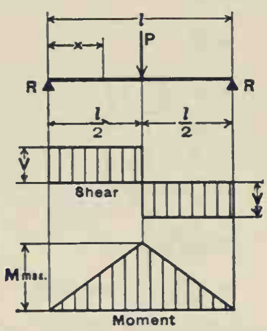
6. Figure 23-82 is the simply loaded beam again, but with the actual application of graphical integration.

   a. The steps summarized in Figure 23-68 to do graphical integration were followed to prepare the diagrams. Scale calculations

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

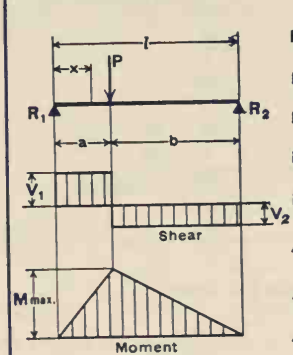
Equivalent Tabular Load is the uniformly distributed load given in beam tables, pages 2 - 28 to 2 - 81.
For meaning of symbols, see page 2 - 196.

7. SIMPLE BEAM—CONCENTRATED LOAD AT CENTER



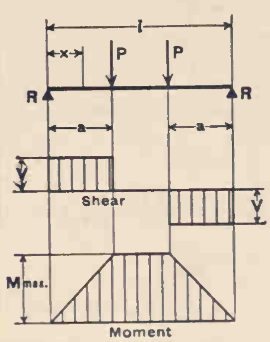
Equivalent Tabular Load	$= 2P$
$R = V$	$= \frac{P}{2}$
M max. (at point of load)	$= \frac{Pl}{4}$
M_x (when $x < \frac{l}{2}$)	$= \frac{Px}{2}$
Δmax. (at point of load)	$= \frac{Pl^3}{48EI}$
Δx (when $x < \frac{l}{2}$)	$= \frac{Px}{48EI}(3l^2 - 4x^2)$

8. SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT



Equivalent Tabular Load	$= \frac{8\,Pab}{l^2}$
$R_1 = V_1$ (max. when $a < b$)	$= \frac{Pb}{l}$
$R_2 = V_2$ (max. when $a > b$)	$= \frac{Pa}{l}$
M max. (at point of load)	$= \frac{Pab}{l}$
M_x (when $x < a$)	$= \frac{Pbx}{l}$
Δmax. (at $x = \sqrt{\frac{a(a+2b)}{3}}$ when $a > b$)	$= \frac{Pab\,(a+2b)\,\sqrt{3a\,(a+2b)}}{27\,EI\,l}$
Δa (at point of load)	$= \frac{Pa^2b^2}{3EI\,l}$
Δx (when $x < a$)	$= \frac{Pbx}{6EI\,l}(l^2 - b^2 - x^2)$

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



Equivalent Tabular Load	$= \frac{8\,Pa}{l}$
$R = V$	$= P$
M max. (between loads)	$= Pa$
M_x (when $x < a$)	$= Px$
Δmax. (at center)	$= \frac{Pa}{24EI}(3l^2 - 4a^2)$
Δx (when $x < a$)	$= \frac{Px}{6EI}(3la - 3a^2 - x^2)$
Δx (when $x > a$ and $< (l - a)$) . .	$= \frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

Figure 23-80 Beam diagrams: handbook (*Courtesy American Institute of Steel Construction*)

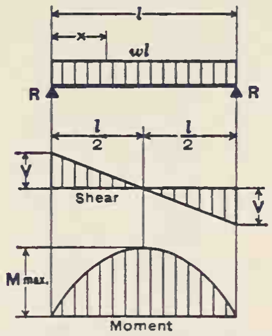
are shown at right. SY1 was arbitrarily selected; the other values were derived using the equation SY2 = (H)(SX)(SY1). The deflection at C equals the derived scale SY4 times the actual measurement at C, divided by the product of E times I.

b. The modulus of elasticity E was needed in the deflection calculation because E is a measure of the material's ability to resist deforming under loads. E for steel equals 30,000,000 pounds per square inch. (SI Units: 210 Giga Pascals) The second param-

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

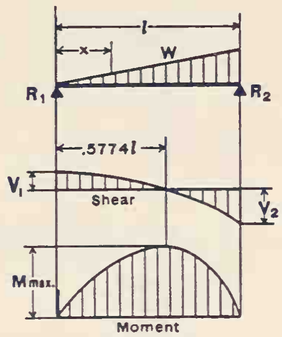
Equivalent Tabular Load is the unifomly distributed load given in beam tables, pages 2 - 28 to 2 - 81.
For meaning of symbols, see page 2 - 196.

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



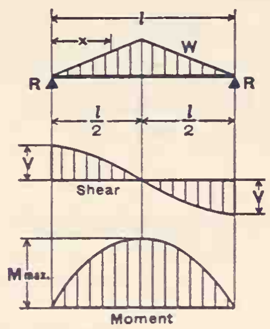
Equivalent Tabular Load . . .	$= wl$
R = V	$= \frac{wl}{2}$
Vx	$= w\left(\frac{l}{2} - x\right)$
M max. (at center)	$= \frac{wl^2}{8}$
Mx	$= \frac{wx}{2}(l - x)$
Δmax. (at center)	$= \frac{5wl^4}{384EI}$
Δx	$= \frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

2. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END



Equivalent Tabular Load . . .	$= \frac{16W}{9\sqrt{3}} = 1.0264W$
$R_1 = V_1$	$= \frac{W}{3}$
$R_2 = V_2$ max.	$= \frac{2W}{3}$
Vx	$= \frac{W}{3} - \frac{Wx^2}{l^2}$
M max. $\left(\text{at } x = \frac{l}{\sqrt{3}} = .5774l\right)$ . .	$= \frac{2Wl}{9\sqrt{3}} = .1283\,Wl$
Mx	$= \frac{Wx}{3l^2}(l^2 - x^2)$
Δmax. $\left(\text{at } x = l\sqrt{1 - \sqrt{\frac{8}{15}}} = .5193l\right)$	$= .01304\,\frac{Wl^3}{EI}$
Δx	$= \frac{Wx}{180EI\,l^2}(3x^4 - 10l^2x^2 + 7l^4)$

3. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER



Equivalent Tabular Load . . .	$= \frac{4W}{3}$
R = V	$= \frac{W}{2}$
Vx $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{W}{2l^2}(l^2 - 4x^2)$
M max. (at center)	$= \frac{Wl}{6}$
Mx $\left(\text{when } x < \frac{l}{2}\right)$	$= Wx\left(\frac{1}{2} - \frac{2x^2}{3l^2}\right)$
Δmax. (at center)	$= \frac{Wl^3}{60EI}$
Δx $\left(\text{when } x < \frac{l}{2}\right)$	$= \frac{Wx}{480\,EI\,l^2}(5l^2 - 4x^2)^2$

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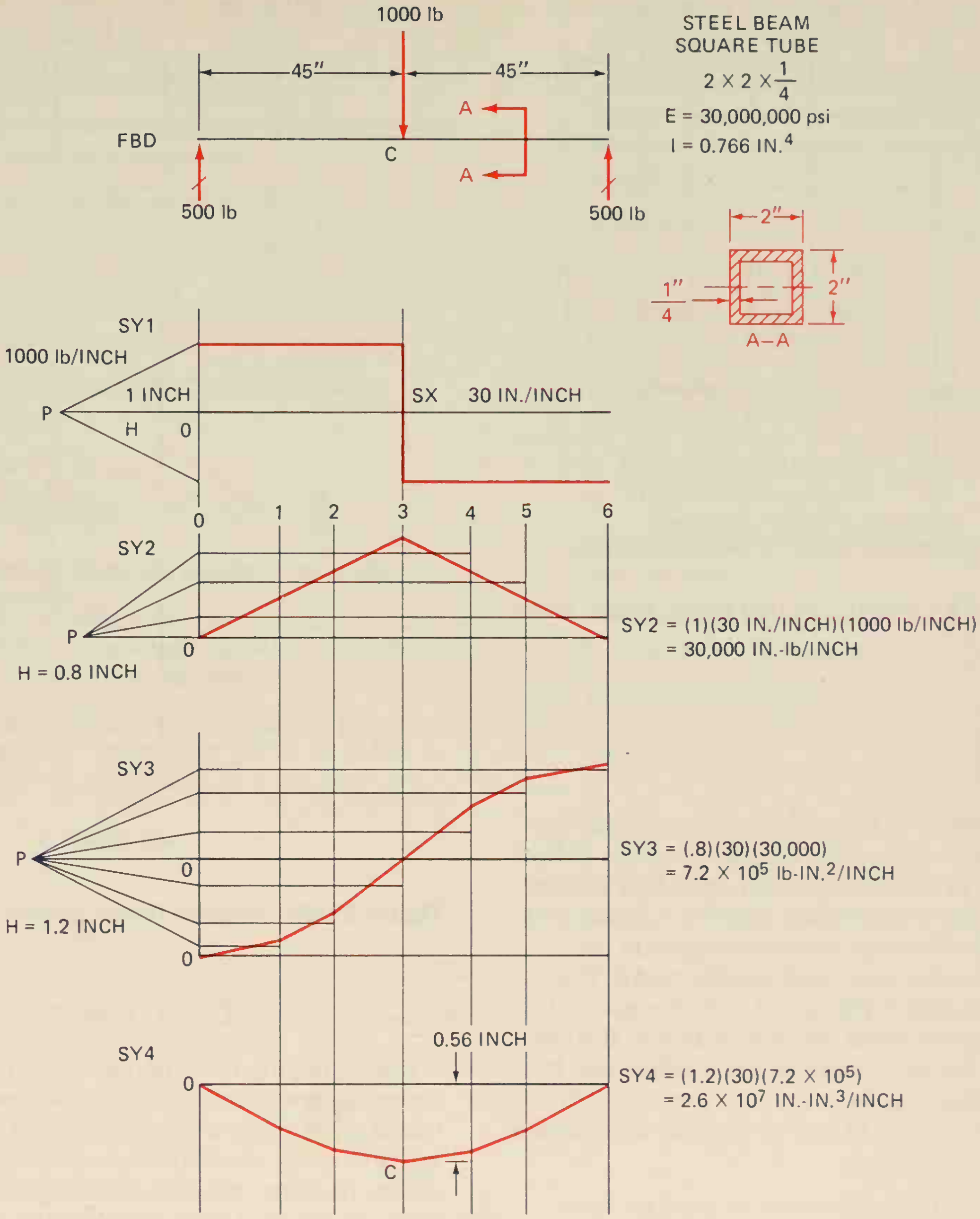
Figure 23-81 Beam diagrams: handbook (*Courtesy American Institute of Steel Construction*)

eter I, moment of inertia in inches to the fourth power, is a geometrical property and is a measure of the beam's tendency to resist bending.

c. Refer to the slope curve for an illustration of the graphical technique used to determine the initial value of the slope. Note that the derived slope curve (integral of the



$$\text{DEFLECTION AT C} = \frac{(.56)(2.6 \times 10^7)}{(30{,}000{,}000)(0.766)} = \underline{\underline{0.63 \text{ IN.}}}$$

Figure 23-82 Centrally loaded beam: graphical integration

moment curve) begins at zero and then, because of the positive area under the moment curve, moves upward (positively) across the beam. Next, a new horizontal axis is established "by eye" so that the area under the new horizontal axis approximately equals the area above. If these negative and positive areas are indeed equal, then the deflection curve will start and end at the level of the horizontal reference line for the derived deflection curve. Returning to the same level confirms the new position of the horizontal axis. Furthermore, the initial value of the slope curve is also confirmed.

d. Suppose that the new horizontal axis was located too low. What would happen? Figure 23-83 shows the slope curve redrawn with the new horizontal axis located too low; that is, the positive area exceeds the

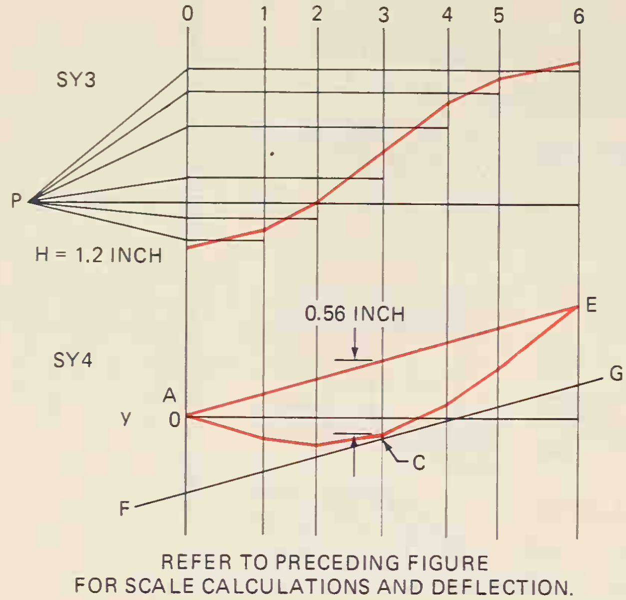


Figure 23-83 Centrally loaded beam: initial slope

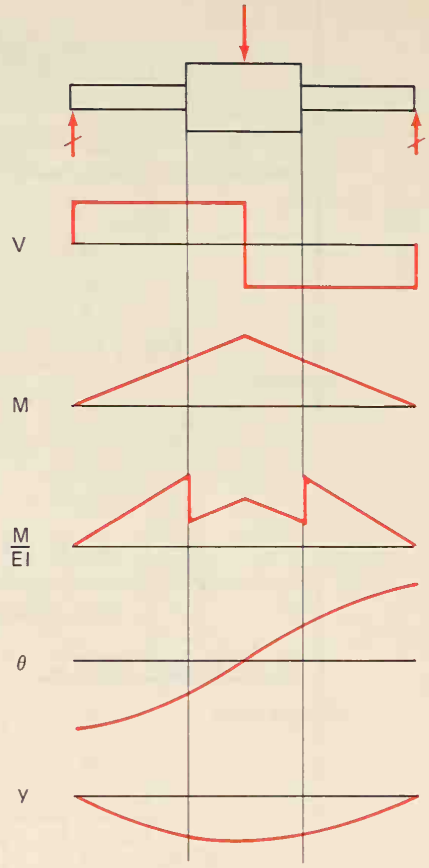


Figure 23-84 Stepped beam: graphical integration

negative, so the deflection curve ends too high. However, the magnitude of the deflection can be easily determined by a simple graphical correction. Line AE is drawn first. Then FG is constructed tangent to the deflection curve and parallel to AE. The deflection is measured from the point of tangency in the *vertical* direction to the line AE. Finally, the deflection is calculated by multiplying the measured distance 0.56 *inches* times SY4 and dividing by EI to obtain 0.63", as before.

7. Graphical integration can be used for most beam analyses; however, the best use is for beams which have a number of different cross sections. These beams are difficult to describe analytically but can readily be integrated using graphical integration. Figure 23-84 shows a complete set of diagrams, without calculations, to demonstrate how graphical integration is used effectively when the cross-section changes. The significant difference in these diagrams comes after the moment diagram. Selected values of moments are divided by appropriate values of EI to obtain a new curve, M/EI, plotted in a new set of axes. The M/EI diagram comes after the moment diagram to incorporate the properties, E and I, to resist deformation and bending, respectively. At this point graphical integration procedures start anew.

Conclusion

After studying this chapter most readers should agree that communicating information is the popular use of *charts* and *graphs* in a variety of media, including textbooks, periodicals, newspapers, and television. However, generating information is the most useful function of *charts* and *graphs* for designers.

Review

1. With respect to *charts* and *graphs*, what was meant by communicating information as compared to generating information?
2. List the five basic components of *charts* and *graphs*.
3. Why were commercial grids, such as logarithmic grids, developed?
4. What is a spreadsheet?
5. Define and describe a vector. How are they added and subtracted?

6. Define equilibrium as used in the study of mechanics.
7. What is a 2-force member?
8. Why are free-body diagrams (FBD) important in the study of mechanics?
9. What is meant by optimization?
10. What does yield strength mean?
11. Define scale modulus.
12. What is a logarithm?
13. Describe the variables in the following equations:

    a. y = mx + b
    b. y = B(x**m)
    c. y = B(e**mx)

14. What determines the length of an alignment chart?
15. Why is the straight-line equation so useful in matching equations to data?
16. How were similar triangles used in this chapter?
17. Describe the short method for designing a parallel alignment chart.
18. List and describe the four graphical techniques used in this chapter to derive equations once the data is plotted in an approximate straight line.
19. What is a spline?
20. Describe the steps to do:

    a. Graphical integration.
    b. Graphical differentiation.

21. Explain the derivations using graphical sketches of:

    a. SY2 = (H) (SX) (SY1).
    b. SY2 = SY1/((H) (SX)).

22. What affect does the distance H have on the next derived curve in:

    a. Graphical integration?
    b. Graphical differentiation?

23. What is an isopleth?

Chapter Twenty-Three Problems

Problems for this chapter are divided into two main categories, To Communicate Information and To Generate Information. A third group contains a miscellaneous collection of related problems. Refer to appropriate sections of the chapter for guidelines and suggested steps to prepare the charts and graphs.

To Communicate Information

Basic Graphs (Refer to the Five Basic Components in the chapter)

Problem 23-1

Prepare plots of BHP (brake horsepower) and T (torque), both as a function of RPM (revolutions per minute), for the following data:

RPM	BHP	T
500	15	190
1000	40	210
1500	65	230
2000	90	232
2200		240
2500	115	234
3000	130	230
3500	145	220
4000	150	200
4500	145	170

Problem 23-2

Electronic parts fail over a period of time in a frequency pattern shaped like a "bath tub." Plot the given failure-rate data with failure-rate ratios as a function of time.

Period	Failure-Rate Ratio	Time (hours)
Break-in Period		
Initial Failure Rate	2.00	0
	1.56	100
Constant Failure Rate	1.40	200
	1.28	300
	1.19	400
	1.12	500
	1.05	700
	1.00	1000
Typical Operating Period		
Constant Failure Rate	1.00	1000 to 5000
Wear Out Period		
Wear Out Failure Rate	1.00	50,000
	1.05	51,000
Constant Failure Rate	1.18	52,000
	1.40	53,000
	1.72	54,000
	2.50	55,000

Problem 23-3

Plot Average Cost in $ vs. Weight of Steel Forgings in pounds for the following:

Cost $	4.20	7.50	15.00	30.00	54.00	115.00
Weight lb	2.0	4.0	10.0	20.0	40.0	100.0

Problem 23-4

Prepare a graph of % Power as a function of Air-Fuel-Ratio for the data representig a typical Internal Combustion Engine.

% Power	90	100	95	87	75	60	43
Air-Fuel-Ratio	10:1	12:1	14:1	16:1	18:1	20:1	22:1

Problem 23-5

During a tension test of a steel bar, the following data was calculated and recorded: prepare a graph of Stress in psi vs. Strain (stretching) in inches per inch.

Stress lbs/square inch (psi)	Strain inches/inch
00000	0.00000
3000	0.00010
5000	0.00020
10,000	0.00030
15,000	0.00050
20,000	0.00070
25,000	0.00080
30,000	0.00100
36,000	0.00120

Problem 23-6

A convenient expression in strength of materials calculations is the relationship of G (shear modulus) as a function of E (modulus of elasticity). The equation is:

$$G = \frac{E}{2(1 + 0.3)} = \frac{E}{2.6}$$

where the 0.3 is Poisson's Ratio.

Prepare a plot of the following data for a variety of engineering materials:

Material	E psi	G psi
Plastic	1,000,000	400,000
Magnesium	2,300,000	6,100,000
Aluminum	3,800,000	10,000,000
Zinc	5,000,000	12,000,000
Copper	6,000,000	16,000,000
Palladium	6,300,000	17,000,000
Platinum	9,300,000	24,000,000
Steel	11,600,000	30,000,000

Problem 23-7

Assigned by Instructor.

Pie Charts

Problem 23-8

Prepare a weekly schedule of your activities for 24 hours per day. Show the different activities in a pie chart.

Problem 23-9

Use a pie chart to show the distribution of percentages of the sources of electrical power generation as follows: Coal, 56; Nuclear, 17; Hydro-electric, 12; Gas, 10; and Oil, 5.

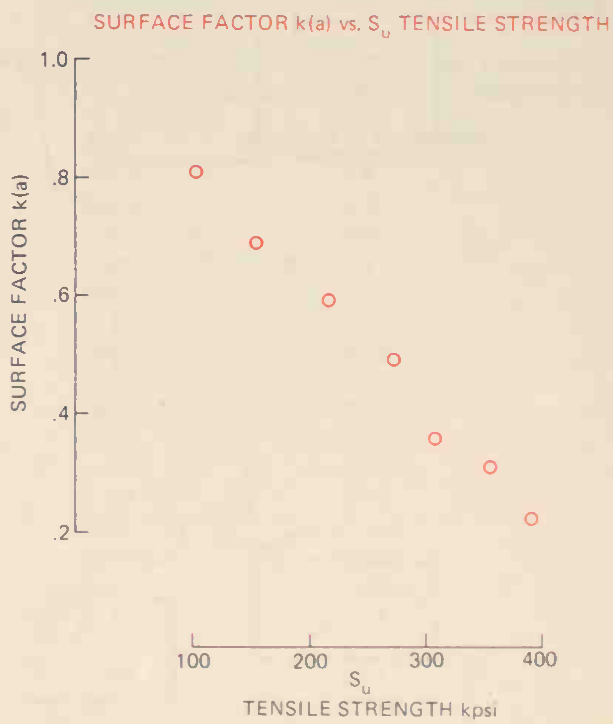
Problem 23-10

Show in a pie chart the relative importance of the qualities of a successful, professional, technical person: Character, 40%; Judgement, 18%; Efficiency, 15%; Understanding People, 14%; and Technical Knowledge, 13%.

Problem 23-11

Select a pie or bar chart from your local newspaper or national business publication and revise it based on the ideas presented in a book by E.R. Tufte titled *The Visual Display of Quantitative Information*. Mr. Tufte contends that charts can, and should, be made much simpler and still convey the required information. Some of his suggestions and observations are:

1. Since desktop computers now have the ability to fill in bound spaces with a variety of patterns, pie charts and bar charts are filled with these patterns—because they are there! Mr. Tufte believes that the patterns only clutter up the charts.
2. Scales should only go as far as the data, as shown in Figure Problem 23-11. The location of zero values are implied.
3. Pleasing "to the eye" dimensions for the overall chart space are approximately equal to the proportions of the "golden rectangle": the height to width ratio of 1:1.618. (Most ancient Greek and Roman structures seemed to fit these proportions.)
4. Try to be creative in presenting the data: for example, Mr. Tufte displayed a photograph of people lined up in columns of various lengths to represent a statistical histogram to approximate a normal distribution.



Problem 23-11

Problem 23-12

Assigned by Instructor.

Bar Charts

Problem 23-13

A local newspaper published data relating to three alternate choices for handling city sewage. The data appeared in tabular form as shown below. Prepare a bar chart to better represent the data.

Monthly Household Sewer Rates (Dollars)

	1995		2005		2030		45 Yr. Avg.	
	Utility Est.	City Est.	Utility Est.	City Est.	Utility Est.	City Est.	Utility Est.	City Est.
Alternative 1	14.95	14.75	9.75	11.45	4.60	6.00	8.85	9.45
Alternative 2	19.70	18.30	11.10	11.45	4.35	6.10	10.45	10.35
Alternative 3	17.65	17.00	10.40	11.20	4.55	6.30	9.75	10.00

Problem 23-14

Prepare a bar chart to represent the population of the United States in Millions vs. Year as listed:

Population in Millions	Year
5.3	1800
7.2	1810
9.6	1820
12.9	1830
17.1	1840
23.2	1850
31.4	1860
38.6	1870
56.2	1880
63.0	1890
76.0	1900
97.0	1910
105.7	1920
122.8	1930
131.7	1940
151.1	1950
179.3	1960
211.4	1970
255.0	1980
300.0 (est)	1990
360.0 (est)	2000

Problem 23-15

A recent newspaper article compared a number of baseball pitchers' fastball speeds to speeds of a sneeze, horses, automobiles (freeway speed), jaguars, and horses in MPH. Prepare a creative bar chart which shows the following:

Pitcher/Other	Speed in MPH
A	100
B	98
C	98
D	97
E	96
F	96
G	95
H	95
I	94
J	94
K	92
L	88
M	88
N	87
O	86
Sneeze	103
Automobile	65
Jaguar	63
Horse	43

Problem 23-16

Assigned by Instructor.

Planning Charts

Problem 23-17

Construct a planning chart to show the activities required to do an experiment in an eight-hour day. A report also is required for this experiment. The activities necessary to do the experiment and the estimated time for each activity are listed below. Some activities will overlap.

	Hours
1. Study experiment	1 hour
2. Set up Apparatus	1-½
3. Take data	3
4. Plot data	4-½
5. Write first draft	1
6. Edit and rewrite on word processor	1-½
7. Collect parts for report and assemble	1
8. Put the report in a folder and submit it	1-½

Problem 23-18

Prepare a planning chart for the activities required to make a float for a parade in your school or community.

Problem 23-19

Prepare a planning chart for any one of the following:

1. A major repair to an automobile or other major appliance.
2. A field trip for 50 students to a local industry.
3. Manufacturing a product which has several components.

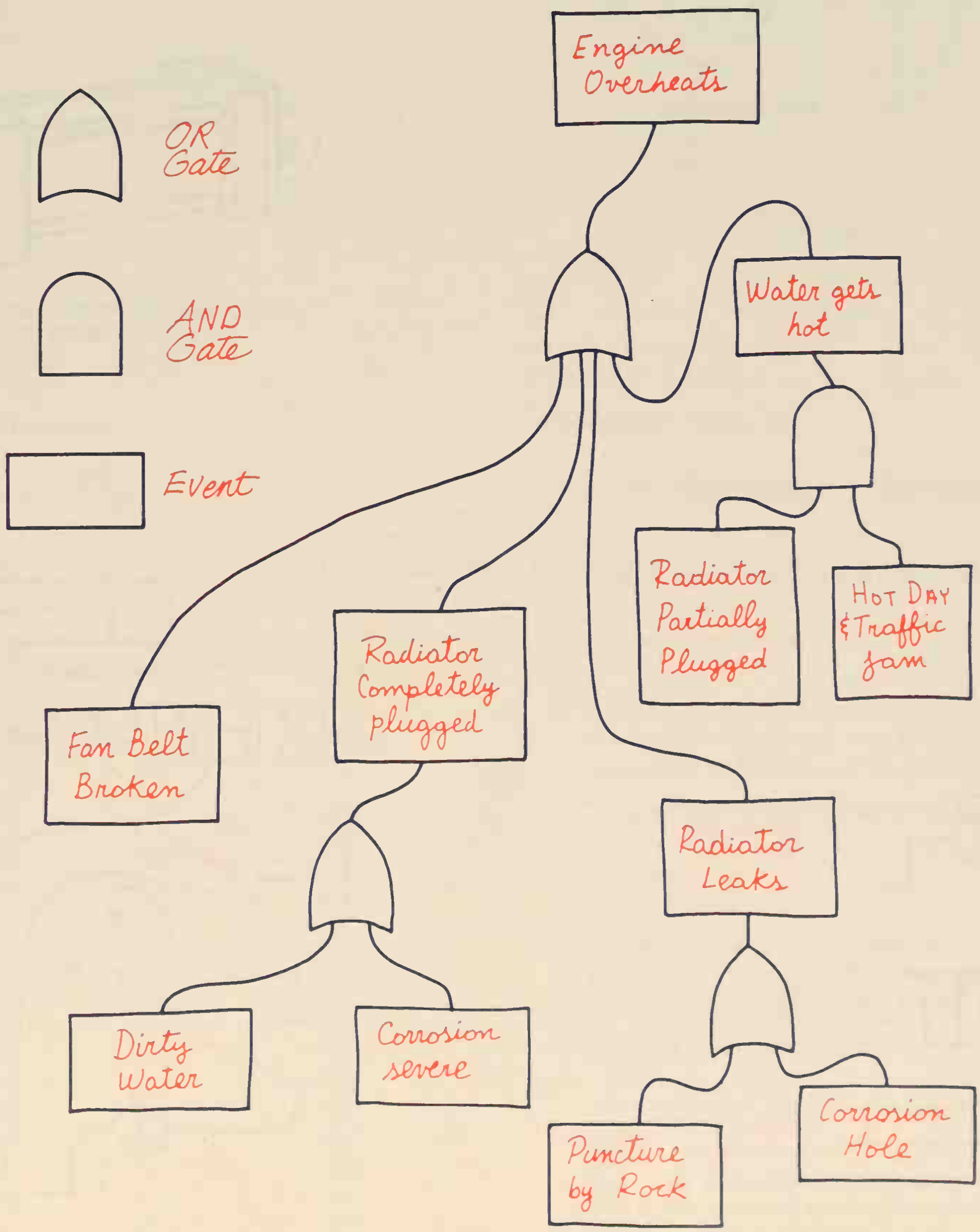
Problem 23-20

Assigned by Instructor.

Flow Charts

Problem 23-21

Redraw the rough sketch in Figure Problem 23-21, which shows an example Fault Tree Analysis flow chart. Flow is upward on the page. Lines are either horizontal or vertical, are drawn with a straight edge, and change direction with 90° corners.



Problem 23-21

Problem 23-22

Construct a flow chart of a computer program used in your classes.

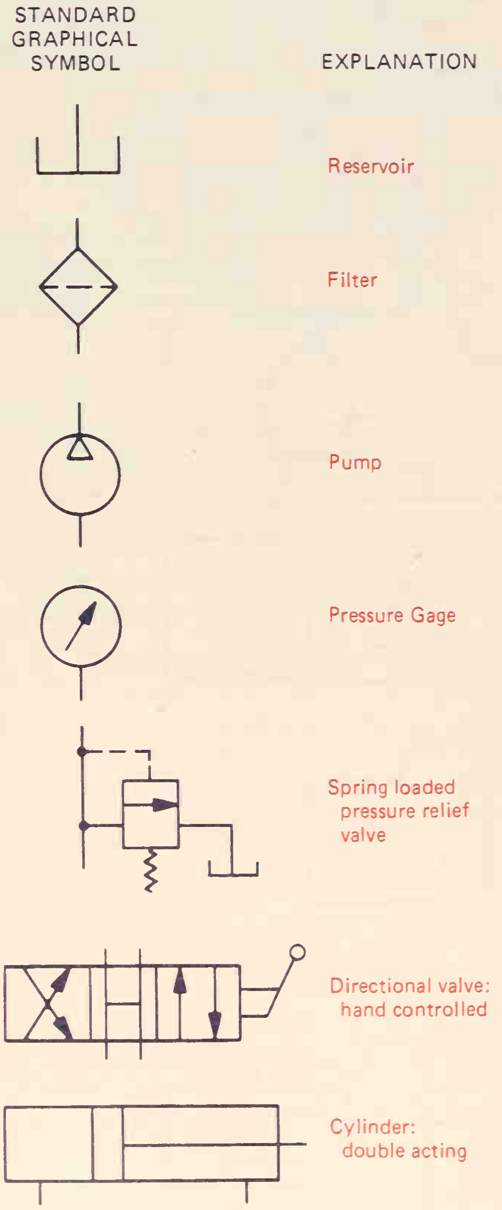
Problem 23-23

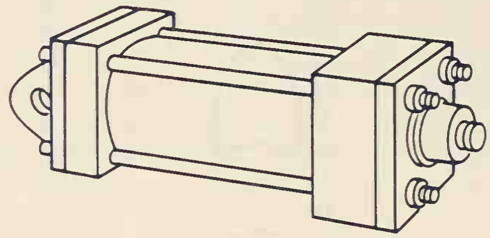
Assigned by Instructor.

Schematics

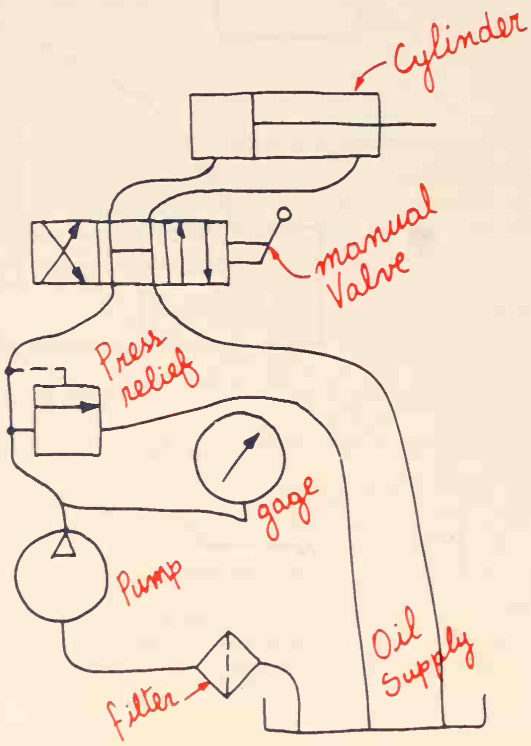
Problem 23-24

Using a straight edge and a circle template, redraw the rough hydraulic power schematic shown in Figure Problem 23-24 and label each component. Show the directional valve in the position for pushing the piston to the right. Lines in schematics are either horizontal or vertical, and change direction in 90° corners.





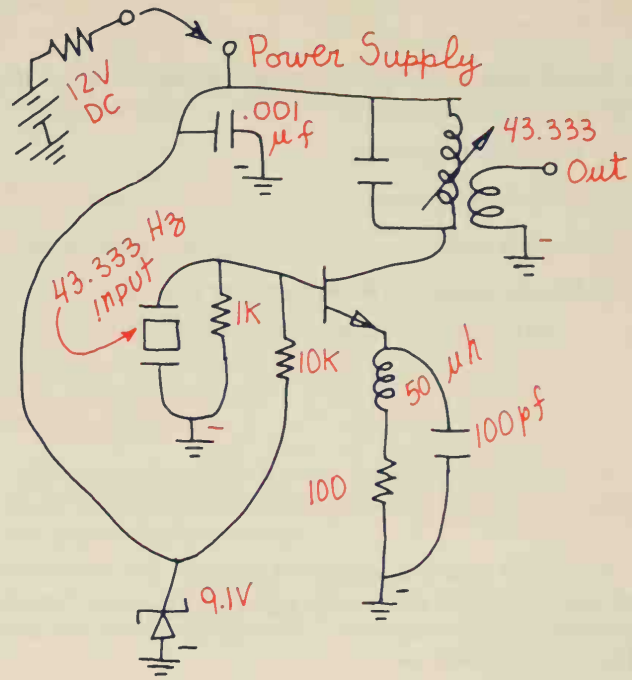
PICTORIAL OF HYDRAULIC CYLINDER (CLEVIS MOUNTING)



Problem 23-24

Problem 23-25

Using a straight edge, redraw the rough schematic of an overtone oscillator shown in Figure Problem 23-25. Generally, signals (voltages, current, and information) travel from left to right; positive voltages are in the upper areas and negative voltages are in the lower.



Problem 23-25

Problem 23-26

Assigned by Instructor.

Polar Charts

Problem 23-27

Use a commercial polar grid to plot noise-level values surrounding a jet engine: decibels vs. angle.

Angle (Zero Degrees is North)		Decibels
0	360	20
20	340	76
25	335	85
30	330	93
35	325	97
40	320	99
45	315	96
60	300	92
70	290	91
80	280	94
90	270	95
100	260	96
110	250	95
125	235	100
140	220	90
150	210	95
160	200	90
170	190	82
180	180	65

Problem 23-28

Assigned by Instructor.

To Generate Information

Nomograms: Adjacent and Non-adjacent

Problem 23-29

1. Design an adjacent alignment chart for the equation E = 33,000 HP, where E is in foot-pounds per minute and HP is horsepower that varies from 2 to 20.
2. Design a non-adjacent chart for the same equation.

Problem 23-30

1. Design an adjacent alignment chart for the equation kW = .746 HP, where HP is horsepower and kW is kilowatts. Let HP vary from 1 to 100.
2. Design a non-adjacent chart for the same equation.

Problem 23-31

1. Design an adjacent alignment chart for the equation 57.3 R = N, where R is in radians and N is number of degrees. Let R vary from 0 to 6.28.
2. Design a non-adjacent chart for the same equation.

Problem 23-32

Design adjacent alignment charts for any or all of the following useful conversions:

1. kilograms to pounds
2. pounds to Newtons
3. Pascals to psi
4. Newton-meters to foot-pounds or pound-inches

Problem 23-33

Design an adjacent alignment chart for the conversion of *stress* in pounds per square inch to MPa, mega-Pascals (Newton per meter squared = Pascal). Let stress vary from 10,000 to 300,000 psi.

Note: 6895 MPa = 1,000 psi.

Nomograms: Parallel, Three Variables

Problem 23-34

Design a parallel alignment chart for the equation

$$KE = \frac{(W)(V^{**}2)}{(2)(g)}$$

where KE = kinetic energy in foot-pounds
W = weight in pounds
V = velocity in feet/second

Let W vary from 1 to 500 pounds and V from 1 to 100 feet/sec. g = 32.2 feet/sec**2

Problem 23-35

Design a parallel alignment chart for the equation

$$S = \frac{PD}{4T}$$

where S = Circumferential Stress in a spherical tank
P = internal gas pressure, psi
D = diameter in inches = 20"
T = thickness of shell

Let P vary from 0 to 150 psi and T from .1" to .5"

Problem 23-36

Design a parallel alignment chart for the following helical spring equation:

$$y = \frac{8\,F\,(D^{**}3)\,N}{(d^{**}4)\,G}$$

where y = deflection in inches
F = force in lb applied
D = mean diameter of coil in inches = .6"
d = wire diameter in inches = .1"
G = shear modulus 11,500,000 psi
N = number of coils

Let F vary from 0 to 50 pounds and N from 3 to 15.

Problem 23-37

Design a parallel alignment chart for the following shaft design equation:

$$S = \frac{16\,T}{(3.14)\,d^{**}3}$$

where S = shear stress, psi
T = torque, inch-pounds (2,000 to 10,000 in-lb)
d = diameter, inches (1 inch to 5 inches)

Note: For a factor of safety of 2, S should not exceed ½ the yield strength of the metal being considered.

Problem 23-38

Design a parallel alignment chart for the following moment of inertia equation for a rectangular cross-sectional member:

$$I = \frac{b\,h^{**}3}{12}$$

where I = moment of inertia
(or actually second moment of area)-----in**4
b = width, inches (0.5 to 3 inches)
h = height, inches (1.5 to 9 inches)

(I is a measure of a members ability to resist bending about an axis parallel to b and perpendicular to h.)

Nomograms: Concurrency Charts

Problem 23-39

The "learning curve" premise says that as workers gain experience on producing a new product they can produce more products in a given length of time. An equation that expresses this improvement in production as learning increases is the following:

$$T = E\,C^{**}m,$$

where T = hours of production time to produce the cumulated total of batches of products (10 to 1000)
C = cumulated total of batches of products (1 to 100,000)
E = initial effort in hours to produce the first batch of products (1000)
m = an exponent which depends on the improvement in learning

For example, assume that the cumulative total of batches of products has doubled, and that the time used for the second half of the double is only 75% of the time used for the first half. Then the exponent m is calculated as follows:

$$\frac{.75\,T}{T} = \frac{E\,(2C)^{**}m}{E\,(C)^{**}m} \text{ so } .75 = (2)^{**}m$$

and from log .75 = m log 2, m = −.415. Then the equation for the learning curve becomes

$$T = E\,C^{**}(-.415) \text{ and } \log T = \log E - .415 \log C$$

which indicates that a straight-line plot could be done on a log-log (logarithmic) grid with a slope of −.415.

Prepare a concurrency chart of percentage learning curves on a 3 × 5 cycles logarithmic grid for 65%, 70%, 75%, 80%, and 85%. Check one of the equations by plotting the curve on linear coordinates until the cumulative total doubles several times.

Problem 23-40

Prepare a concurrency chart of the equation for determining the deflection at the center of a beam that has a concentrated load at the center and is simply supported at the ends. The equation is:

$$y = \frac{W\,L^{**}3}{48\,EI}$$

where y = deflection in inches
W = the applied concentrated load (1000 to 5000 pounds)
L = length between supports (30" to 100")
EI = (30,000,000psi for steel) × (.766 in**4 for a 2 × 2 × ¼ inch tube) = (2.3)(10**7) lb-in**2

Problem 23-41

Prepare a parallel alignment chart of the equation in Problem 23-40.

Problem 23-42

Prepare a concurrency chart for an equation from one of your courses.

Problem 23-43

Assigned by Instructor.

Empirical Equations: Semilogarithmic

Problem 23-44

Derive an equation for the following data taken in a grassy field downwind from a source of radioactive Iodine, over a period of one month.

Activity (counts/second)	Day
102	1
48	5
29	10
13	15
7	20
3	25
2	31

Problem 23-45

Derive an equation for the following data for the change in electrical resistance in a ceramic because of a change in temperature.

Resistance R (ohms)	Temperature (degrees Fahrenheit)
240.0	750
120.0	840
54.0	930
32.0	1020
15.0	1100
7.0	1200
3.7	1300
1.9	1370
1.0	1450

Problem 23-46

Derive an equation that describes the voltage across a resistor in a circuit where a capacitor is being charged using the following data:

Voltage	Time (tenths of a second)
10.0	0
5.4	2
3.0	4
1.5	6
1.0	8
.6	10

Problem 23-47

Derive an equation that describes the relative response of an electric recording device as a function of frequency.

Relative Response (decibels)	Frequency (Hertz)
−38	10
−20	100
−12	200
−7	300
−5	400
−3	500
−2	600
−1	700

Empirical Equations: Logarithmic

Problem 23-48

Verify the *Weir equation* that was derived in the discussion of Empirical Equations in the chapter. The data is repeated here for convenience.

Flow Q (cubic feet per minute)	Head H (feet)
14.2	2
41.5	3
80.0	4
135.2	5
225.3	6
330.5	7
445.5	8
620.5	9
790.6	10

Problem 23-49

Derive an equation that describes data taken from film showing height vs. time of an object dropped by students from an airplane flying at 10,000 feet elevation.

Airplane Height Minus Object Height (feet)	Time (seconds)
4	.5
17	1.0
120	3.0
400	5.0
1500	10.0
3700	15.0
6500	20.0

Problem 23-50

During a laboratory exercise students measured the deflection of a cantilevered beam due to a concentrated load applied at the end vs. the length of the cantilevered beam. Derive an equation from their data to show them how deflection varies as the length is increased for the same cross section of beam.

Deflection (inches)	Beam Length (inches)
.01	10
.09	20
.25	30
.60	40
1.50	50
3.40	70
6.00	80
10.00	100

Miscellaneous

The data for the next seven problems should be plotted first on linear-coordinate paper to determine the type of equation—linear, power, or exponential—the data matches. Then, appropriate grids can be used to derive an equation for the data.

Problem 23-51

In the Saturated Steam: Pressure Table, Specific Volume V(g) is tabulated as a function of Absolute Pressure P in psi. Derive an equation with Specific Volume vs. Absolute Pressure for the following steam table data:

P	V
1.000	333.60
5.000	73.53
10.000	38.42
14.696	26.80
15.000	26.29
20.000	20.09
30.000	13.74
40.000	10.50

Problem 23-52

Iron pipe without insulation loses heat to the atmosphere at various rates, depending on the diameter of the pipe. Determine an equation for the following data relating standard pipe sizes to measured heat loss:

Pipe Size P (see std tables for dimensions)	Heat Loss (Btu/foot/hour)
1	79
1-½	114
2	143
2-½	173
3	211
3-½	240
4	271
4-½	300
5	334
6	398
8	518
10	647

Problem 23-53

A typical centrifugal fan creates a pressure differential across the fan which causes air to flow. Derive an equation to relate *air flow* to *revolutions per minute* of this squirrel-cage type fan, from the following data:

Air Flow (cubic feet per min.)	500	800	1050	1400	1900	2100	2550	3000
RPM R	110	290	510	700	1010	1190	1520	1800

Problem 23-54

A sample exposed to neutron radiation became radioactive. The decay in energy of the sample was recorded hourly. Derive an equation for counts per minute as a function of time. (Note: If this data is exponential, a tangent to the beginning of the curve, assuming that the curve is plotted on linear-coordinate paper, will intersect the horizontal axis at a time when the counts equal approximately 36% of the initial value of counts per minute. Try this check when it is believed that the data is exponential.)

Counts Per Minute CPM	Time (minutes)
450	60
215	125
138	175
110	250
95	300
90	355
80	550
75	650

Problem 23-55

The following measurements of diameter vs. station (distance in the horizontal direction) were found in a design notebook. Plot the measurements and derive an equation relating diameter to station distance.

Diameter D (mm)	Distance to Station (mm)
3.93	10
3.18	20
2.42	30
1.78	40
1.12	50
0.43	60

Problem 23-56

During a recent consumer product research project an observer noted that the level of popcorn in a box descended rapidly at first, and then the rate of descent decreased slowly. The level of the popcorn was noted by the observer at one-minute intervals. Use the data to derive an equation for popcorn level vs. time.

Depth of Popcorn H (mm)	Time (minutes)
250	0
130	1
100	2
70	3
40	4
26	5
17	6
11	7
8	8
5	9
3	10

Problem 23-57

Assigned by Instructor.

Graphical Differentiation

Problem 23-58

During a broadcast of a space launch an armchair observer made notes on the speed of the launch vs. time. Plot the observer's data, fair-in a best fit curve, and differentiate it to determine a curve of acceleration vs. time.

Time (minutes)	Speed (kilometers/hour)
0	0
1	1700
2	5800
3	11 500
4	15 000

Problem 23-59

Plot the following data related to a field test of an automobile and fair-in a best fit curve through the data. Since the data is velocity vs. time, integrating the curve will give distance vs. time, and differentiating the curve will give acceleration vs. time. Do both for the data:

Velocity (mph)	Time (sec)
0	0
20	3
29	4
34	5
48	10
58	15
63	20
66	25
67	30
68	35

Problem 23-60

Occasionally, known quantities, known equations, and known results are used to build confidence in techniques new to an individual, such as graphical differentiation and integration. The data listed below represent the x and y values for the equation y = (2)(x**2) − (3)(x) + 10. Plot the points, draw a curve through the points, and then differentiate the curve. Check your results analytically. Where does the curve have zero slope?

x	y
0	10
1	9
2	12
3	19
4	30

One technique for assisting "by-eye" drawing of tangents to curves while doing graphical differentiation is to use a small mirror so that the plane of the mirror is perpendicular to the curve at the point of tangency. When the reflected curve appears "smooth" and "in-line", use the mirror to construct the perpendicular to the curve. Then draw the tangent at 90°.

Graphical Integration

Problem 23-61

Some equations cannot be integrated analytically, so other methods are used, such as numerical integration and graphical integration. Use graphical integration to integrate the expression y = (5sinX)/(X**2).

Problem 23-62

The objective in this problem is to use graphical integration to graduate the volume in a water tank. The tank looks like a light bulb upside down. Use the diameters at the given elevations to calculate cross-sectional areas, then plot area vs. elevations. Integrate and divide the tank into 1/4, 1/3, 1/2, 2/3, and 3/4 full.

Diameter (feet)	Elevation (feet)
10.0	0
10.0	10
10.0	20
10.2	30
11.8	32
13.0	34
15.0	36
18.4	38
26.4	40
32.8	42
37.0	44
39.0	46
40.2	48
40.0	50
39.0	52
36.6	54
31.0	56
26.0	58
0.0	60

Problem 23-63

Do the Aircraft Launch example discussed in the chapter and add the speed of the Aircraft Carrier (24 knots) to the speed of the aircraft attained by graphical integration. Will the aircraft stay airborne?

Problem 23-64

Use the same beam shown in Figure 23-82, but assume that the 1000-pound load is applied 30" from the left end instead of 45". The reaction at the left end will be 667 pounds, and at the right, 333 pounds. Use graphical integration to do the diagrams, and determine the deflection of the beam at the point where the 1000-pound force is applied. Check your answer using the beam deflection calculation equation in Figure 23-80:

$$\text{delta (a)} = y = \frac{P\,(a^{**}2)\,(b^{**}2)}{3\,E\,I\,L}$$

where P = 1000 lbs
a = 30"
b = 60"
E = 30,000,000 psi
I = .766 in**4
L = 90"

Problem 23-65

Use Figure 23-82 as a guide for graphically integrating to obtain the deflection at the center of a beam that is 90" long, that is loaded at the center with a 2500-pound concentrated force, and that is an S beam ("eye" beam) S 3 × 5.7 with a value of I = 2.52 in**4. Use the equation in Figure 23-80 to check your results:

$$\text{delta (max)} = y = \frac{P\,(L^{**}3)}{48\,E\,I}$$

where: P = 2500 lbs
L = 90"
E = 30,000,000 psi
I = 2.52 in**4

Problem 23-66

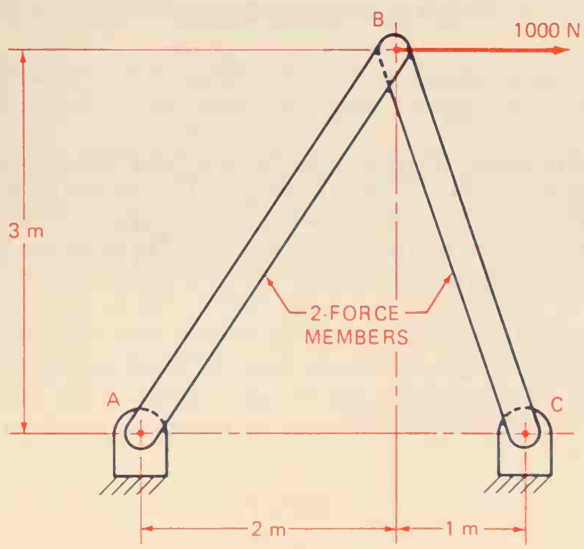
Differentiation and integration problems assigned by Instructor.

Force Polygons

Problem 23-67

Refer to Figure Problem 23-67 and do the following:

1. Draw the figure to scale using only single lines for members AB and BC.
2. Show a free-body diagram of joint B.
3. Use a force polygon, drawn to scale, to graphically determine the internal forces F (AB) and F (BC).
4. Label the values of F(AB) and F(BC) on the force polygon and indicate also whether these internal forces are going into joint B (compression) or away (tension).

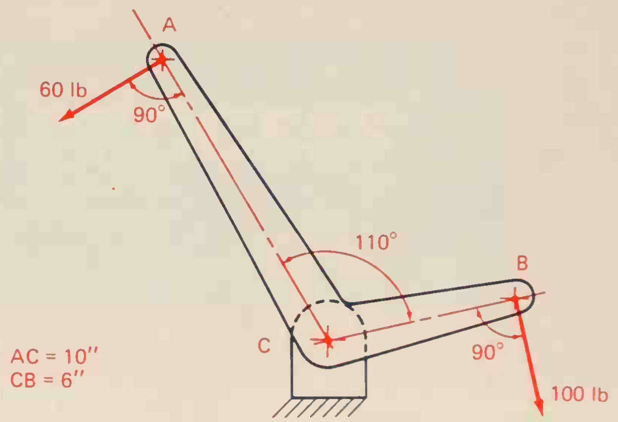


Problem 23-67

Problem 23-68

Figure Problem 23-68 shows a Bell Crank with forces F(A) and F(B) equal to 60 lbs and 100 lbs, respectively. The two applied forces and the reaction at C must go through a common point P for equilibrium conditions. Do the following:

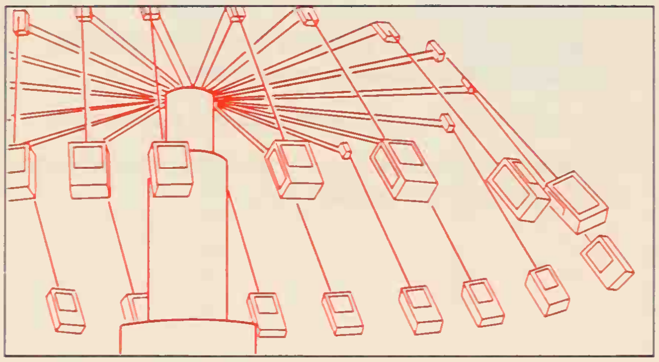
1. Draw the Bell Crank, to scale, using single lines for AC and BC.
2. Extend the lines of action of the forces until they intersect; label the intersection point P.
3. From P, construct a line through the pivot point C.
4. Construct a force polygon to scale to determine the magnitude of the reaction at C.

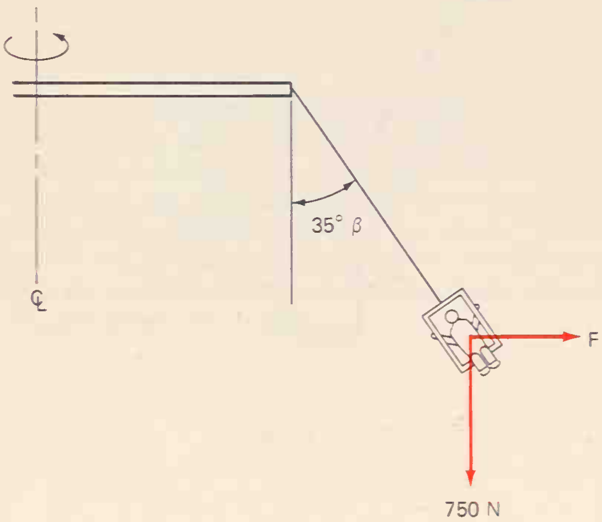


Problem 23-68

Problem 23-69

Figure Problem 23-69 shows an excited rider in a carnival-ride chair. The rider plus the chair weigh 750N, and the angle beta of the cable supporting the chair is 35°. Use a force polygon drawn to scale to determine the tensile force in the cable and the centrifugal force.





Problem 23-69

Problem 23-70

Assigned by Instructor.

Miscellaneous

Problem 23-71

Optimization problem. The two equations below give costs for insulating steam pipes over a period of a year.

$ (Fixed Cost) = 50t + 50
$ (Heat Loss) = 150/t, where t = insulation thickness

Plot both equations plus their sum as a function of insulation thickness t, and determine the optimum thickness to give the least cost.

Problem 23-72

Curve matching technique. There are a number of curve matching techniques other than graphical ones; however, to visualize whether the results of a particular technique has indeed matched the curve, a plot of the results is usually done. One technique for matching a cyclic curve—that is, one which repeats periodically—is called a Fourier Series. The following series was derived to match a cyclic, square wave, function that varied from 1 to 2 every 3.14 radians.

$$y = \frac{3}{2} - \frac{2}{3.14}\left(\sin X + \frac{\sin 3X}{3} + \frac{\sin 5X}{5} + \ldots\right)$$

Calculate and plot values of y for X varying from zero to 10 radians. One radian = 57.6 degrees.

Problem 23-73

Curve matching technique. A quadratic equation is used sometimes to match an equation to a curve. Try 3 sets of data from the Weir problem discussed in the chapter (H, Q: 4, 80; 6, 225.3; 8, 445.5) in the following equation: Q = A(H**2) + B (H) + C. Substitute the 3 sets of data to obtain 3 equations and solve them simultaneously for A, B, and C. Then check the derived equation with additional data, e.g.,

H = 5 and Q = 135.2.

Problem 23-74

Investigate ANSI (American National Standards Institute) Standard ANSI Y15.1M-1979 entitled "Illustrations for Publication and Preparation" and prepare a report for classmates, telling why the standard is useful to designers and showing several illustrations.

Problem 23-75

Assigned by Instructor.

CHAPTER 24

This chapter describes the design process, or problem-solving strategy, used by a host of professionals in product and systems design. Covered are the five phases of product design, including the steps within each phase. Both routine and non-routine design projects are discussed.

THE DESIGN PROCESS

The *design process* is a plan of action for reaching a goal. The plan, sometimes labeled problem-solving strategy, is used by engineers, designers, drafters, scientists, technologists, and a multitude of professionals. This strategy, the *design process*, occurs in five *phases* during a product design, and each *phase* has a number of *steps*. The *phases* listed below occur sequentially with some overlapping, as shown in Figure 24-1.

Phase I	Recognize and Define the Problem
Phase II	Generate Alternative Solutions: SYNTHESIS
Phase III	Evaluate Solution Ideas: ANALYSIS
Phase IV	Document, Specify, and Communicate the Solution
Phase V	Develop, Manufacture, and Deliver

The *steps*, not shown in Figure 24-1, may occur sequentially; however, each *phase* has a different number of steps depending on the complexity of the problem to be solved and the time available.

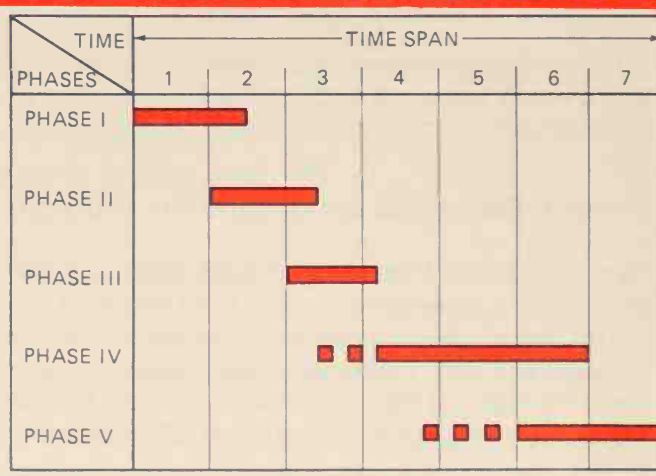


Figure 24-1 The phases in the design process

Time

The available *time*, whether hours, days, months, or years, controls the starting and stopping of the phases during the design process. Therefore, successful problem solving requires careful planning. And since the phases must occur within the time span, they must be scheduled as needed to reach the required goal.

Learning The Design Process

The most efficient way to learn the design process is to do it! That is, follow the phases and steps as a guide while doing several design projects, first individually and later in an organized group. Then, use these experiences to modify the phases and steps to suit your own interests and assignments. Start with this chapter, which provides the following:

1. An outline and discussion of the *phases and steps* in the design process
2. A discussion of *routine* design projects, the type usually assigned to neophyte engineers, designers, and drafters as their first job
3. A discussion of *non-routine* design projects, the type experienced engineers, designers, and drafters acquire as they assume more responsibility in their respective jobs
4. Review questions
5. A collection of *design hints* to enhance your problem-solving skills
6. Exercises to complement the design process
7. A list of *design project ideas*, routine and non-routine

DESIGN PROCESS: PHASES AND STEPS

PHASE I
RECOGNIZE AND DEFINE THE PROBLEM

STEP 1 Establish Plans for the Phases, Steps, and Records

STEP 2 Gather Information
- a. Primary Sources
- b. Secondary Sources

STEP 3 Combine Information Into a Preliminary Definition
- a. Constraints
- b. Specifications
- c. Preliminary Solution Ideas
- d. Iterate

STEP 4 Prepare A Progress Report
- a. Internal Client
- b. External Client

PHASE II
GENERATE ALTERNATIVE SOLUTIONS: SYNTHESIS

STEP 5 Generate Solution Ideas
- a. Use Systematic Techniques
- b. Use Creative Techniques and Attitudes

PHASE III
EVALUATE ALTERNATIVE SOLUTION IDEAS: ANALYSIS

STEP 6 Sift, Combine, and Prepare Solution Ideas for Analysis
- a. Preliminary Preparation
- b. Specific Preparation

STEP 7 Compare Solution Alternatives to Constraints and Specifications
- a. Iterate
- b. Persevere
- c. Qualitative Evaluation
- d. Quantitative Evaluation

STEP 8 Conduct a Design Review
- a. In-House Design Reviews
- b. Outside Design Reviews

STEP 9 Refine the Final Solution

PHASE IV
DOCUMENT, SPECIFY,
AND COMMUNICATE THE SOLUTION

STEP 10 Prepare Drawings and a Written Report

STEP 11 Give an Oral Presentation

PHASE V
DEVELOP, MANUFACTURE, AND DELIVER

STEP 12 Prepare Technical Detail Drawings of Each Component To Be Manufactured

STEP 13 Schedule Assembly, Final Testing, Packaging, and Delivery

STEP 14 Keep Records

Figure 24-2 Phases and steps in the design process

The Design Process: Phases and Steps

Follow the phases and steps shown in Figure 24-2, which are in sequence and numbered. Use them as a checklist.

Phase I Recognize and Define the Problem

Step 1 Establish Plans for the Phases, Steps, and Records. Make a *planning chart*, which is an excellent visual display of when phases and steps are scheduled to begin and end, Figure 24-3. Note that over each bar is the name of the individual responsible for that activity, whether the individual does all of the work or not.

Start and keep a *log* of activities and the time spent. Each individual in the group should keep a *log*. Newspaper-style entries, who—where—what—when—why, are useful because they tell specifically what was done. Supervisors use the information for checking progress and for accounting purposes. But more importantly, the phone numbers, names, dates, and facts may be useful on future projects. Instructors use the log information for checking progress and for grading purposes. See Figure 24-4 for a sample log from a student's notebook.

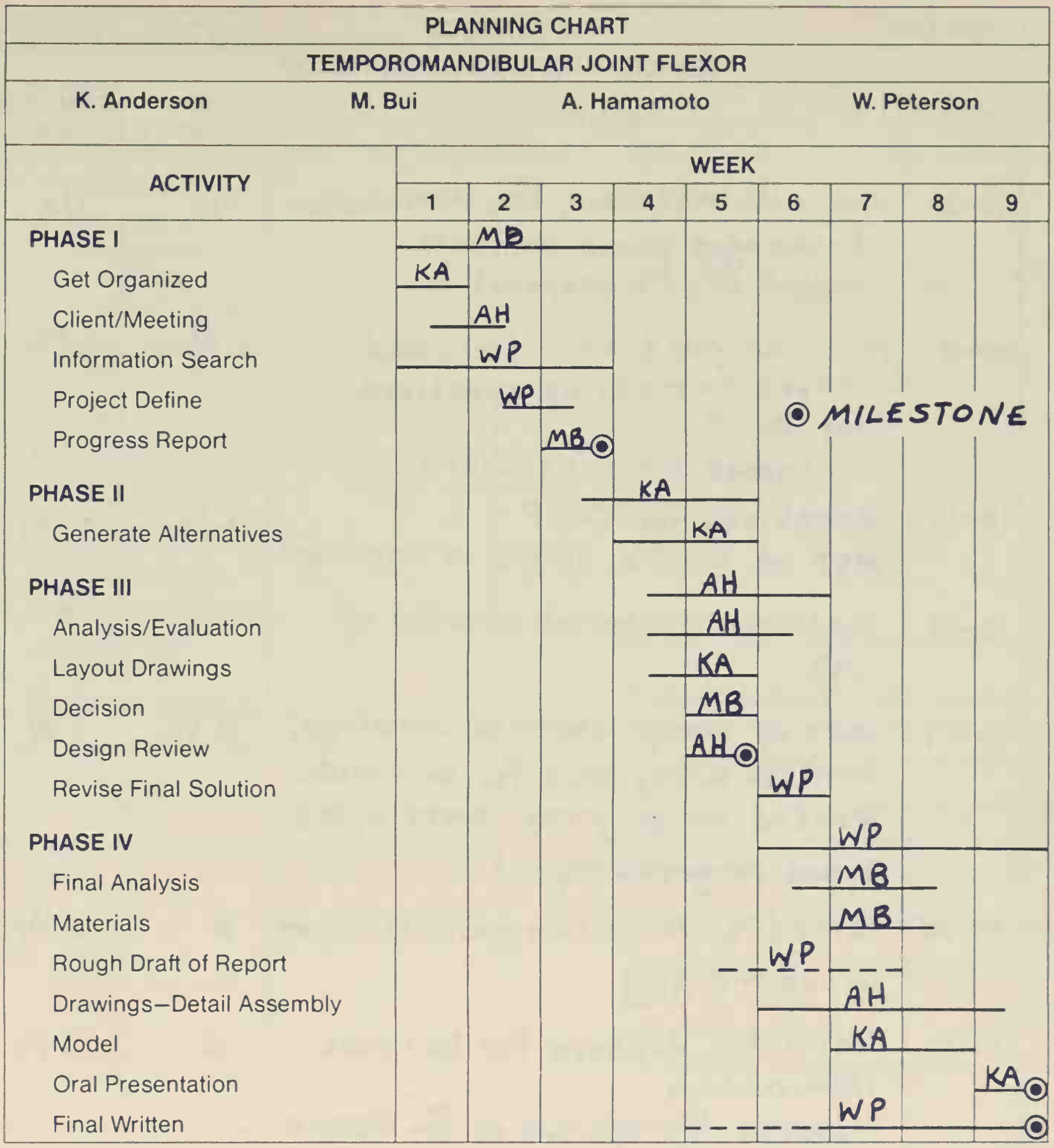


Figure 24-3 Planning chart for student group

Some companies may require selected individuals to keep a more detailed log-design notebook for legal purposes or for patent development. For patent development, each page is bound, numbered, and then arranged to be signed by a knowledgeable witness.

Start a *design file* with every page dated to agree with the log, and file the pages chronologically for easy reference. Each individual keeps a *design file* which includes freehand sketches, machine copies of technical information, copies of related drawings, summaries of telephone conversations and interviews, and vendor brochures. Samples from a student's *design file* are in Figures 24-5, 24-5B, and 24-5C. A group log and file may be required by a supervisor in industry.

Step 2 Gather Information.

a. *Primary Sources.* Contact the source of the problem, who will provide information to establish most of the project's constraints and specifications, verbally or in writing. Later, in STEP 4, confirm any verbal decisions made by the source in a progress report.

Next, review similar products and experiences for information because most designs are actually new combinations of existing ideas.

b. *Secondary Sources.* Investigate secondary sources, which include a variety of people and references. The following checklist can be expanded to fit the needs of specific problems.

TIME LOG	W. PETERSON		
TEMPOROMANDIBULAR JOINT FLEXOR			
DATE	ACTIVITY	TIME HR	CUM. TIME HR
10-2	Met with Anderson, Bui, Hamamoto- -Exchanged phone numbers -Copied Dr. P's proposal	1/2	1/2
10-8	MET - KA MB & AH - discussed proposal - made up questions for Dr. P Discussed planning chart	2 3/4	3 1/4
10-10	Questions for Dr. P MET at Dr. P's OFFICE IN MED SCHOOL	2 1/2	5 3/4
10-15	Discussed electrical circuits w/ MB	1/4	6
10-17	MET w/ group, checked drawings/ Went to hobby shop for solenoids Worked on progress report w/ MB Typed progress report	2 1/4	8 1/4
10-20	Talked to Mike Wieggand re: valves Group meeting	2	10 1/4
10-30	Contacted vendors for bellows information Prepared transparencies for DESIGN REVIEW - worked with Hamamoto	3	13 1/4
11-1	Trip to surplus yard- found plastics	2 1/2	15 3/4

Figure 24-4 Log

People: Shop personnel (machine, structural, electronic, electrical, packaging, shipping, welding . . .)

Practicing professionals: (engineers, lawyers, doctors, technologists, scientists . . .)

City services: (fire, police, waste, utility, library.)

Most helpful for students: (Instructors, Librarians, and Shop Personnel.)

Patents: Note that only 20% of the information in Patents appears elsewhere; that is, 80% is only available in Patents!

References:

Books (textbooks on specific topics):

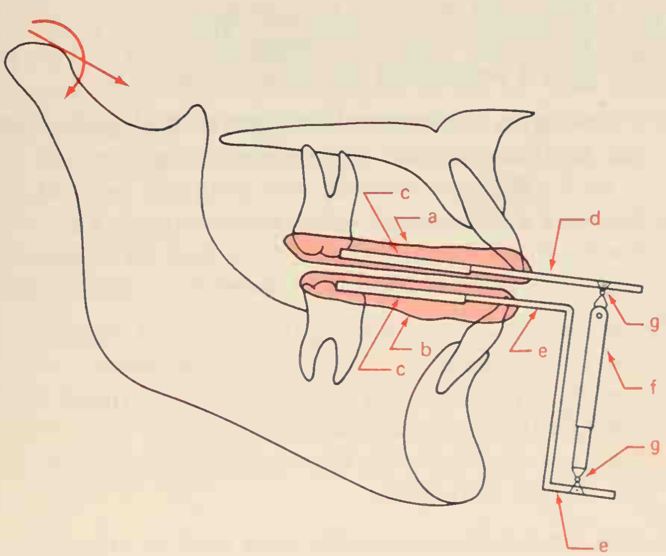
Best listing of references found to date: Kolb, John and Ross, Steven, PRODUCT SAFETY

PRELIMINARY DESIGN CONSIDERATIONS

1. SIZE
2. POWER
   —BELT POWER PACK
   —CHARGER
3. CONTROLS
   —FREQUENCY
   —OPENING
   —PATIENT OR DR.?
4. EXPECTED PRODUCTION
   —REUSABLE?
5. COST
6. MATERIALS
   —STAINLESS
   —PLASTIC
   —FDA RESTRICTIONS
7. NOISE LEVEL
8. FORCES REQUIRED
   —OPENING
   —CLOSING
9. SAFETY OVERRIDE
10. JAW DIMENSIONS
11. ACCURACY

Figure 24-5A File: preliminary design considerations

LATERAL VIEW



a – MAXILLARY ACRYLIC SPLINT
b – MANDIBULAR ACRYLIC SPLINT
c – BUCCAL TUBES
d – UPPER MEMBER
e – LOWER MEMBER
f – PNEUMATIC PISTON
g – UNIVERSAL JOINTS

Figure 24-5B File: information from client

FRONTAL VIEW

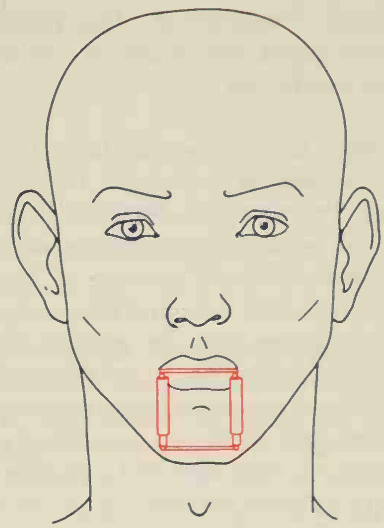


Figure 24-5C File: information from client

AND RELIABILITY, 1980, McGraw-Hill, Inc. (It also contains more than 45 pages of checklists for Designers and Installers.)

Handbooks: Each engineering discipline has a handbook, e.g., aeronautical, chemical, civil, electrical, mechanical, materials . . .

Standards and Codes (a small sampling):

ANSI American National Standards Institute
ASTM American Society for Testing Metals
Mil Military Standard
UL Underwriters Laboratory

Catalogs:

Vendor (products, hardware, electrical, electronic, structural shapes . . .)

Thomas Register (listing of companies, what they make, their address, sample catalogs . . .)

McMaster-Carr Supply Co. (Most complete hardware catalog found to date, P.O. Box 54960, Los Angeles, CA 90054, 213/945-2811.)

Step 3 Combine Information into a Preliminary Definition. Prepare a preliminary definition of the problem so that all parties concerned can see the direction and course of the project. The definition mainly consists of two types of statements, *constraints* and *specifications*. These are written as specifically as possible even at this early stage in the project. For example, a vague specification might say that the product is to be safe to use. A more specific specification would say that the product will be safe to use by a 12-year-old child who can read and understand simple directions, and that the directions will be affixed to the product.

a. *Constraints.* List the more restrictive *constraints*, such as cost, delivery date, availability of materials, codes, and standards. Then, list the less restrictive ones, such as shop capability, available personnel, product life, and aesthetics.

b. *Specifications.* Divide specifications into two main categories, *performance* and *design*. *Performance* specifications describe what the design is to do, what it is to accomplish, what it is to produce, who is to use it, what environment it will operate in, how it will be maintained, how safe it is, and how easy it is to use. *Design* specifications indicate what materials are to be used and how they are to be fabricated and finished. Purchased products also are included.

Well-written specifications are stated so that they can be tested or measured. For example, the chemistry and strength of a material can be measured and tested, respectively. Resistance, frequency, volume, temperature, and weight can all be measured.

c. *Preliminary Solution Ideas.* Collect *preliminary solution ideas* which occur while the definition, constraints, and specifications are being developed and written. File these for use in Phase II.

d. *Iterate.* Return to STEP 2 to gather further information and to revise the definition. Returning and revising is an *iterative* process that occurs continually throughout the design process.

Step 4 *Prepare a Progress Report.* Prepare a *progress report* to the *client* who is usually the primary contact during the project. By now, approximately one-fourth of the project time will have been used, so a report to the client should be made preferably in writing. Include the current definition—constraints and specifications—so that if there are any misunderstandings, they can be resolved early in the project. Decisions made verbally should be summarized. Indicate immediate plans and ask for confirmation as soon as possible. The *client*, a person or an organization, wants to know how the project is progressing and if any problems have arisen.

For the purposes of this discussion, clients are divided into two groups.

a. *Internal Clients* are instructors in classrooms and supervisory persons in industry. And even with this close proximity to the client, important communications should be in writing.

b. *External Clients* comprise a large variety of people and organizations, both in classrooms and in industry. In classroom situations, an *external client* could be another instructor, a student, a department, a design contest, a handicapped person, a rehabilitation department, a local government, or a national organization. In industry, the *external client* could be another company; an individual; a department in a city, state, or national government; the military; or even another nation.

Figure 24-6 shows a sample *progress report* from a student project. A copy was sent to their instructor.

Phase II Generate Alternative Solutions: Synthesis

Step 5 *Generate Solution Ideas.* Review the solution ideas already collected and realize that additional effort and discipline need to be exerted to generate more. Frequently, an idea for a solution occurs early in the process, and there is a tendency—especially among students, because of their time constraints—to select the first idea as the final solution. A successful problem solver knows that more ideas will surface. Use the following techniques to generate additional ideas.

a. *Use Systematic Techniques.* *Verb lists* provide a systematic checklist for generating new ideas, primarily building on existing ones. Ask the following questions regarding an idea being considered:

- Can it be *modified*?
- Can it be made *larger*? *Smaller*?
- Can it be used for *something else*?
- Can other materials be *substituted*?
- Can components be *rearranged*?
- Can it be *combined* with another idea?

Divide an idea into *smaller parts* so that each part can be systematically examined and developed.

Try a *180-degree approach*. For instance, instead of breaking a walnut shell with a hammer, poke a hollow needle inside to explode the shell with air pressure.

List the *obvious attributes* of an object to uncover ideas.

- Describe the size using dimensioned sketches.
- List the intended functions of the object.
- Outline how it was probably manufactured.
- List the materials used to make it.
- Describe any other features, such as aesthetics, weight, and color.

Also list the *not-so-obvious attributes*, such as other uses which were not intended functions.

Figure 24-7 shows the obvious attributes of a paper clip, and the not-so-obvious ones are listed in Figure 24-8.

Browse through *technical texts*, *periodicals*, and *handbooks* that contain numerous ideas for components, mechanisms, and applications of existing products. The partial list that follows includes the three types.

Department of Mechanical Engineering
(School)
(City, State, Zip Code)

Dr.
University Hospital
(City, State, Zip Code)

Dear Dr.,

This letter is to inform you of our design team's progress and decisions regarding your CPM (continuous passive motion) device. We have discussed the design criteria set forth in your proposal and also examined the additional criteria we discussed with you at our last meeting. Presently, we are considering the feasibility of a pneumatic device with an external power pack. We are currently evaluating this concept and its ability to meet the following criteria:

1) Weight: less than 4 oz
2) Accurate and adjustable movement
3) Frequency in the range of 2-3 cycles per minute with a maximum range of 1-4 cycles per minute
4) Device must be safe for use by a 10-year-old and older for 24 hours at a time
5) Operation must be simple (few moving parts and adjustable by anyone who can read and understand simple directions)
6) Low cost (less than $500, including labor and materials)
7) Parts must be readily available (most from local sources)

Based on our pending evaluation of the above, we will pick what we feel is the best design, and prepare a report outlining our choice. Included in the report will be a cost analysis, detail and assembly drawings, and an overall evaluation. This report will be presented to you at a date and time decided by our instructor.

If you have any questions, please contact us through our instructor.

Sincerely,

W. Peterson

K. Anderson

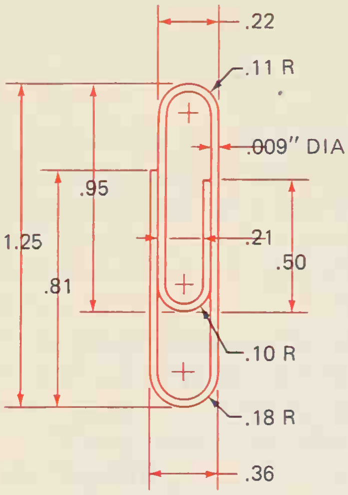
M. Bui

A. Hamamoto

Figure 24-6 Progress report

EXAMPLE OF OBVIOUS ATTRIBUTES

SIZE



FUNCTION
Clip 2 or more papers together with spring action
Reusable

MATERIAL
Steel wire .009" dia, ductile
Copper coated

MANUFACTURED
Coiled wire fed into automatic machine
——cut to length
——bent as shown
——copper coated

OTHER
Easy to attach
Low cost
Simple
Other shapes, but one shown is most common

Figure 24-7 Attributes of a paper clip

Texts:

Herkimer, Herbert, THE ENGINEERS ILLUSTRATED THESAURUS, 1952, Chemical Publishing Co.

Schwartz, Otto B./Grafstein, Paul, PICTORIAL HANDBOOK OF TECHNICAL DEVICES, 1971, Chemical Publishing Co.

McCormick, Ernest J., HUMAN FACTORS ENGINEERING, 1970 McGraw-Hill, Inc.

Chapanis, A., MAN-MACHINE-ENGINEERING, 1965, Wadsworth Publishing Co.

Periodicals (found in most libraries):

Machine Design
Product Engineering
Test and Measurement World
Control Engineering
Medical Product Manufacturing News
Hydraulics and Pneumatics
Research and Development
Engineer's Digest

Handbooks:

Shigley, Joseph E., STANDARD HANDBOOK OF MACHINE DESIGN, 1986, McGraw-Hill, Inc.

Laughner, V.H./Hargan, A.D., HANDBOOK OF FASTENING AND JOINING OF METAL PARTS, 1956, McGraw-Hill, Inc.

Horger, A.J., ASME HANDBOOK METALS ENGINEERING DESIGN, 1965, ASME Publisher

b. *Use Creative Techniques and Attitudes.* A clear understanding of the *creative process* will help to generate ideas. The process—as described by technical people, composers, writers, builders, doctors, hobbiests, and many others—proceeds as follows:

1. *Accumulate* all the information about the problem being attacked; that is, thoroughly and conscientiously get involved in the problem, even emotionally if necessary. This involvement, according to creative individuals, causes the subconscious portion of the brain to be alerted that a problem needs solving. Next, relax and let the information collected . . .

2. *Incubate* with other ideas that the subconscious brain retrieves from memory locations. Take a walk. Jog. Plop both feet upon a desk and lean back while contemplating the ceiling. (Super-

EXAMPLES OF NOT-SO-OBVIOUS ATTRIBUTES	
AS IS	**CHANGE**
—dig out ear wax	—fish hook
—make a chain	—cake tester
—balance for paper airplane	—electrical conductor
—clip other items	—chess pieces
—sinker for fishing	—lock pick
—checkers	—artistic shape
—poker chips	—therapy—bend for relaxing
—hanger for small picture	—melt many to make casting
—standard of weight	—fatigue failure demo

Figure 24-8 Not-so-obvious attributes

visors may need to be informed that the "process" is working.) Soon, one hopes an idea will surface in the conscious portion of the brain: that is, the idea . . .

3. *Illuminates* its presence and causes exclamations like, "Eureka, I've got it!" Finally, the idea needs to be . . .
4. *Verified*. Does it actually solve the problem? Meet the constraints? Satisfy the specifications?

Develop a *creative attitude* and *behavior* by adopting characteristics of creative people. Several are listed here.

1. *Keep an open mind*. Be willing to *accept change* and *new* ideas.
2. *Look for similarities and unusual relationships.*
3. *Think positive. Avoid* or ignore *negative comments* such as: "It's been tried before." "It's not logical." "What a dumb idea." "It'll never work."
4. *Be persistent.*
5. ALWAYS CARRY A NOTEBOOK!!!!!!!!! Ideas come when least expected and may be lost if not recorded.

Build a *simple model* related to the design problem being developed. Building a model, or a prototype, almost always produces new ideas because of the simultaneous involvement of the hands, eyes, and brain, plus the three-dimensional insight.

Do *exercises* to develop imagination, for the same reason that muscles are exercised: for growth and to avoid atrophying. One convenient source of creative exercises is the daily newspaper, which contains word puzzles, crossword puzzles, and picture puzzles.

Read books devoted to developing creativity and try some of their recommendations. Several are:

1. Osborne, A.F., APPLIED IMAGINATION, 1953, Charles Scribners Publisher.
2. Harrisberger, Lee, ENGINEERSMANSHIP, 1966, Brooks/Cole Publishing Co.
3. Adams, James, CONCEPTUAL BLOCKBUSTING, 1974, W.H. Freeman and Co.
4. Gordon, J.J., SYNECTICS, 1961. Harper and Row.
5. Raudsepp, Eugene, CREATIVE GROWTH GAMES, 1977, Jove Publications, Inc.

Brainstorm according to the ideas of Alex Osborne in his APPLIED IMAGINATION. The procedure is simple to follow. Meet with a group who are willing to abide by the following guidelines:

1. Have one person *record ideas* as they are generated, on a surface visible to all participants. New ideas often stem from the visible ones.
2. Agree that *no one is to criticize* any ideas while the brainstorming is in progress, no matter how ridiculous an idea may seem. Frequently, viable ideas stem from less obvious ones.
3. Meet in as *pleasant surroundings* as practical, and include refreshments. Several one-hour sessions produce better results than one long session.
4. Finally, meet to *critique* the ideas for possible solutions.

Brainstorming can also be done individually.

Develop *observation skills* through freehand sketching by looking at a component while imagining how a sketch of the component would be made. Of course, do the sketch if possible! Looking at an object while imagining how a sketch would be made causes the viewer to see more about the object than he or she would if only a casual glance were given. Try sketching assemblies of components, also.

Assume now that a number of design ideas have been generated. The group usually wants to continue in this creative mode because creating is a satisfying activity. However, since *time* controls the schedule, the group needs to move on. Students involved in the design process for the first time reluctantly leave this synthesis phase believing that if they had more *time* they could do a better job. Creative professionals know that they must do the best they can in each phase, in the time available, and then move on to complete their projects within the schedule.

So now is the time to focus on evaluating instead of generating.

Phase III Evaluate Alternative Solution Ideas: Analysis

Step 6 Sift, Combine, and Prepare Solution Ideas for Analysis. *Sift* through all the collected ideas and keep those which seem to have a potential as a part solution or as a complete solution. File the remaining ideas for possible use in the future.

a. *Preliminary Preparation.* Expand each potential idea in more detail. Clarify if possible, vague statements and generalities. Ask each member of the group to develop *preliminary statements* and *sketches* of those of his or her ideas that survived the initial sifting and culling.

Do further research, if needed, to expand the ideas.

b. *Specific Preparation.* Prepare *layout development drawings* of the preliminary sketches. Layout drawings are essentially a designer's freehand sketch redrawn to scale with instruments. Designers use two types, *design development* and *kinematic development* (the latter is used primarily for mechanical products). Schematic layouts, using lines and symbols, but not to scale, are used for electronic circuits, electrical circuits, piping diagrams, routing paths, processing steps, chemical plants, and logic circuits.

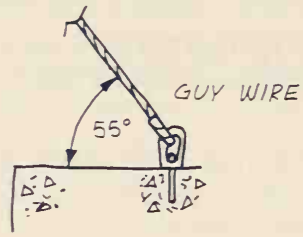
A *design development layout drawing* made from a freehand sketch of a design idea for an anchor bolt puller is shown in Figure 24-9A. The freehand sketch, Figure 24-9B, has complete information of sizes, materials, and functional requirements. The *design development layout* also has the complete information; however, the design idea is drawn to scale. Notes and comments may be in writing or in casual lettering. Compare this informal approach to the formal technical detail and assembly drawings for shop use, which have standard lettering, lines, and symbols made on standard size drawing sheets, complete with title blocks.

Use the design development layouts to establish the locations and sizes of parts to be fabricated so as to ensure the functions of the final product. Also use this layout to verify that purchased products will fit where required.

In industry, designers forward their *design development layout drawings* to drafters who prepare the formal technical detail and assembly drawings. Students in classrooms do both.

A *kinematic development layout drawing* is shown in Figure 24-10. This type of layout shows the relative motions of assembled components, verifies the function of the assembly, checks for interferences, and does velocity plus acceleration analyses. The kinematic analyses are usually done in a two-dimensional format even though the assemblies are, of course, three dimensional.

A useful complement to the *kinematic development layout drawing* is a simple cardboard-thumbtack model, as illustrated in Figure 24-11. CADD systems with programs for kinematic analyses are also useful and available.



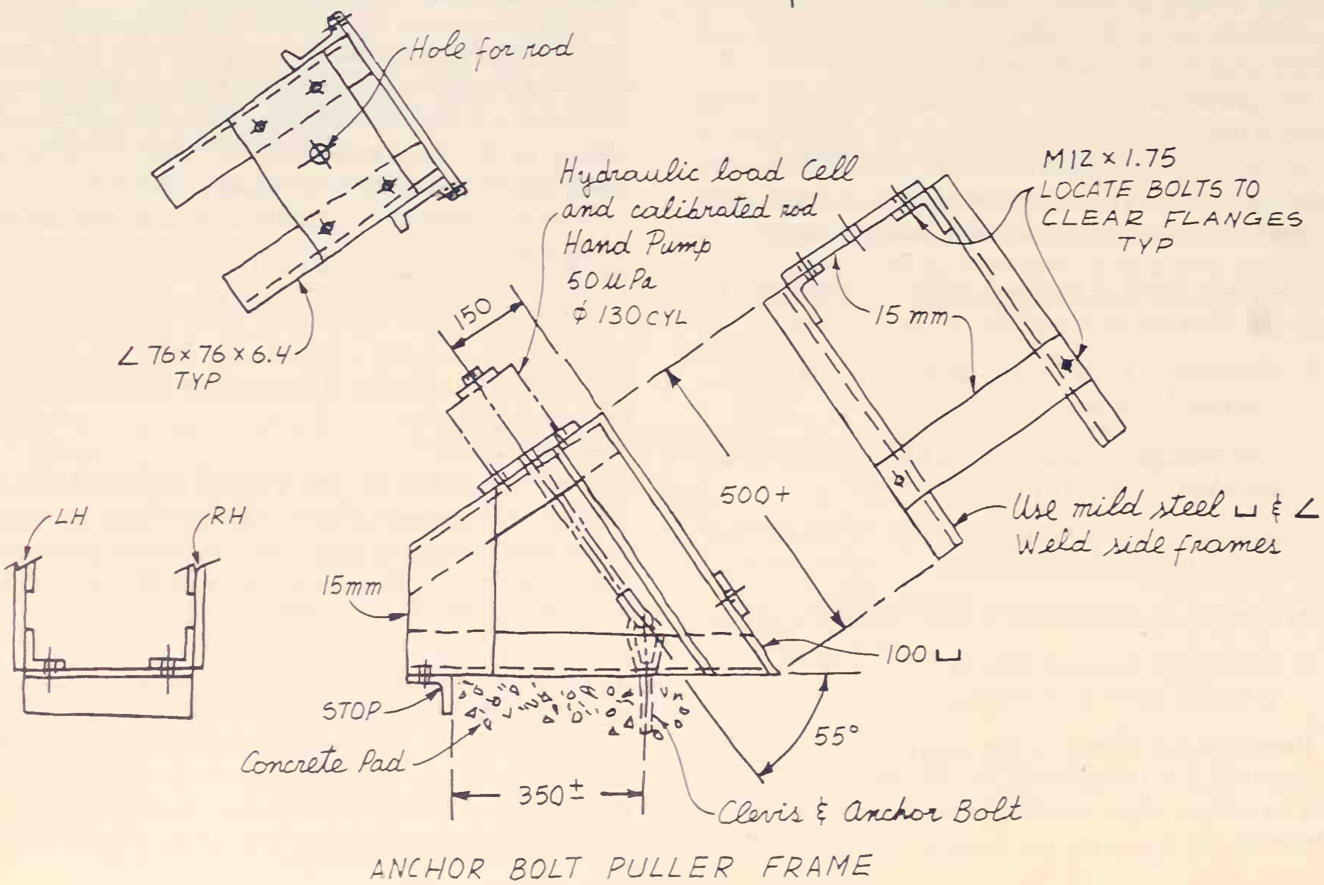


Figure 24-9A Freehand sketch of a design idea

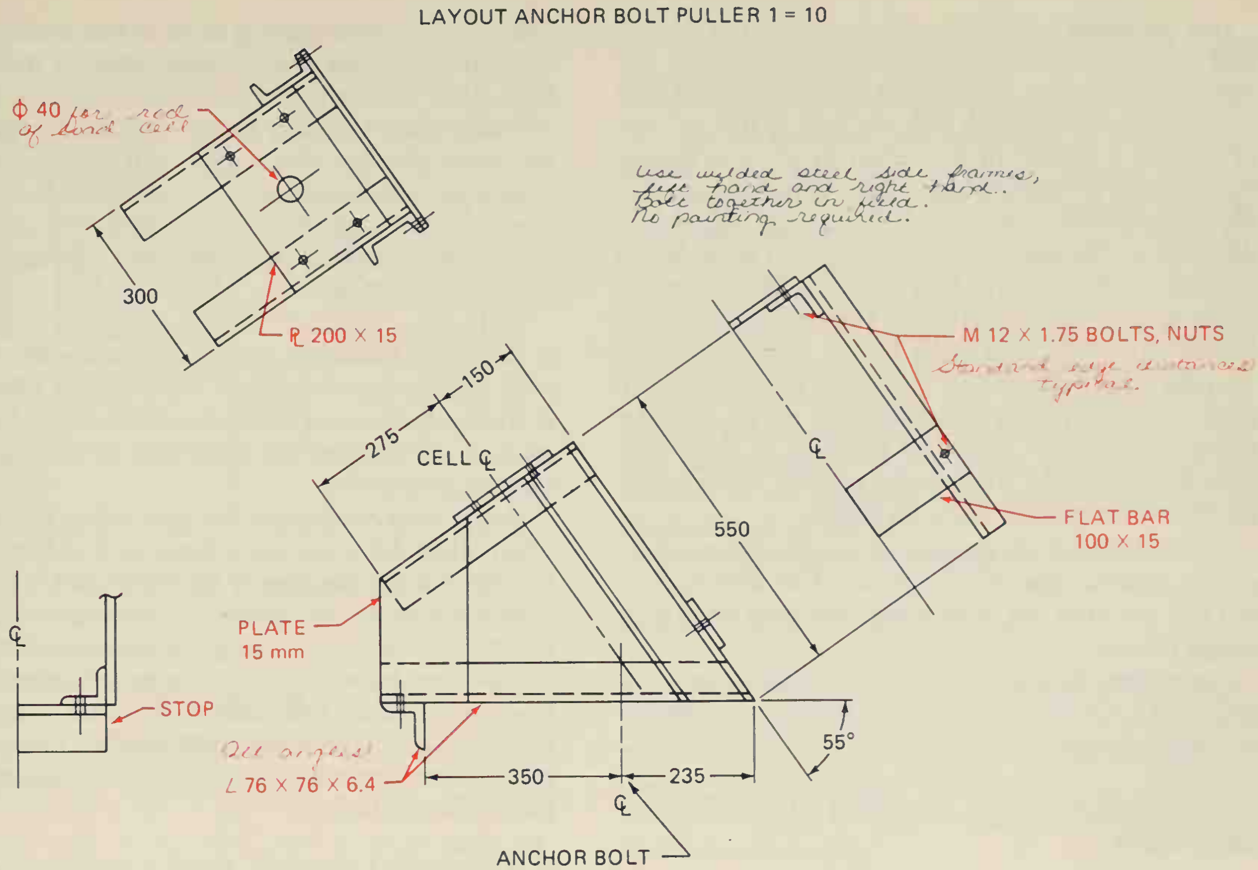


Figure 24-9B Design development layout

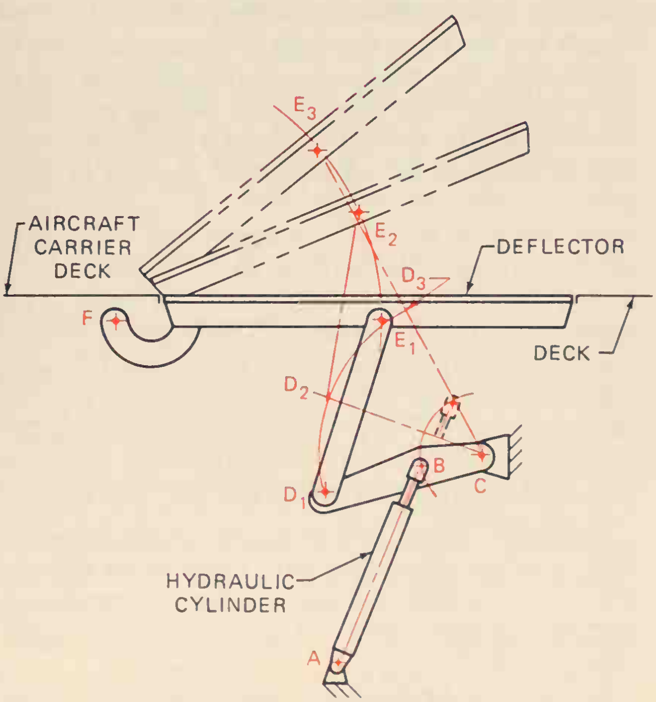


Figure 24-10 Kinematic development layout

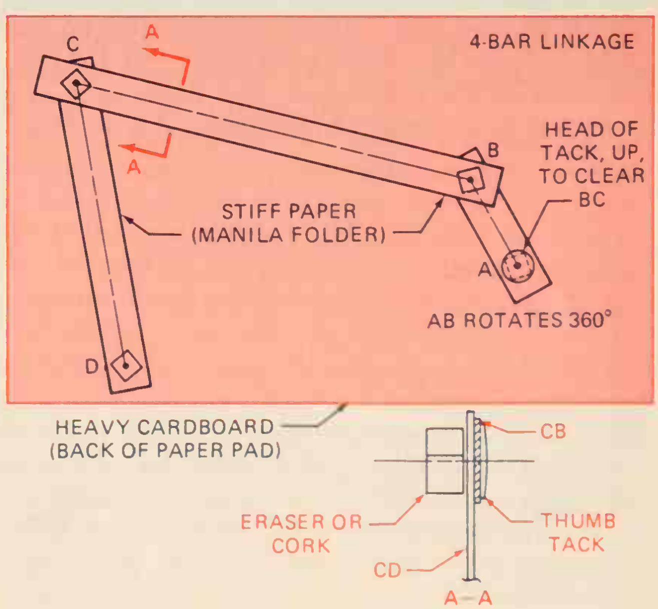


Figure 24-11 Kinematic model

Use "*cardboard and glue" models* (noted earlier) to further complement the layout drawings. Students, designers, drafters and practicing engineers attest that two major phenomenon happen during the process of making a model of a portion or all of a design from a *design development layout*. One, they discover that the components in the three-dimensional model may not work as planned, so adjustments and refinements are required. And two, new solution ideas surface, ideas no one had considered. They believe that the combination of using their hands and eyes while shaping and assembling materials triggers an untapped area in their subconscious mind. Furthermore, since ideas evolve as pictures in the mind, sketching, drawing, and model making seem to enhance the forming of these pictures.

Two additional advantages of cardboard models are the relative low cost (compared to prototypes) and the fact that the model may be used later in a design review.

The *solution ideas* which have been expanded and prepared for further analyses can now be considered as *solution alternatives*.

Step 7 Compare Solution Alternatives to Constraints and Specifications.

a. *Iterate.* Review Phases I and II for possible additions or deletions to the constraints and specifications. New information may have been discovered. The client may want changes made.

b. *Persevere.* Be cognizant of a *morale* problem that may occur at about this time in the design process. Imagine that a group, or an individual, has started a project with high hopes and confidence that a solution can be found. However, even though the first five or six STEPS have been conscientiously done, no real viable solution ideas have been generated. The individual or all the participants find themselves at a low point in the *morale* curve shown in Figure 24-12.

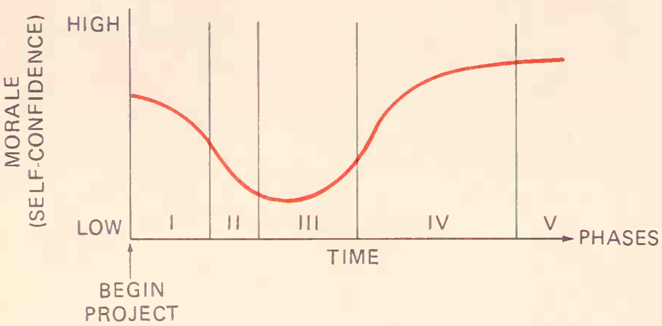


Figure 24-12 Morale curve

They discover that there is more to the problem than they thought, and useful information is difficult to find. They become discouraged. However, experienced problem solvers know that perseverence will get them through the slump, and that satisfactory results eventually will follow. They know that toward the end of Phase IV their morale and self-confidence for attacking problems will be higher than when they started.

c. *Qualitative Evaluation.* Compare solution alternatives with *what-has-been-done-before.* If a solution alternative is similar to existing designs, either within the company or in industry, the feasibility of it is relatively easy to determine.

Use a *range* technique for evaluating preliminary alternatives. Intuition, experience, and judgment help to determine if the size or thickness of a member is within a reasonable range. For example, most students could evaluate design alternatives for home-use ladders, based on their own experiences. Similar *range* approaches have names like *back-of-the-envelope calculations* and *order-of-magnitude analyses.* Interestingly, all of these approaches are useful in designing as well as in evaluating.

d. *Quantitative Evaluations.* Build a *prototype* of part or all of a solution alternative. For example, a student group had the problem of compressing a $2' \times 2' \times 4'$ bale of hay into a $2' \times 2' \times 2'$ cube so that their farmer client could ship more hay per shipload from Seattle, Washington, to a port in northern Alaska. The hay compressor was to be part of a complete hay-baler machine. One key factor that they needed for their design was the force required to compress a bale to half size. So they made a crude, but effective, set of rectangular welded-steel boxes, one to telescope within the other, to hold a bale in a testing machine that could generate up to 60,000 pounds of compressive force. See Figure 24-13 for a conceptual sketch showing the two containers and the bale of hay. The students learned that to compress the bale to half size required 14,000 pounds of force. A hydraulic cylinder was selected to provide the force.

Consider the *feasibility* of each alternative by asking questions such as: How much will it cost? Can the shop make it? Are engineering materials available? Are finished components available? Are sufficient labor hours available? Can the delivery date be met?

Prepare a *decision table* to systematically compare each solution alternative with every other alternative as to how well each one satisfies the constraints and specifications from the definition of the problem in STEP 3.

An example *decision table* is shown in Figure 24-14. Although the example is simple, and was made up for illustration purposes, the procedure is the same

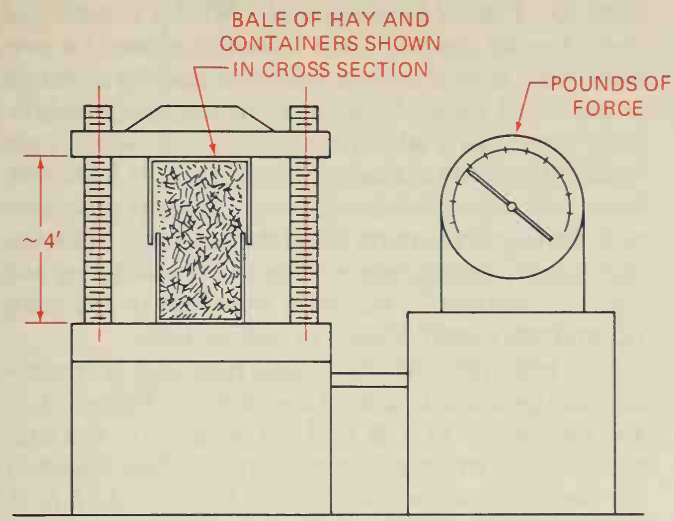


Figure 24-13 Prototype test

DECISION TABLE									
Criteria	Weighting Factor	Walk		Bike		Bus		Car	
$	10	10	100	7	70	6	60	4	40
Protection from weather	7	3	21	2	14	7	49	8	56
Time spent	6	2	12	5	30	4	24	6	36
Safety	3	7	21	6	18	9	27	8	24
Reliability	8	9	72	8	64	6	48	7	56
		226		196		208		212	

Figure 24-14 Decision table

for more complex analyses. The example is based on the question to a class, "Which alternative for transportation to and from school for a distance of five miles (10 miles round trip) is the best one?" The class was asked to create a *decision table* for a quantitative evaluation of four transportation alternatives, walk, bike, bus, and car. First, a list of criteria was generated and tabulated in the left-hand column. Next, each criterion was compared to every other criterion and was given a *weighting factor* for its relative importance according to the students.

The four alternatives then were systematically compared against each other for each criterion. First, the expense criterion was considered. Walking was the least expensive so it rated a score of 10 as compared to a car, which was given a 4. Biking and bussing scored 7 and 6, respectively.

After the four alternatives were compared in relation to each criterion, products of the weighting factors and the scores were totaled for each alternative. Walking scored the highest; therefore, walking would be the alternative to investigate and develop further. The bus and car are close contenders and should also be looked over once more.

To evaluate solution alternatives in a design project, list the *constraints* and *specifications* in the left-hand column and give them weighting factors. Then list the alternatives across the top. Compare and rate every alternative with the others for each constraint and specification. Finally, compute the products of the weighting factors and the alternative scores, total the products for each alternative, and select the alternatives with the higher totals for further study.

Finally, select the best one, realizing that it is the best for the time available, the information collected, and the judgment of the group. Even though it is difficult to do, a *decision* must be made so that the project stays on schedule.

Schedule a *design review* next.

Step 8 Conduct a Design Review.

a. *In-House Design Reviews.* Prepare drawings, transparencies, slides, models and appropriate documents to effectively and efficiently communicate the design solution to the attendees. Also, distribute machine copies of written material or drawings to transmit information.

In a *classroom*, present sufficient information so that the students in other groups will ask thoughtful questions and make helpful comments. The goal of the review is to benefit from the collective expertise of classmates, and to be sure that all facets of the design have been considered.

The instructor may be the only non-student present, as clients usually do not attend. Also, the instructor may schedule more than one design review throughout the project or may have conferences with each group.

During the *design review* have someone record the questions and comments for modifying or reassessing the solution soon afterwards.

An in-house *design review* in *industry* is more comprehensive because, in addition to technical personnel, representatives from accounting, finance, sales, management, manufacturing, shipping, and installation may be present. Furthermore, the design solution discussed may involve a variety of products or an entire complex system.

b. *Outside Design Reviews.* An *outside design review* provides information to the client at a location selected by the client. Often, the main objective of an *outside design review* is to "sell" ideas to a client, whether the client is a private citizen, a private company, or a governmental organization. Companies and governmental organizations publish requests for bids or proposals on a variety of projects, such as aircraft, spacecraft, dams, highways, buildings, chemical processes, electronic devices, electrical systems, power plants, vehicles, military devices, ships, submarines, and numerous products. The bidding individual or proposing organization prepares an *outside design review*, and if the bid or proposal is accepted and a contract is signed, the bidder starts a new *design process* in more detail than the one leading to the *outside review*.

Students may give *outside design reviews* to a client as progress reports; however, most classroom projects require only *in-house design reviews* that lead to the final solution.

Step 9 Refine the Final Solution. Review the questions, comments, and suggestions recorded during the in-house review and decide which ideas to incorporate in design changes or additions. Revise previous steps if necessary; however, time constraints dictate that the next phase should be started soon.

Phase IV Document, Specify, and Communicate the Solution

In classroom projects, Phase IV requires about one-half of the time available. Moreover, most classroom projects end with Phase IV because of limited time, limited shop facilities, and limited funds.

In industry, Phase IV and Phase V overlap, and together they consume approximately one-half of the time available.

Step 10 Prepare Drawings and a Written Report. Use the informal development layout drawings for preparing the formal *technical detail* and *assembly* drawings in standard views, lines, dimensions, and symbols. Only those parts which require shop processes are detailed in *technical drawings*. Parts—such as fasteners, keys, and pins—that do not require shop processes only appear in the parts list of the assembly drawings. Purchased components such as motors, switches, and bearings appear in assembly drawings in the parts list and are usually drawn in outline form.

Four examples of *technical detail* drawings of components to be made in a shop are shown in Figure 24-15 and Figures 24-16 A, B, and C. Figure 24-15 is a subassembly of structural steel parts, welded together for use in the anchor bolt puller. Figures 24-16 A, B, and C show several individual components. Figure 24-17A is an *assembly* drawing with a parts list (Figure 24-17B) for the complete anchor bolt puller. Note, that the subassembly from Figure 24-15 is given only one part number in the assembly drawing parts list.

Technical detail and *assembly* drawings in industry are similar to the anchor bolt puller drawings, but with several differences. Complex drawing-numbering systems tell the user which ones are details, where individual components are used, which ones are assemblies, and which job or contract used the drawings. These systems are as varied as the number and

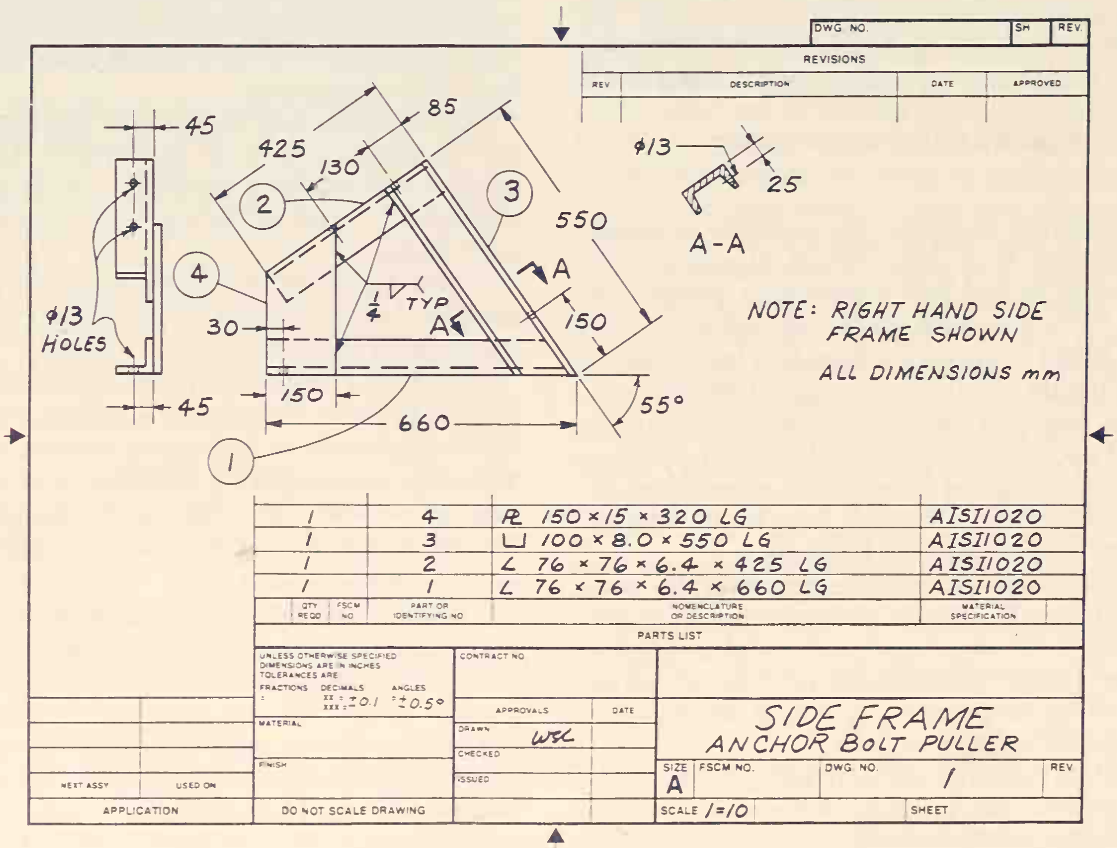


Figure 24-15 Technical detail drawing of sub-assembly

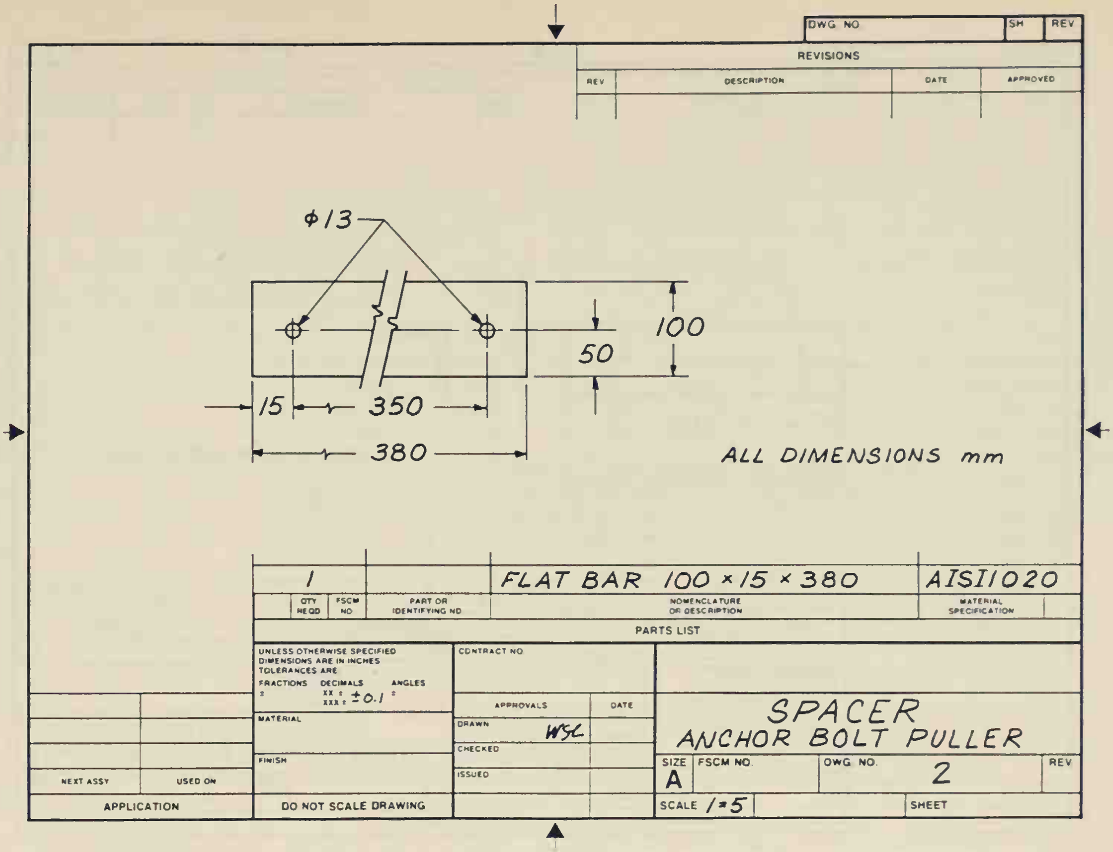


Figure 24-16A Technical detail drawing of a spacer

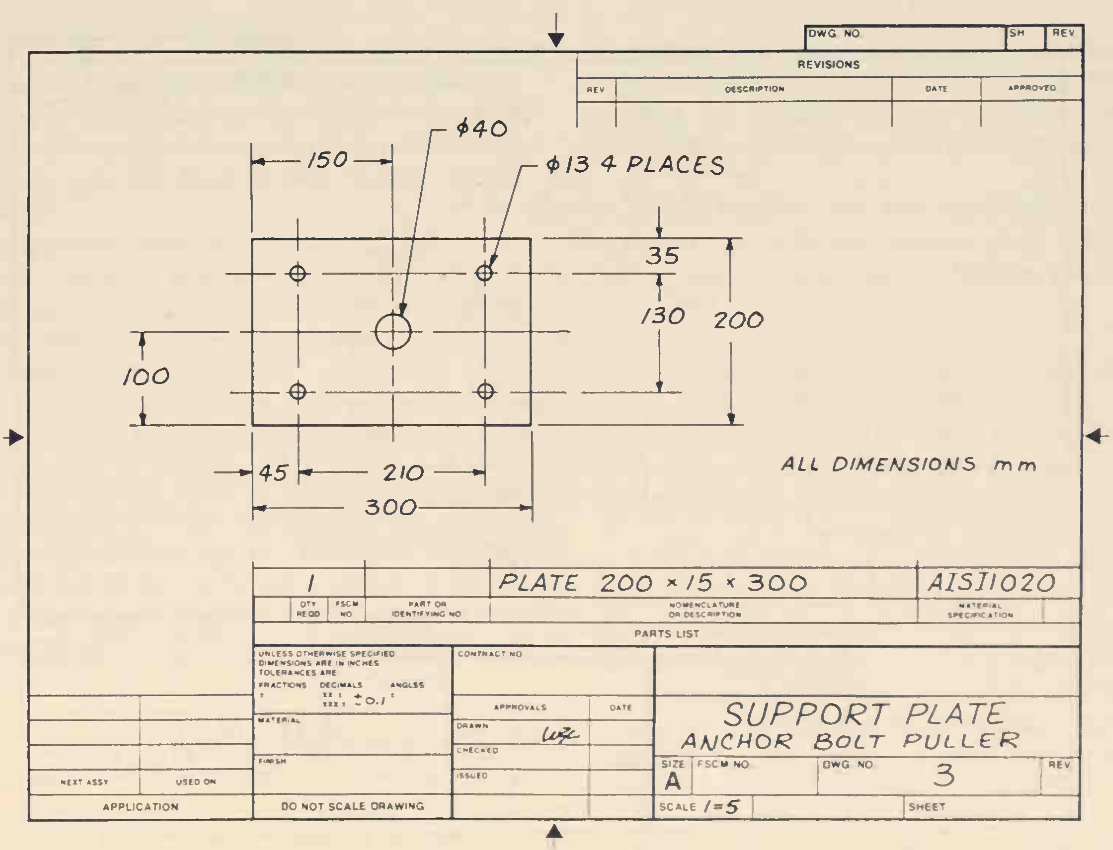


Figure 24-16B Technical detail drawing of a support plate

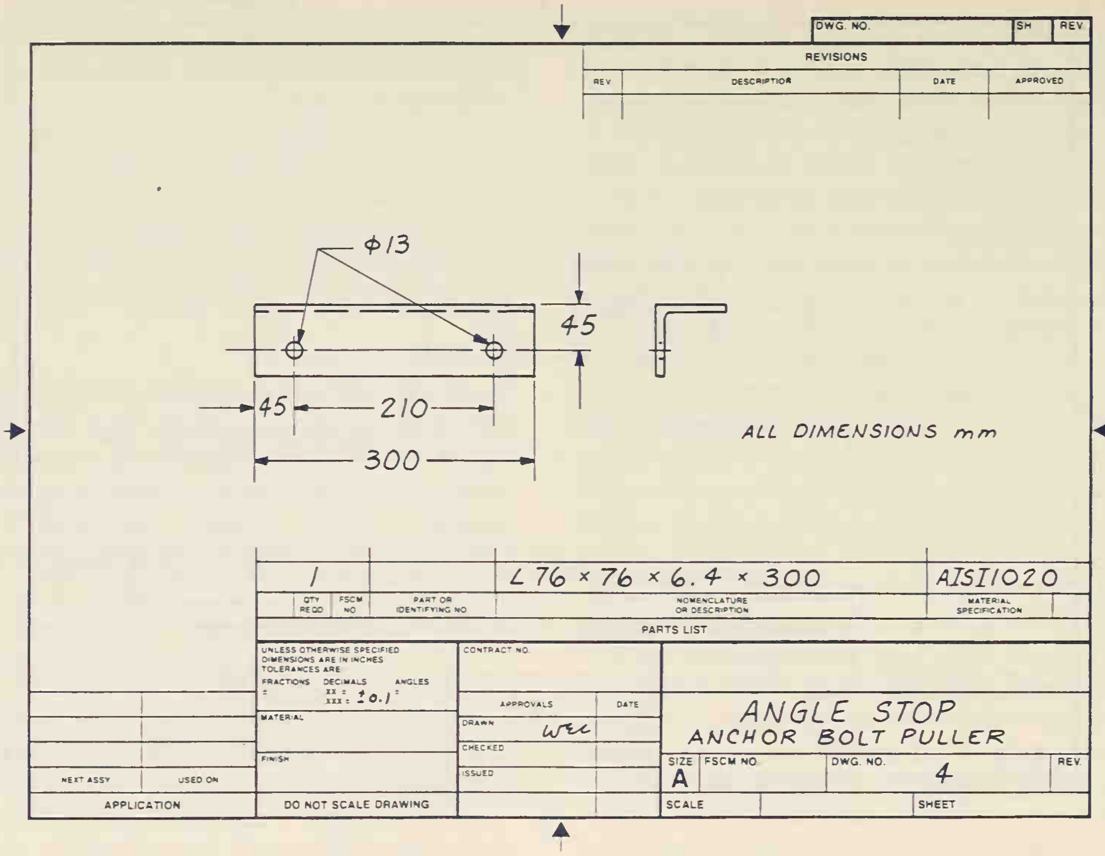


Figure 24-16C Technical detail drawing of an angle stop

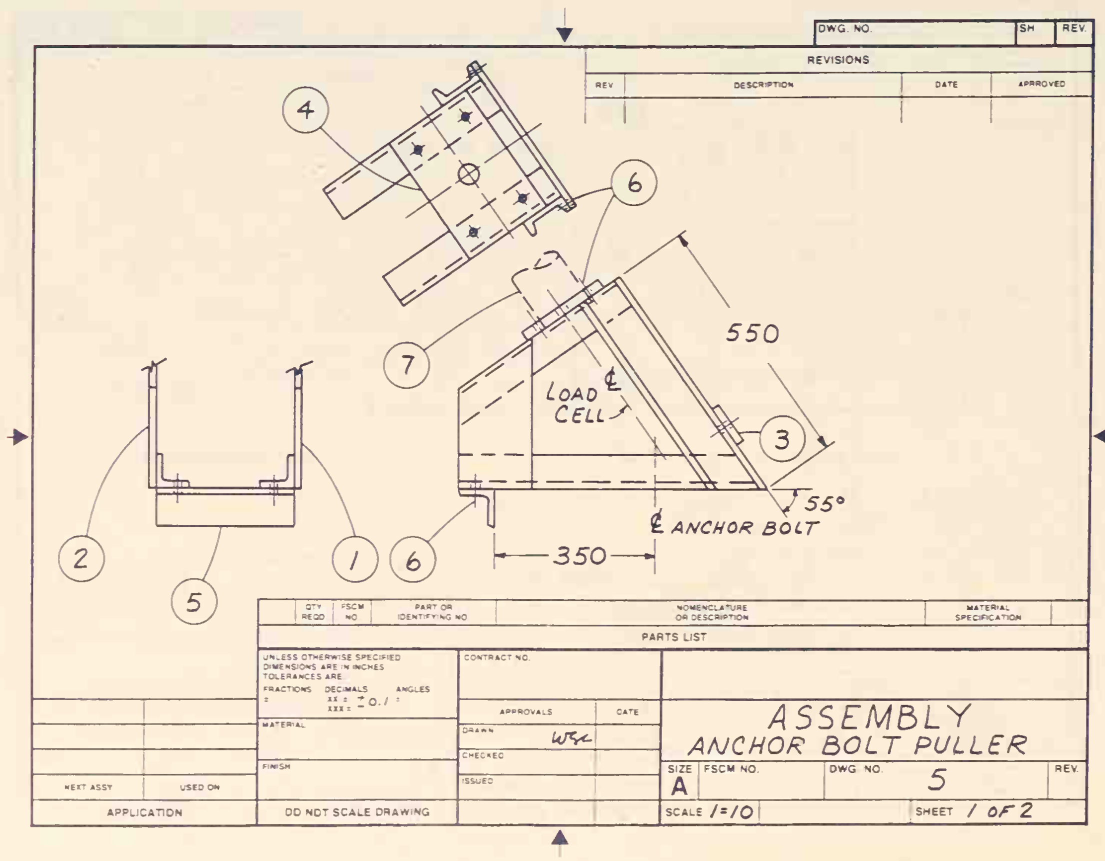


Figure 24-17A Assembly drawing of anchor bolt puller frame

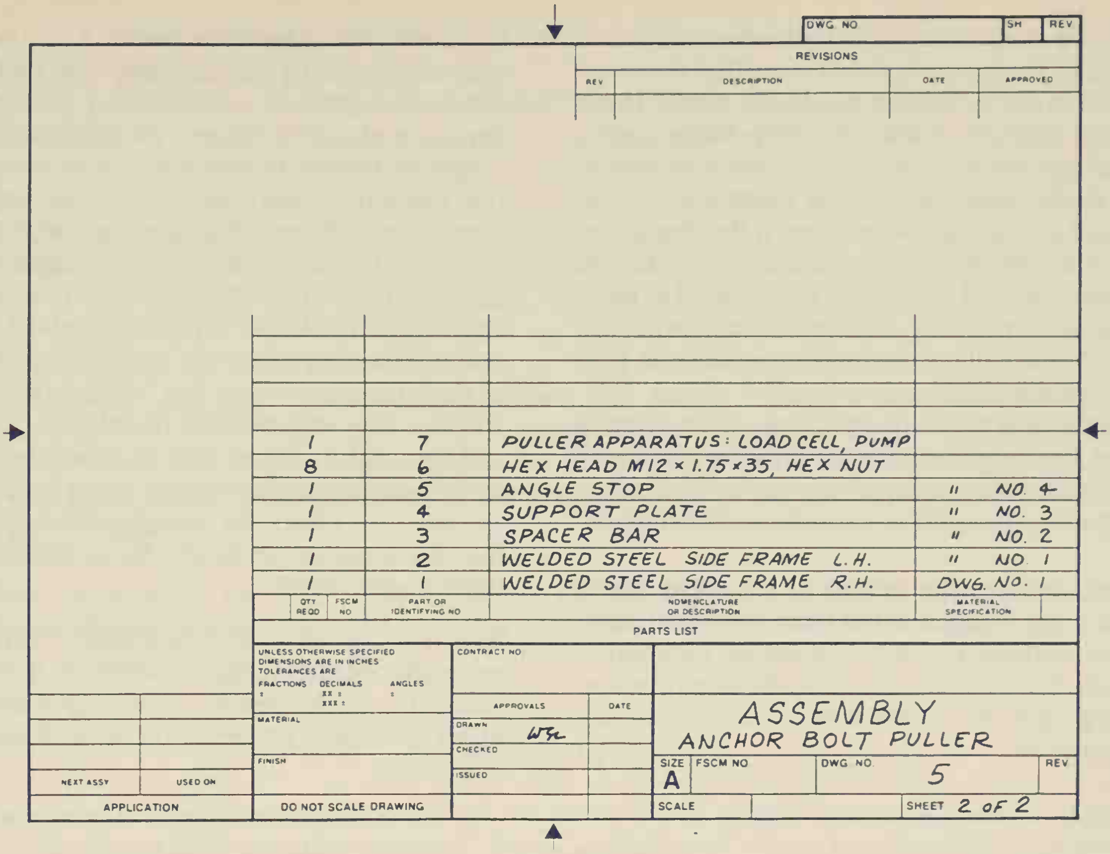


Figure 24-17B Parts list for anchor bolt puller

size of industries and organizations. Usually the drawings are on larger sheets. Also, each individual part needing to be processed in a shop is detailed separately to accommodate accounting procedures and to merge into the flow of information within the company.

Prepare a *written report* for the client. Although each client's needs in a report differ, the parts of reports are similar and all the parts should be included. The order is arranged to suit the information to be communicated.

Use the following discussion as a guide for preparing professional, typed project-reports to clients.

a. *Letter of Transmittal.* A letter to the client, separate from but enclosed with the report, says the project has been completed, the report is enclosed, and that working with the client on future projects is anticipated. Fee statements may be a part of the letter. Include phone number(s) where the client can call for questions, and an address for mailing fees.

b. *Cover.* Enclose the report in a folder, unless otherwise directed.

c. *Title Page.* Include, title, by whom written, to whom submitted, date, and organization (college or company).

d. *Abstract.* Include one or two sentences about the content of the report to capture a potential reader's interest. For product designs, describe the product, specify its performance, and give the cost or price.

e. *Table of Contents.* List the main headings and the subheadings, with appropriate page numbers. List the illustrations, drawings, and tables, plus an appendix if used.

f. *Introduction.* Describe briefly—what, who, when, where, and why—the origin of the project/problem, because even though the client knows this information, other members of the client's organization may read the report.

g. *Solution Description.* A *written* portion should use a liberal number of headings and subheadings, and should describe the final solution, including the performance specifications and the design specifications. List the constraints, costs, materials, and special features. Also include the delivery date. Refer to illustrations, figures, charts, graphs, and drawings for efficient communication.

h. *Analyses.* Summarize the major assumptions and calculations. Place detailed analyses in an appendix.

i. *Costs.* For a classroom project, which usually ends with Phase IV, list the basic direct costs that the client would have to outlay to have the design made. These costs could include, materials, shop labor, and a number of purchased components—such as fasteners, pins, shafts, switches, controls, electronic circuits, motors, and similar hardware. Even if the classroom project continues through Phase V and a prototype is built, the client will most likely be required to reimburse the students only for their actual expenses incurred. The excellent learning experience is payment for the students' labor!

In industry, only the selling price would be given in the report, because the basis for arriving at the selling price (labor rates, material costs, overhead, sales, and profit margin) would be proprietary information.

j. *Drawings.* Include the technical assembly drawings in the main report, and the technical detail drawings in an appendix. *Pictorial* drawings (isometric, oblique, or perspective) may also be appropriate, depending upon the client's technical experience and background.

k. *Illustrations, Figures, Charts,* and *Graphs.* Check the illustrations, figures, charts, and graphs for complete information. Each one should have a legend. In addition, charts and graphs should have clearly marked and labeled axes.

l. *Alternatives.* Convince the client that a thorough investigation was done by the design group by including a brief summary of the alternatives that were considered but discarded. Use partially dimensioned sketches, drawings, and pictorials with appropriate comments as to why the alternatives were not selected.

m. *Recommendations.* Discuss briefly any recommended further developments or investigations that relate to the project. For example, one of the discarded alternatives may have some potential and should be investigated further.

n. *References.* List references and the specific pages that were used. Number the references, and use these numbers in the text of the report.

o. *Appendices.* Place information in the appendices that does not logically fit in the main report. Such information includes extensive calculations, computer printouts (separated, of course), vendor brochures, catalogs, machine copies of reference material, and technical detail drawings.

In industry, when a company or organization wants to "sell" its expertise to clients it includes a roster of individuals, indicating each individual's technical skills, education, and experience. A summary of projects completed by the company may be included.

Selected parts of a final report prepared by students are shown in Figures 24-18 through 24-25.

Written reports in industry include parts similar to the students' report; however, most organizations have an established format for their reports. Furthermore, a number of companies and organizations use computers to store "boiler plate" information that appears in all of their reports. Standard paragraphs and phrases appear at the beginning and at the end of their reports—hence, the "wrap-around" image of a boiler. New material fills the blanks.

Rewrite the report text at least two (2) times, whether a classroom report is being prepared or one in industry!! Check for completeness. Check grammar, punctuation, and style. Avoid clichés. Eliminate unnecessary words.

Step II Give an Oral Presentation. Prepare an *oral presentation* of the design solution to the client. The following guidelines for planning a presentation apply to student presentations as well as those done in industry.

a. For a simple, but effective presentation, first tell the audience what is going to be presented. Then, present the material. Concluding, tell the audience what was presented.

b. Use transparencies on an overhead projector in relatively small classrooms (30 persons) and boardrooms. Cardboard borders for mounting transparencies are useful for notes, key words, and phrases.

c. Use slides in larger rooms, lecture halls, and auditoriums.

d. Make projected words and numbers large enough so everyone can read them. A conservative guide is to make the letters on the screen as high as 1/250 of the distance to the person the farthest away from the screen. Thus a 25-meter distance requires letters on the screen to be 0.1 meter high. Typed material reproduced on transparencies is usually unsatisfactory.

e. Restrict the number of different ideas on a visual to five or less. If more are on the transparency, distribute a copy to the audience beforehand.

f. Use a pointer.

g. Use models large enough to be seen easily.

h. PRACTICE at least once. One or more persons can do the presentation.

i. Allow time for questions.

Department of Mechanical Engineering
(School)
(City, State, Zip Code)

Dr.
University Hospital
(City, State, Zip Code)

Dear Dr.,

This letter is to inform you that we have completed our design for a CPM device to be used in your research project. The enclosed report details the design, giving complete drawings, a cost analysis, and future design considerations. The design is now ready for the prototype stage.

We are pleased to have had the opportunity to work on this project for you, and we hope we will be able to work with you more in the future.

Sincerely,

W. Peterson

K. Anderson

M. Bui

A. Hamamoto

Figure 24-18 Letter of transmittal

DESIGN PROJECT: TEMPOROMANDIBULAR JOINT FLEXOR

SUBMITTED TO: DOCTOR

DEPARTMENT OF ORTHODONTICS
UNIVERSITY MEDICAL SCHOOL
(CITY, STATE, ZIP CODE)
DATE

BY: W. PETERSON
K. ANDERSON
M. BUI
A. HAMAMOTO

ABSTRACT

This report contains a description of a continuous passive motion (CPM) device to exercise the temporomandibular joint (TMJ). Briefly, the design incorporates the use of two compressible bellows that are connected by an air hose. While one of the bellows is compressed at a controlled rate, the other bellows expands at a controlled rate. The system is based on user feedback and provides for excellent emergency override, which is essential for safe use. The device costs less than $200.

Figure 24-19 Title page and abstract

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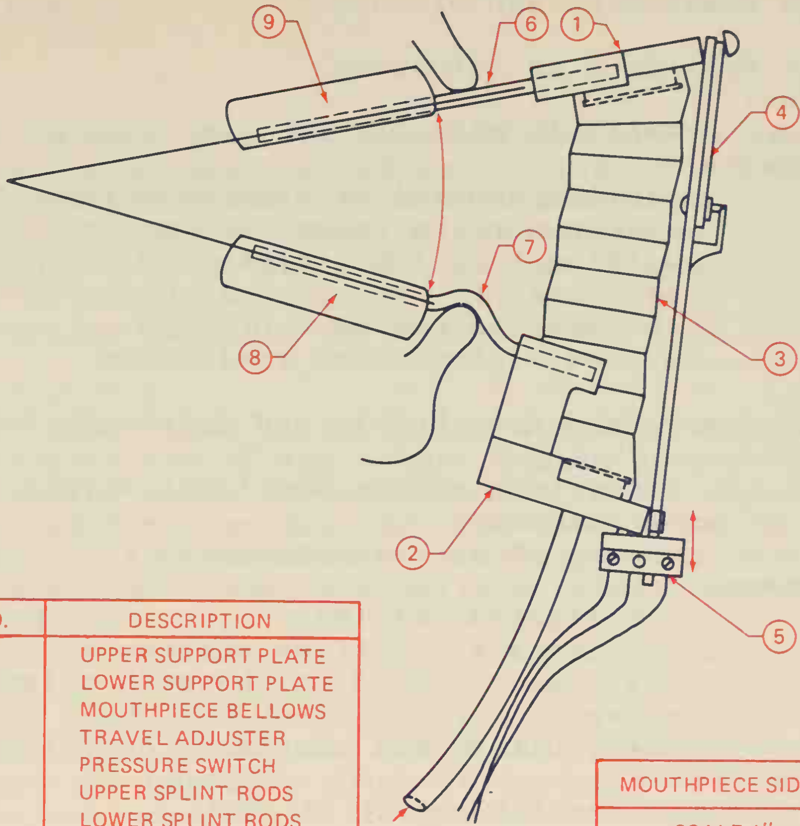
INTRODUCTION

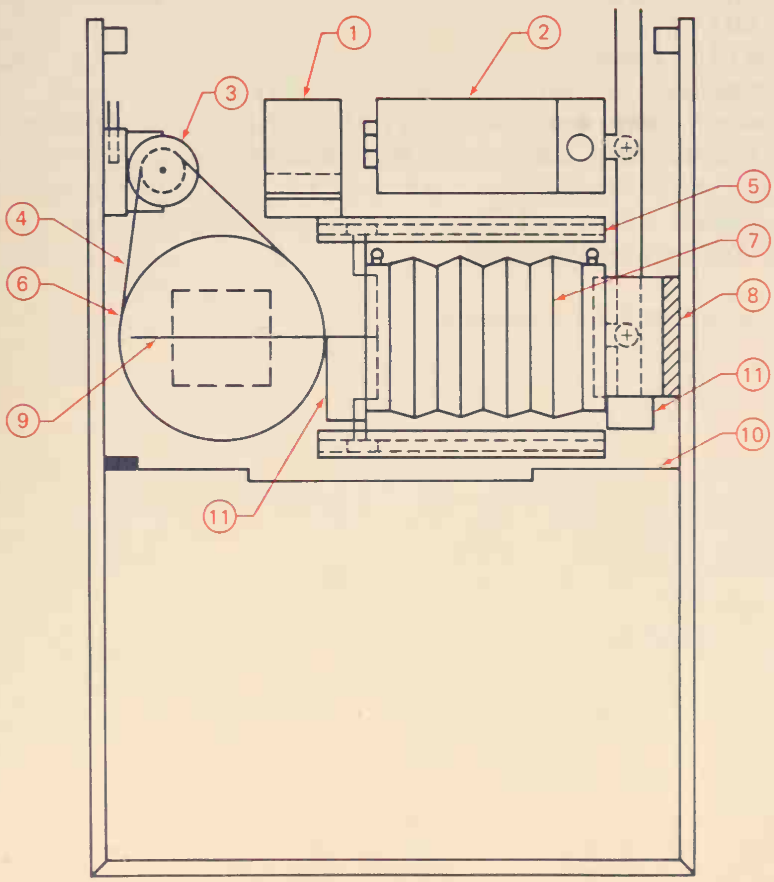
This project stems from a graduate research project in the department of orthodontics. Studies have shown that continuous passive motion (CPM) on joints such as knees, elbows, and fingers have proven to be quite successful in alleviating post-operative pain, swelling, and adhesions. It is the Doctor's hopes as well as ours that a similar application of this research on the temporomandibular joint will prove to be equally successful. Our task was to develop a device that would work the jaw up and down to a controlled distance in a slow cyclic manner and at the same time provide a maximum in safety. It was also necessary to use feedback switches to control the inflating and deflating of a bellows that opened and closed the jaw of the patient so that any irregularities or overwhelming resistance to CPM by the individual (sneezing, coughing, yawning, etc.) will immediately be sensed by the system and the necessary override would be provided automatically.

Figure 24-21 Introduction



COMPONENT NO.	DESCRIPTION
1	UPPER SUPPORT PLATE
2	LOWER SUPPORT PLATE
3	MOUTHPIECE BELLOWS
4	TRAVEL ADJUSTER
5	PRESSURE SWITCH
6	UPPER SPLINT RODS
7	LOWER SPLINT RODS
8	LOWER SPLINT
9	UPPER SPLINT

MOUTHPIECE SIDE VIEW
SCALE 1″ = 1″
DRAWING NO. 1.b.



1	RELAY
2	SOLENOID VALVE
3	MOTOR
4	MIN-E-PITCH CHAIN
5	SLIDER TRACK
6	DRIVE GEAR
7	BELLOWS
8	BELLOWS MOUNT
9	CONNECTING ROD
10	BATTERY
11	PRESSURE SWITCH

Figure 24-22 Power pack assembly sketch

ALTERNATIVES CONSIDERED AND DISCARDED

1. Pneumatic Cylinders as Actuators
   Advantages:
   ...small in size
   Disadvantages:
   ..limited control of expansion rate
   ..higher working pressures, noise
   ..difficult to find stroke and size in standard products
   ..lubrication may be a problem
   ..allows minimal user resistance

2. Source of Compressed Air: Bottle and Intricate Valving
   Advantages:
   ..power pack simple and light-weight
   ..no batteries
   ..volume of air easily varied
   Disadvantages:
   ..complicated valving
   ..supplying air bottles cumbersome
   ..compressor needed to charge bottles
   ..noise
   ..difficult to get emergency override

3. Motor Driven Cam and Linkage
   Advantages:
   ..simple to construct
   Disadvantages:
   ..difficult to interrupt
   ..excessive weight
   ..bulky, physically restrictive
   ..little adjustment
   ..little freedom of jaw movement (patients need rotation, translation, and lateral movements)

Figure 24-23 Alternatives discarded

FINAL RECOMMENDATIONS

ASSUMPTIONS

It is important to note that any state-of-the-art design is subject to change since so many variables, having no cut and dry answers, must be dealt with, and values must sometimes be assumed using good engineering judgment. Some of the variables in this design project include average mouth dimensions, forces to open and close the jaw, allowable weights for the mouthpiece and powerpack, influence of an oversize solenoid valve on battery life, and so on.

PROTOTYPE

The presence of these types of variables strongly implies a need for prototype testing to see if the actual design concept is valid. A second type of testing might be called human factor testing, which involves sizing and comfort factors. Are the dimensions on the mouthpiece satisfactory to accommodate an average-size person? Is the size of the powerpack cumbersome? Are weights unbearable? Are jaw movements restricted?

SOLENOID

It was previously mentioned that the specific solenoid valve was oversized. At this point in time the valve is the smallest one made. Because of its power consumption, which is excessive (7 watts max), the battery must be extraordinarily large. It is hoped that eventually a smaller solenoid valve could be purchased or even designed to be much more economical. This could drastically increase battery life and decrease battery size, ultimately decreasing the size of the powerpack.

CNC LATHE

From a manufacturing viewpoint it is recommended that the prototype have all its plastic parts machined on the CNC lathe, since molds are expensive as used in injection molding. However, if the device is ever mass produced, it is recommended that injection molding be the way to go, since production would be much faster, decreasing labor costs per unit.

Figure 24-24 Final recommendations

APPENDIX NO. 1

DELRIN

The material chosen to use for the mouthpiece is Delrin. Delrin is a trade name for an acetal homopolymer. It was chosen because it has many desirable characteristics. Some of the advantages of Delrin are:

1) Good chemical resistance, especially to organic compounds

2) Desired regulatory status:
   a) FDA approved for intermittent contact with aqueous or alcohol-based foods
   b) USDA approved for meat and blood

3) Can be machined like soft brass

4) Can be welded or adhesively bonded

5) Forms good mechanical joints

6) Has good structural integrity

7) Tensile strength (at break) 9700 psi

8) Yield strength 9500-1200 psi

9) High impact resistance

10) Rockwell hardness 92-94

Figure 24-25A Appendix: Material

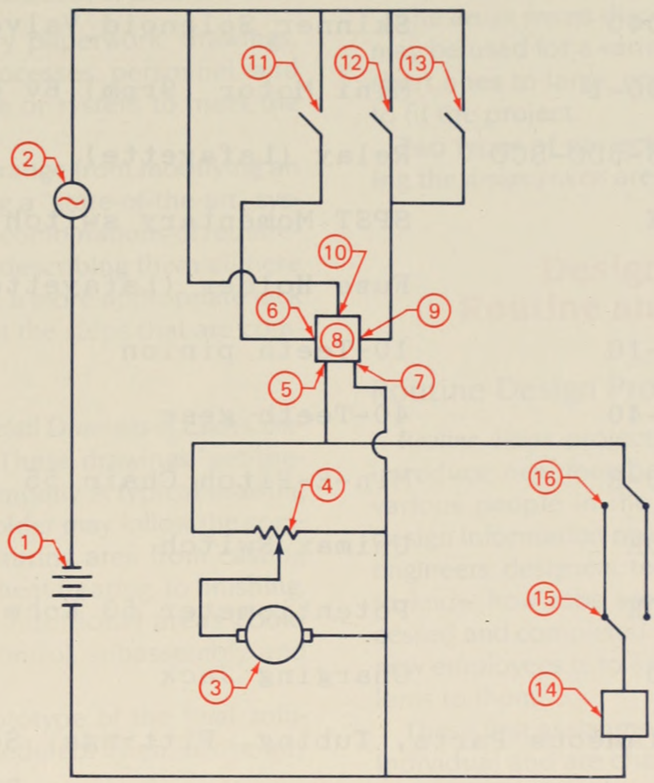


Figure 24-25B Appendix: Electrical schematic

QUANTITY	PART NO.	DESCRIPTION	COST
1	NP8-6	Yuasa Battery	$29.55
1	BC-3B	Yuasa Charger	$5.39
1	B11DK 040	Skinner Solenoid Valve	$33.00
1	1615 900-1	Mini Motor (9rpm) 6v DC	$50.00
1	Rel CY6-5DC-SCO	Relay (Lafayette)	$4.88
2	80511-E	SPST Momentary switch (Lafayette)	$2.94
1	ZC-10B	Fuse Holder (Lafayette)	$1.20
1	3MP10A-10	10-Teeth pinion	$6.34
1	3MP10A-40	40-Teeth gear	$8.59
1	3CCF-50-E	Min-E-Pitch Chain 55 link	$3.24
1	E-62-10K	Unimax Switch	$3.08
1	4PTN-50K	Potentiometer 50 Kohm	$1.98
1	CH3-R10	Charging Jack	$2.99
	Miscellaneous Parts, Tubing, Fittings, Screws		$30.00
		TOTAL	$183.18

Figure 24-25C Appendix: Costs

In industry, a final *oral presentation* made to a client at the end of Phase IV would be done by a consulting-type firm whose final "product" consists of engineering drawings and a written report.

Phase V Develop, Manufacture, and Deliver

Arrange for the necessary paperwork, drawings, materials manufacturing processes, personnel, and funds to develop the device or system to meet the client's requirements.

These requirements may range from modifying an existing device to producing a "state-of-the-art" system. Thousands of different combinations of requirements occur in industry, so describing them all here is impractical. Consequently, a more appropriate tack for this chapter is to present the steps that are common to most industries.

Step 12 Prepare Technical Detail Drawings of Each Component to Be Manufactured. These drawings "get-the-wheels-turning" within a company. A typical drawing enclosed in a clear-plastic folder may follow the component through a manufacturing area from casting or forging, to machining, to heat treating, to finishing, to assembly and delivery. Additional areas could include checking, quality control, subassembly, and temporary storage.

Construct and test a prototype of the final solution if a prototype was scheduled. Then, revise any part of the design as needed.

Step 13 Schedule Assembly, Final Testing, Packaging, and Delivery. Plan the final processes prior to sending the product to the client. Compare appropriate subassemblies and complete assemblies with the specifications, particularly performance specifications. For example, an electronic device may be tested in a variety of environments before being released for shipment.

Design packaging and shipping containers so that the product will survive shipping without damage. Some devices and assemblies must endure more severe loading enroute than after being installed—for example, large frames, large cylindrical-shaped housings, and pressure vessels.

Write maintenance and service manuals to help prolong the life of the product. Provide instructions for proper and safe use of the product.

Step 14 Keep Records. Document and file all aspects of the product's development and use. Record the sources and quality of materials used. File the detail and assembly drawings. Summarize the manufacturing processes, and prototype testing results. Add feedback comments from the client. Request cost, accounting, purchasing and related records from appropriate personnel.

These records are useful for future use if the client wants replacement parts or another complete product. Also, other customers may purchase the product.

But more importantly, keep good records and documentation in case the product becomes involved in a product liability suit.

The *design process* discussed in the preceding pages may be used for a variety of projects, from relatively short ones to large, complex ones. Adapt the *process* to fit the project.

Two types of projects for students who are learning the *design process* are discussed next.

Design Projects: Routine and Non-Routine

Routine Design Problems

Routine design projects and problems are used to introduce new members of an organization to the various people in the company and to the routes design information needs to flow through. Beginning engineers, designers, technologists, and drafters need to know how jobs are initiated, documented, processed and completed. An effective way to start these new employees is to assign *routine* projects and problems to them.

These first assignments usually are assigned to an individual and are characterized as follows:

a. The problem may be a modification to an existing product line, a change in the company's plant facilities, or just a drawing change.

b. The problem difficulty matches the individual's abilities and skills.

c. Information is communicated in a memorandum in a typical industrial format, such as an ECO (engineering change order) or an EDO (engineering design order).

d. Requirements are clearly stated and the information is nearly complete; however, some new data may be needed.

e. An analysis may be required.

f. For guidance, there are similar designs, knowledgeable colleagues, the company library, and vendor catalogs.

g. Technical drawings are required; they become part of the documentation of the modification or change.

h. Labor and materials costs are always present.

i. A condensed *design process* is followed; however, all the essential steps are followed, including *planning*, keeping a *log*, keeping a *file*, understanding the problem, *synthesis, analysis, comparing* alternatives, *reviewing* designs with supervisors, *documenting* the project in *drawings* and *text, manufacturing, assembly* and *installation.*

An example first assignment that a newly graduated engineering student received in an EDO was to design a support for a tank containing a liquid for a paper-making process. But before resolving the technical parts of the support, the new engineer, escorted by the chief engineer, was introduced to personnel in drafting, purchasing, the shop, and the paper-making area where the tank was to be installed. Further introductions included individuals in general supplies, copy service, and even those who made coffee.

The technical challenges involved load calculations, sizing beams and columns, and, finally, making a *design development layout* drawing. The chief engineer was consulted before the layout was handed to a drafter. The drafter questioned a few items and then produced *technical detail drawings* plus an *assembly* drawing.

The new engineer checked, approved, and signed the drawings. Then he followed them through the shop and ultimately used the drawings at the installation site.

The last step was to document the project. The drawings and vendor information were filed. A short written report summarized the need for the tank support, and a copy of the EDO was included. Cost information from the accounting department completed the file.

Non-Routine Design Problems

Non-routine design problems are assigned to experienced engineers, designers, technologists, and drafters—their complexity and level of difficulty in direct proportion to the experience, skills, and ability of the recipients. Usually a team of technical personnel attack *non-routine design* problems.

Non-routine design problems are characterized as follows:

a. The problem originates outside the company, and it stems from the needs of a client who may be an individual, another company, or a governmental organization.

b. A team of individuals with diverse backgrounds or a group with similar backgrounds is formed, depending on the experience, skills, and abilities required.

c. The problem, not clearly defined, must be researched thoroughly so that constraints and specifications can be written.

d. A complete *design process*, phases and steps, is required, from the initial planning to the final delivery and installation. More alternatives are generated than for routine problems, and, therefore, more decisions are made.

e. The projects require a longer time span than routine projects.

f. Detailed planning is required for personnel assignments and hours, materials procuring, budget allocations, production processes, and delivery/installation.

g. More engineering *trade-offs* occur. A *trade-off* is a compromise, usually between costs and materials. For example, an expensive material (titanium) may cost more but weigh less than a less costly material (aluminum) that weighs more.

Since *non-routine design* problems vary as widely as the number and size of the sources (individuals to organizations), there are no typical non-routine problems. However, the manner in which they are attacked —*the design process*—is typical. Therefore, follow the phases and steps presented in this chapter to obtain an insight into the efficacy of this process. Then design your own *design process* as needed.

Design Hints

Use *design hints* during all phases of the *design process* as extensions to the design hints already included. These *design hints* help in initial designing and become checklists as the project progresses. Keep a file during design problem experiences to expand these lists, and remember: CARRY A NOTEBOOK AT ALL TIMES!!!

Attribute Listing for Checking Drawings. Use the technique of *attribute listing* as a systematic guide for checking the completeness of technical detail drawings. For example, ask the following questions:

a. What is the *function*? The function dictates the dimensioning plan.

b. What *size* is it? Are all geometrical shapes dimensioned? Are all the features located?

c. What materials are used?

d. Can it be made? How will it be manufactured? What processes will be used?

e. What other facets need to be checked? Surface finish? Weight? Vibration? Safety? Aesthetics?

"Rules of Thumb". Use *"rules of thumb,"* practical guides based on experience, to establish or check "ballpark" (within + or −10%) quantities. Use them as qualitative checks.

a. *Tolerance.* As a beginning problem solver in technical fields, keep in mind that the tighter the tolerance on the dimensions of an object, the more the object costs. Tolerances should only be as tight (small) as needed to ensure the function of the part. Use as a conceptual reference the thickness of the paper this sentence is written on: It is .003" to .004" or .008 mm to .010 mm thick. Most machinists and machines can easily work to .001", but .0001" takes more time, and so forth.

b. *Rigidity.* "When in doubt make it stout." This statement is just a reminder that not all designs need to be based on an extensive stress analysis and strength of a material. Rigidity and accurate locations may be more important than strength. For example, a surveyor's transit needs to be rigid to keep the lenses aligned. Instrument panels need to be rigid to support the dials and meters, and to prevent vibration. Another practical application of the statement refers to sizing members when budgets are low. That is, a brief stress analysis producing a conservative size (stout) is less expensive than an extensive analysis and a more exact size.

c. *Murphy's Law.* "If an event can happen, it will." Use this guide to evaluate how a designed part or assembly might behave. A more important application is to ask, "How could someone misuse the part or assembly?"

d. *Weld Size.* Fillet and butt welds constitute approximately 85% of all welds used in industry. And if the thinnest cross-section dimension of the weld is at least as thick as the thinnest member joined, the weld will be as strong as the members, assuming that the weld is done by a skilled welder.

e. *Threads.* The depth of threads for steel threaded fasteners should be equal to the diameter of the fastener. Use 1.5 to 2.0 times the diameter for the depth of threads for nonferous threaded fasteners.

f. *Intuitive Ranges.* Early in a design, establish sizes by asking what would be a reasonable range for this size? Establish performance, weights, and function in a similar manner. During an analysis, ask questions such as: Is this a reasonable size? Weight? Function? Performance?

Human Factors. There are published tabulations of body dimensions of average males, females, and children. This statistical data may be found in textbooks and handbooks; however, for classroom designs use a classmate or yourself for measurements, since most of the adult population is close to the average size. Use children if needed.

For a design file, observe or measure objects designed for average humans. Typical designs include chairs, tables, desks, computer stations, work counters, door knobs, ladder rungs, switches, handles, and numerous objects encountered daily.

Also, consider and observe the various techniques that are used to "interface" machines with human operators. A variety of sounds such as voices speaking messages, a number of visual devices using a multitude of colors, numerous tactile devices such as clicks during dialing, and different shapes of knobs are all used.

Manufacturing Process Costs. The following sample list is headed by the least costly and ends with the more costly manufacturing process. Costs are also related to the roughness of the surfaces of the materials. The roughness is a result of the manufacturing or production processes.

Sawing	Rough Surfaces
Cutting (torch)	(lower cost)
Drilling	
Turning	
Punching	
Milling	Average Surface Roughness
Reaming	(Average Cost)
Broaching	
Grinding	
Polishing	
Honing	
Lapping	Smooth Surface
	(Higher Cost)

Relative Costs of Materials. Use relative cost numbers as an aid to evaluating the feasibility of a design alternative, and for establishing approximate costs. Mild steel is given a factor of 1.00; all other engineering materials are given relative numbers. Find the current cost of mild steel, and use the relative numbers to establish costs of the other materials. Revise the numbers as needed.

Material	Relative Cost (By Weight)
Mild steel	1.00
Spring steel	2.00
Tool steel	11.00
Cast iron	3.00
Aluminum	6.00
Stainless steel	7.00
Brass	7.00
Copper	7.50
Titanium	130.00
Teflon	67.00
Nylon	19.00
Rubber	4.00
Wood	1.00

Filing System. Create a design file that uses an alphabetical-numerical cross referencing system for efficient retrieval of design information.

a. The alphabetical part includes the subjects and their numerical references. For example:

A	Aluminum	111.2
	Angles	112.4
B	Bar Stock	121.1
C	Casting	230
	Ceramics	112.1

b. The numerical file contains the numbered folders in a file cabinet. For example:

100	Engineering Materials
110	Categories
111	Metals
111.1	Ferrous Based
111.2	Aluminum
112	Non-Metals
112.1	Ceramics
112.2	Plastics
120	Shapes
121	Rounds
122	Flats
123	Plate
124	Angles
200	Manufacturing
300	Mechanical Designs
400	Power Transmission
500	Electrical
600	Electronic
700	Hydraulic Power
800	Pneumatic Power
900	Codes and Standards
etc.	

Create new categories and subcategories as needed.

Vendor Catalogs. Vendors provide customers with convenient guides to select products and materials from their catalogs.

a. *Machine Elements* such as V-Belt drives, ball and roller bearings, roller chain drives, clutches, brakes, couplings, gearmotors (motor and gear reduction box as one unit), shafting, motors (AC and DC), and controls, all have similar guidelines for selecting them. These guidelines include formulas, tables, and charts to convert most customer applications and environmental conditions to numbers or letters in their catalogs.

For example, assume that the belt conveyor shown in Figure 24-26 needs a roller chain drive to transmit power from the gearmotor's 200 RPM output shaft to the headshaft of the conveyor. Calculations indicate 14 horsepower to operate the conveyor at 500 FPM (feet per minute).

The roller chain drive, sprockets and chain, can be selected from a vendor's catalog using the tables in Figures 24-27 A-E. Figure 24-27A contains general guidelines for selecting and applying roller chain drives. To select a roller chain drive, follow the five steps in Figure 24-27B. The first step determines the service factor to be 1.25, as indicated in Figure 24-27C, asuming heavy duty, not uniformly fed and operating less than 10 hours per day. Step two says that the design horsepower is the calculated horsepower times the service factor, (14) (1.25) = 17.5. The third step is to use the design horsepower in the selection table in Figure 24-27B to determine chain size. Chain size No. 120 with a 17-tooth smaller sprocket will work. The next step (using Figure 24-27D)

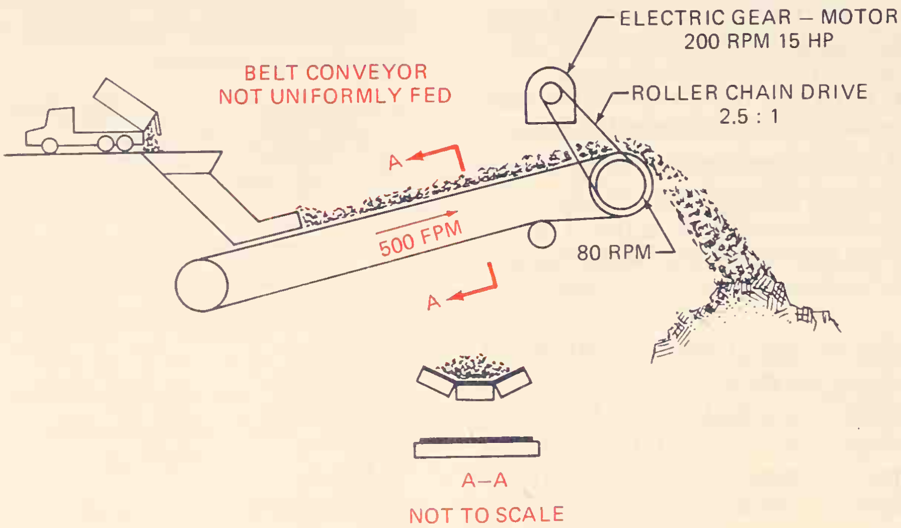


Figure 24-26 Belt conveyor system schematic

indicates that an 11-tooth smaller sprocket will theoretically work; however, good practice dictates the use of a 17-tooth sprocket according to comments in Figure 24-27A. Finally, for the fifth step use Figure 24-27E to find the larger sprocket to give a drive ratio of 2.50. A 42-tooth sprocket combined with a 17-tooth gives a ratio of 2.47, which is close enough. The center distance between the two sprockets using a 64-inch long chain will be 16.777 inches.

b. *Engineering materials and shapes* can be selected from vendor catalogs.

(i) The catalogs published by vendors of materials list materials and their typical uses to aid in their selection. To illustrate, one catalog describes 6061 aluminum as being heat treatable, having good formability (will not crack during bending), having good weldability, and being corrosion resistant. Also, 6061 aluminum is used for structural applications, boats, and transportation equipment.

(ii) Some materials are selected primarily on the basis of their shape; for example, steel and aluminum are rolled into plates, bars, channels, beams, and angles, and are extruded into pipe, square tubes, and rectangular tubes. Square and rectangular shapes are easier to join in fabricating than pipe sections. Pipe sections are equally strong in all directions.

(iii) Materials may be selected on the basis of their weight, rigidity, and coefficient of expansion due to temperature changes. INVAR is used in instrumentation because of its low coefficient of expansion of 1.6×10^{-6} inches per inch per degree Fahrenheit.

(iv) Additional bases for selecting materials are corrosion resistance, machinability, strength, and electrical properties.

(v) Combinations of all of the above, plus aesthetics and prior experiences, may be used for selecting materials.

Call or visit a local vendor of materials or machine elements, and request one of their catalogs. Usually, they are eager to have their catalogs in the hands of future buyers, so they are happy to donate one or more.

Furthermore, since most vendors handle a variety of products, a call or a visit may result in a small library!

Logical Dimensioning. Design components so they can be measured readily and logically—for two main reasons. One, shop personnel need to locate points, planes, and features such as holes, from reference planes or surfaces. Two, the function of the component needs to be ensured.

Shop personnel use a large number of measuring devices, some very sophisticated, some relatively simple, but all measure from a reference plane or surface that is usually machined. Some of the more

ROLLER CHAIN DRIVE SELECTION

The following considerations are very important in the selection and application of roller chain drives:

HORSEPOWER RATINGS—This catalog lists Horsepower Ratings for ANSI Series, single pitch, single strand chains No. 25 through No. 160 (and lightweight machinery series No. 41 and No. 43). Ratings are listed for various numbers of teeth and speeds of the smaller sprocket. Ratings for intermediate numbers of teeth or RPM may be determined by interpolation. The ratings reflect a service factor of 1, a chain length of approximately 100 pitches, the use of recommended lubrication methods and a drive arrangement where two aligned sprockets are mounted on parallel horizontal shafts. For maximum service life, sprockets with small numbers of teeth, operating at moderate to high speeds or near the rated horsepower should have hardened teeth. Approximately 15,000 hours of service life at full load operation may be expected under these conditions.

NO. OF TEETH—It is good practice to select a pinion sprocket with no less than 17 Teeth, to assure 120° of chain wrap and minimize overhung load. However, certain conditions, i.e., space limitations, light loads, intermittent duty, etc. will permit the use of smaller pinions.

RATIO—Sprocket ratios should not exceed about 6 to 1 for normal chain life.

HARDENED TEETH—Boston Gear steel sprockets can be hardened. Consult the factory for recommended procedure.

CENTER DISTANCE—The correct center distance is very important. In designing chain drives, it is important that the Center Distance should be long enough to provide at least 120° of chain wrap on the smaller sprocket.

RELATIVE SHAFT LOCATIONS—It is desirable that the line between the two shaft centers be as nearly horizontal as possible. If this line is more than 60° from the horizontal, special precautions should be taken.

Figure 24-27A Roller chain drive selection considerations (*Courtesy Boston Gear Incom International Inc.*)

ROLLER CHAIN DRIVE SELECTION *(Continued)*

A roller chain consists essentially of numerous small bearings operating under high pressures and requires adequate lubrication. There are four basic types of lubrication suggested for chain drives, depending upon the chain speed and the power transmitted. The Horsepower Rating Tables indicate the type of lubrication recommended.

TYPE I—MANUAL LUBRICATION

Manual lubrication is accomplished by applying oil with a brush or spout can to the inside of the chain at the edges of the side plates. Volume and frequency should be determined by periodic inspection.

TYPE II—DRIP LUBRICATION

Oil is directed between link plate edges from a drip lubricator. Only enough oil to keep the chain moist is necessary and a light metal splash guard will keep the floor and surroundings clean.

TYPE III—BATH OR DISC LUBRICATION

With bath lubrication, the lower strand of the chain runs through a sump of oil. The oil level should reach the pitch line of the chain at its lowest point while operating. With disc lubrication, the chain operates above the oil level. The disc picks up oil from the sump and deposits it on the chain, usually by means of a trough. The disc diameter should be such as to produce rim speeds from 600 minimum to 8000 maximum FPM. This type of lubrication requires that the drive be enclosed in an oil tight chain case.

TYPE IV—OIL STREAM LUBRICATION

The lubricant is uaually supplied by a circulating pump capable of supplying the chain drive with a continuous stream of oil. The oil should be applied inside the chain loop evenly across the chain width, and directed at the lower strand. This type of lubrication requires that the drive be enclosed in an oil tight chain case.

Recommended lubricant viscosities for various ambient temperatures are listed in the following table:

Temp. Degrees F.	Lubricant	Temp. Degrees F.	Lubricant
20-40	SAE20	100-120	SAE40
40-100	SAE30	120-140	SAE50

SURROUNDING CONDITIONS—Abrasive, corrosive, or high temperature conditions can shorten chain life. If adverse conditions exist, special precautions should be taken. It may be advisable to use a drive with higher capacity than normal, stainless steel chain, etc.

Roller chain drives may be selected with the following procedure:

a. From Table #1 of the Application Classification Chart on Page A94. determine the Service Factor.
b. Multiply the Application HP by the Service Factor to obtain a Design HP.*
c. The Selection Table below may be used to select an appropriate chain size using a sprocket of 17 teeth or larger.
d. From the appropriate horsepower rating table (pages B6-B8) determine the minimum size sprocket needed to provide, at the required speed, a rating equal to (or greater than) the Design horsepower.
e. The tables on pages B9-B11 may then be used to select number of sprocket teeth, shaft center distance and chain length of a drive suitable for the application.

*For Stainless Steel Chains, operating under wet or dry conditions, the Design Horsepower must be multiplied by a Factor (see Table below) for selection purposes.

NOTE: Standard Steel Chains are not recommended for wet or dry applications.

Application Conditions	Factor
Wet (Moisture)	2.0
Dry (Unlubricated)	5.0

Horsepower ratings of Multiple Strand chain may be obtained by multiplying the Single Strand rating by the proper Factor from the following table:

MULTIPLE STRAND RATING FACTORS

Number of Strands	Double	Triple	Quadruple
Rating Factor	1.7	2.5	3.3

These Horsepower Ratings are based on certain operating conditions, see Page B4.

SELECTION TABLE

RPM of Smaller Sprocket	DESIGN HORSEPOWER												
	1/2	1	1-1/2	2	3	4	5	7-1/2	10	15	20	25	30
	CHAIN NUMBER												
1800	25	25	35	35	35	40	40	40	50	80	60—2	80—2	—
1500	25	25	35	35	35	40	40	40	60	60	80	60—2	80—2
1200	25	35	35	35	40	40	40	50	60	60	60	80	100
1000	25	35	35	35	40	40	40	50	60	60	80	80	80
800	25	35	35	40	40	40	50	50	60	60	80	80	80
700	25	35	35	40	40	50	50	50	60	80	80	80	80
600	35	35	35	40	40	50	50	60	60	80	80	80	100
500	35	35	40	40	50	50	50	60	80	80	80	100	100
400	35	35	40	40	50	50	60	60	80	80	100	100	100
350	35	40	40	40	50	50	60	80	80	80	100	100	100
300	35	40	40	50	50	60	60	80	80	100	100	100	120
250	35	40	40	50	50	60	60	80	80	100	100	120	120
200	35	40	50	50	60	60	80	80	80	100	120	120	120
175	40	40	50	50	60	80	80	80	100	100	120	120	140
150	40	50	50	60	60	80	80	80	100	120	120	120	140
125	40	50	50	60	80	80	80	100	100	120	120	140	140
100	40	50	60	60	80	80	80	100	100	120	140	140	160
80	40	50	60	80	80	80	100	100	120	140	140	160	160
70	50	60	60	80	80	80	100	120	120	140	160	160	
60	50	60	80	80	80	100	100	120	120	140	160		
50	50	60	80	80	80	100	100	120	140	160	160		
40	50	60	80	80	100	100	120	120	140	160			
30	60	80	80	100	100	120	120	140	160				
25	60	80	80	100	120	120	140	140	160				
20	60	80	100	100	120	120	140	160					
15	80	100	100	120	120	140	160						
10	80	100	120	120	140	140							

*Based on 17 Tooth Sprocket. For other numbers of teeth refer to the applicable Horsepower Table, pages B6-B8.

Figure 24-27B Roller chain drive selection procedure (*Courtesy Boston Gear Incom International Inc.*)

APPLICATION CLASSIFICATION FOR VARIOUS LOADS

Type of Machine To Be Driven	Chart I For all Drives		
	Service Factor		
	Loading		
	Not More Than 15 Mins. In 2 Hrs.	Not More Than 10 Hrs. per Day	More Than 10 Hrs. Per Day
AGITATORS			
Pure Liquid	0.80	1.00	1.25
Semi-Liquids, Variable Density	1.00	1.25	1.50
BLOWERS			
Centrifugal and Vane	0.80	1.00	1.25
Lobe	1.00	1.25	1.50
BREWING AND DISTILLING			
Bottling Machinery	0.80	1.00	1.25
Brew Kettles—Continuous Duty	—	—	1.25
Cookers—Continuous Duty	—	—	1.25
Mash Tubs—Continuous Duty	—	—	1.25
Scale Hopper—Frequent Starts	—	1.25	1.50
CAN FILLING MACHINES	—	1.00	—
CANE KNIVES	—	1.50	—
CAR DUMPERS	—	1.75	—
CAR PULLERS	—	1.25	—
CLARIFIERS	—	1.00	1.25
CLASSIFIERS	—	1.25	1.50
CLAY WORKING MACHINERY			
Brick Press & Briquette Machine	—	1.75	2.00
Extruders and Mixers	1.00	1.25	1.50
COMPRESSORS			
Centrifugal	—	1.00	1.25
Lobe—Reciprocating, Multi-Cycle	—	1.25	1.50
Reciprocating—Single Cycle	—	1.75	2.00
CONVEYORS—UNIFORMLY LOADED & FED			
Apron	—	1.00	1.25
Assembly-Belt—Bucket or Pan	—	1.00	1.25
Chain—Flight	—	1.00	1.25
Oven—Live Roll—Screw	—	1.00	1.25
CONVEYORS—HEAVY DUTY NOT UNIFORMLY FED			
Apron		1.25	1.50
→ Assembly-Belt—Bucket or Pan	—	1.25	1.50
Chain—Flight	—	1.25	1.50
Live Roll	—	—	—
Oven—Screw	—	1.25	1.50
Reciprocating—Shaker	—	1.75	2.00
CRANES AND HOISTS			
Main Hoists			
Bridge and Trolley Drive	*	1.00	1.25
CRUSHER			
Ore, Stone	—	1.75	2.00
Sugar	—	1.50	1.50
ELEVATORS			
Bucket—Uniform Load	—	1.00	1.25
Bucket—Heavy Load	—	1.25	1.50
Centrifugal Discharge	—	1.25	1.50
Freight	—	1.25	1.50
Gravity Discharge	—	1.00	1.25
ELEVATORS			
Bucket—Uniform Load	—	1.00	1.25
Bucket—Heavy Load	—	1.25	1.50
Centrifugal Discharge	—	1.25	1.50
Freight	—	1.25	1.50
Gravity Discharge	—	1.00	1.25
FANS			
Centrifugal—Light (Small Diam.)	—	1.00	1.25
Large Industrial	—	1.25	1.50

Type of Machine To Be Driven	Chart I For All Drives		
	Service Factor		
	Loading		
	Not More Than 15 Mins. In 2 Hours	Not More Than 10 Hours per Day	More Than 10 Hours Per Day
FEEDERS			
Apron—Belt—Screw	—	1.25	1.50
Disc	—	1.00	1.25
Reciprocating	—	1.75	2.00
FOOD INDUSTRY			
Beet Slicer	—	1.25	1.50
Cereal Cooker	—	1.00	1.25
Dough Mixer—Meat Grinder	—	1.25	1.50
GENERATORS (NOT WELDING)	—	1.00	1.25
HAMMER MILLS	—	1.75	2.00
HOISTS			
Heavy Duty	—	1.75	2.00
Medium Duty and Skip Type	—	1.25	1.50
LAUNDRY TUMBLERS	—	1.25	1.50
LINE SHAFTS			
Uniform Load	—	1.00	1.25
Heavy Load	—	1.25	1.50
MACHINE TOOLS			
Auxiliary Drive	—	1.00	1.25
Main Drive—Uniform Load	—	1.25	1.50
Main Drive—Heavy Duty	—	1.75	2.00
METAL MILLS			
Draw Bench Carriers & Main Drive	—	1.25	1.50
SLITTERS	—	1.25	1.50
TABLE CONVEYORS—NON REVERSING			
Group Drives	—	1.25	1.50
Individual Drives	—	1.75	2.00
Wire Drawing, Flattening or Winding	—	1.25	1.50
MILLS ROTARY TYPE BALL & ROD			
Spur Ring Gear and Direct Connected	—	—	2.00
Cement Kilns, Pebble	—	—	1.50
Dryers and Coolers	—	—	1.50
Plain and Wedge Bar	—	—	1.50
Tumbling Barrels	—	—	2.00
MIXERS			
Concrete—Continuous	—	1.25	1.50
Concrete—Intermittent	—	1.25	1.50
Constant Density	—	1.00	1.25
Semi-Liquid	—	1.25	1.50
OIL INDUSTRY			
Oil Well Pumping	—	—	*
Chillers, Paraffin Filter Press	—	1.25	1.50
Rotary Kilns	—	1.25	1.50
PAPER MILLS			
Agitator (Mixer)	—	1.25	1.50
Agitator—Pure Liquids	—	1.00	1.25
Barking Drums—Mechanical Barkers	—	1.75	2.00
Bleacher	—	1.00	1.25
Beater	—	1.25	1.50
Calender Heavy Duty	—	—	2.00
Calender Anti-Friction Brgs.	—	1.00	1.25
Cylinders	—	1.25	1.50
Chipper	—	—	2.00
Chip Feeder	—	1.25	1.50
Coating Rolls—Couch Rolls	—	1.00	1.25
Conveyors—Chips—Bark—Chemical	—	1.00	1.25
Conveyors—Log and Slab	—	—	2.00
Cutter	—	—	2.00
Cylinder Molds, Dryers (Anti-Friction Brg.)	—	—	1.25
Felt Stretcher	—	1.25	1.50
Screens—Chip and Rotary	—	1.25	1.50
Thickener (AC)	—	1.25	1.50
Washer (AC)	—	1.25	1.50
Winder—Surface Type	—	—	1.25

Figure 24-27C Service factors for various applications (*Courtesy Boston Gear Incom International Inc.*)

Small Sprocket		HP RATINGS—STANDARD SINGLE* STRAND ROLLER CHAIN—NO. 120—1-1/2″ PITCH																		
RPM→		10	20	30	50	75	100	125	150	200	250	300	400	500	600	700	800	900	1000	1200
Teeth	P.D.																			
11	5.324″	1.37	2.56	3.68	5.82	8.40	10.9	13.3	15.6	20.3	24.8	29.2	37.8	46.3	54.5	46.3	37.9	31.8	27.1	20.6
13	6.268	1.64	3.06	4.41	6.97	10.1	13.0	15.9	18.7	24.3	29.7	35.0	45.3	55.4	65.3	59.5	48.7	40.8	34.9	26.5
15	7.215	1.91	3.57	5.14	8.13	11.7	15.2	18.6	21.9	28.3	34.7	40.8	52.9	64.6	76.1	73.8	60.4	50.6	43.2	32.9
17	8.164	2.19	4.09	5.88	9.31	13.4	17.4	21.3	25.0	32.4	39.7	46.7	60.5	74.0	87.2	89.0	72.8	61.0	52.1	39.6
19	9.114	2.47	4.61	6.64	10.5	15.2	19.6	24.0	28.2	36.5	44.8	52.7	68.2	83.4	98.3	105	86.1	72.1	61.6	46.8
21	10.064	2.75	5.13	7.39	11.7	16.9	21.8	26.7	31.4	40.7	49.8	58.7	76.0	93.0	110	122	100	83.8	71.6	54.4
Lubrication #		Type I		Type II					Type III				Type IV							

Figure 24-27D Horsepower ratings for No. 120 roller chain (*Courtesy Boston Gear Incom International Inc.*)

SPEED RATIOS – CENTER DISTANCES – CHAIN LENGTHS

Teeth on DriveN Sprocket	Teeth on DriveR Sprocket														
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
15	1.36 6.469 26	1.25 7.235 28	1.15 6.993 28	1.07 7.748 20	1.00 7.500 30										
16	1.45 7.207 28	1.33 6.971 28	1.23 7.736 30	1.14 7.494 30	1.07 8.249 32	1.00 8.000 32									
17	1.55 7.943 30	1.42 7.710 30	1.31 7.473 30	1.21 8.237 32	1.13 7.994 32	1.06 8.749 34	1.00 8.500 34								
18	1.64 7.669 30	1.50 8.446 32	1.38 8.212 32	1.29 7.975 32	1.20 8.737 34	1.13 8.495 34	1.06 9.249 36	1.00 9.000 36							
19	1.73 8.404 32	1.58 8.174 32	1.46 8.949 34	1.36 8.714 34	1.27 8.477 34	1.19 9.238 36	1.12 8.995 36	1.06 9.749 38	1.00 9.500 38						
20	1.82 8.124 32	1.67 8.909 34	1.54 8.679 34	1.43 9.452 36	1.33 9.216 36	1.25 8.978 36	1.18 9.739 38	1.11 9.495 38	1.05 10.249 40	1.00 10.000 40					
21	1.91 8.857 34	1.75 8.632 34	1.61 9.414 36	1.50 9.183 36	1.40 9.955 38	1.31 9.718 38	1.24 9.479 38	1.17 10.239 40	1.11 9.995 40	1.05 10.749 42	1.00 10.500 42				
22	2.00 9.590 36	1.83 9.365 36	1.69 9.139 36	1.57 9.918 38	1.47 9.686 38	1.37 10.457 40	1.29 10.220 40	1.22 9.980 40	1.16 10.740 42	1.10 10.496 42	1.05 11.249 44	1.00 11.000 44			
23	2.09 9.304 36	1.92 10.098 38	1.77 9.872 38	1.64 9.645 38	1.53 10.422 40	1.44 10.189 40	1.35 10.959 42	1.28 10.721 42	1.21 10.481 42	1.15 11.240 44	1.10 10.996 44	1.05 11.749 46	1.00 11.500 46		
24	2.18 10.037 38	2.00 9.815 38	1.85 10.605 40	1.72 10.378 40	1.69 10.150 40	1.50 10.926 42	1.41 10.692 42	1.33 11.461 44	1.26 11.222 44	1.20 10.982 44	1.14 11.741 46	1.09 11.496 46	1.04 12.249 48	1.00 12.000 48	
25	2.27 9.744 38	2.08 10.547 40	1.92 10.324 40	1.79 11.112 42	1.67 10.884 42	1.56 10.654 42	1.47 11.429 44	1.39 11.195 44	1.31 11.963 46	1.25 11.723 46	1.19 11.483 46	1.14 12.241 48	1.09 11.996 48	1.04 12.750 50	1.00 12.500 50
30	2.72 11.345 44	2.50 12.161 46	2.31 11.943 46	2.14 12.746 48	2.00 12.522 48	1.88 12.299 48	1.76 13.087 50	1.67 12.858 50	1.58 13.638 52	1.50 13.406 52	1.43 13.172 52	1.36 13.942 54	1.30 13.705 54	1.25 14.469 56	1.20 14.228 56
32	2.91 12.812 48	2.66 12.597 48	2.46 12.379 48	2.28 13.188 50	2.14 12.967 50	2.00 13.765 52	1.88 13.539 52	1.78 13.314 52	1.68 14.099 54	1.60 13.869 54	1.52 14.646 56	1.45 14.413 56	1.39 14.178 56	1.33 14.946 58	1.28 14.708 58
35	3.18 13.976 52	2.92 13.761 52	2.69 13.546 52	2.50 14.361 54	2.33 14.141 54	2.19 13.921 54	2.06 14.721 56	1.94 14.497 56	1.84 15.288 58	1.75 15.061 58	1.67 14.833 58	1.59 15.613 60	1.52 15.382 60	1.46 16.155 62	1.40 15.921 62
36	3.27 13.668 52	3.00 14.495 54	2.77 14.279 54	2.57 14.063 54	2.40 14.874 56	2.25 14.653 56	2.12 14.433 56	2.00 15.230 58	1.89 15.006 58	1.80 15.795 60	1.71 15.567 60	1.64 15.338 60	1.56 16.117 62	1.50 15.886 62	1.44 16.658 64
40	3.64 15.561 58	3.34 15.349 58	3.08 15.136 58	2.86 15.961 60	2.67 15.746 60	2.50 15.528 60	2.35 16.339 62	2.22 16.119 62	2.10 16.920 64	2.00 16.697 64	1.90 16.473 64	1.82 17.262 66	1.74 17.035 66	1.67 17.818 68	1.60 17.588 68
42	3.82 15.983 60	3.50 15.773 60	3.23 16.605 62	3.00 16.391 62	2.80 16.177 62	2.62 16.994 64	2.47 16.777 64	2.34 16.557 64	2.21 17.364 66	2.10 17.142 66	2.00 17.939 68	1.91 17.714 68	1.83 17.489 68	1.75 18.275 70	1.68 18.047 70
45	4.09 17.139 64	3.75 16.930 64	3.46 16.719 64	3.22 17.553 66	3.00 17.340 66	2.81 18.161 68	2.65 17.945 68	2.50 17.728 68	2.37 18.536 70	2.25 18.317 70	2.14 18.096 70	2.04 18.895 72	1.96 18.671 72	1.88 19.463 74	1.80 19.237 74

RATIO
CENTER DISTANCE – IN PITCHES
CHAIN LENGTH – IN PITCHES

To obtain corresponding values in INCHES, multiply by the appropriate Chain Pitch.

Figure 24-27E Speed ratios–center distances–chain lengths common measuring devices and their measuring capabilities are:

a. Flat, stainless steel scale: to 0.010"

b. Micrometer: inside and outside: to 0.0002"

c. Vernier Calipers: inside and outside: to 0.001"

d. Lathes, milling machines, shapers, boring machines, and gear cutters with calibrated dials to indicate the movement of the cutting tool or the part being machined: to 0.0005"

e. Some newer milling machines and numerically controlled machines with electronic readouts: to 0.0001"

Engineers, designers, and drafters can facilitate these shop processes by dimensioning components from obvious reference planes or surfaces. The plane or surface may need to be created in the manufacturing process.

Ensure the function of a component or an assembly of components by dimensioning to common reference planes or surfaces. An example to illustrate reference planes is shown in Figure 24-28. The two identical L-shaped brackets are cast iron. Surface No. 1 is milled to establish a plane of reference to locate vertical surface No. 2 to be perpendicular to surface No. 1. Then, the hole at No. 3 is drilled perpendicular to surface No. 2 (and hence parallel

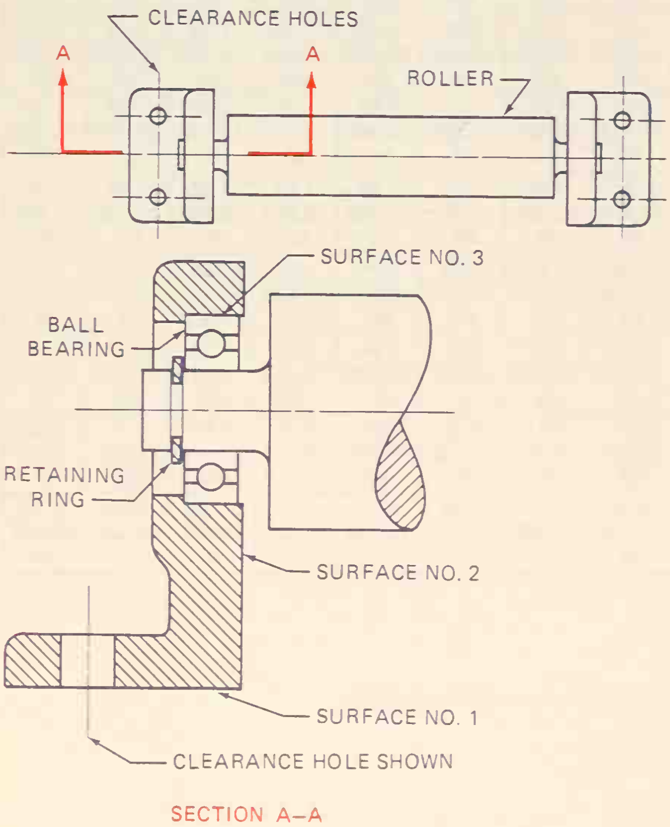


Figure 24-28 Reference plane for dimensioning

to surface No. 1) so the shaft for the roller will be horizontal. The two holes in the bracket would probably be located with respect to vertical surface no. 2 and centered about the centerline of the machined hole, surface No. 3.

A more exact dimensioning technique called positional tolerancing and form tolerancing (or geometrical tolerancing) establishes datum surfaces for referencing dimensions and features. The technique requires more skill and time to apply; however, time and money are saved because less parts are scrapped. They fit better and their function is assured.

This tolerancing technique has grown as machines and systems have become more complex and expensive. Furthermore, when one company manufactures components that will be assembled together with components from another company, the dimensioning and features need to be accurately located so the components will go together.

Oral Presentations. According to William L. Trippe in GRADUATING ENGINEER, January 1988, 90% of respondents in a survey indicated that they regularly gave oral presentations several times per week. More than 90% considered public speaking skills to be an important part of the job.

During the design process discussed in this chapter, oral presentations are scheduled at least two times, the design review and the final presentation. As a guide for giving these two presentations, and others, use the following three practical steps:

1. Tell them what you're going to tell them.
2. Tell them.
3. Tell them what you've told them.

Further guidelines are in the exercises at the end of the chapter.

Safe Designs. Use the following checklist to provide safe designs, safe installations, and protection against negligence suits.

Document the design to show evidence of the following:

a. Accurate calculations

b. Proper use of codes and standards

c. Use of state-of-the-art technology

d. Proper use of materials and hardware

e. Having run tests, if appropriate

f. Use of proper manufacturing processes, proper fasteners, and appropriate heat treatments

g. A quality control program

h. Preparation of instructions for safe use

i. Addition of warning signs to the product

j. Having told future owners of the proper safety devices and practices needed, such as guards around any exposed moving parts of machines, and painted stripes to show danger areas

k. Thorough exploration of all possible uses of the product other than those for which it was designed

Access. Locate fasteners and components for installation and servicing so personnel can have access to them with their hands and tools. Also, provide access to weld areas for welders.

Vibration. Use locking devices such as lock washers and lock nuts on threaded fasteners subjected to vibration. Some high-speed engines have wires passing through holes in the nuts to prevent the nuts from "backing off" because of vibrating conditions.

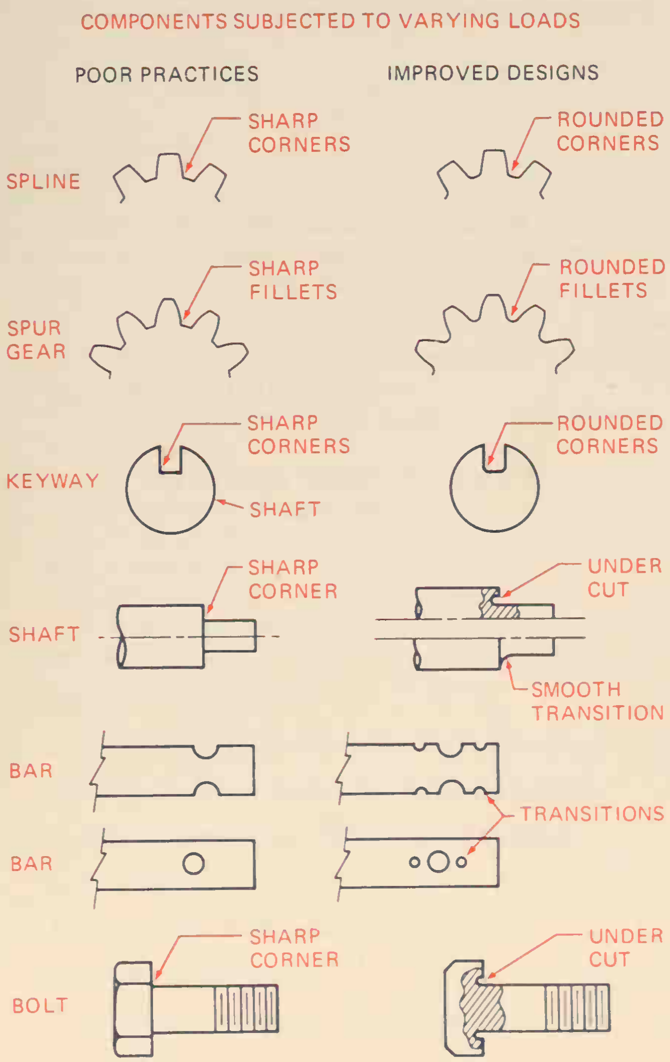


Figure 24-29 Fatigue considerations

Fatigue. Avoid sharp changes of cross-section and small fillet radii on parts subjected to varying loads. See Figure 24-29 for examples of good and poor practices. The sharp corners and radii (and scored surfaces) cause stress concentrations and therefore, possible fatigue failure.

Cleaning/Corrosion. Provide sloping surfaces wherever standing fluids could cause corrosion. For example, tank bottoms should slope toward a drain hole so that chemicals and cleaning fluids can be completely drained. Upper surfaces should slope to prevent standing rainwater or melting snow.

Temperature. Avoid stringent tolerances on dimensions of parts subjected to extreme temperature changes. Furthermore, check the strength and ductility of materials at extreme temperatures. Also, the temperature of a part may need to be specified for verifying some critical dimensions at that temperature if the dimension is less than 0.0002".

Review

1. What are the five phases of the design process? Since the design process is a problem-solving strategy, describe how it might apply to a non-technical problem, such as:
   a. borrowing the car from parents
   b. generating money for a student organization
   c. writing a paper for a non-technical class
2. Why is a planning chart used?
3. Why keep a log and a design file?
4. What sources of technical information are available in your school, and where can they be found?
5. What are the two major categories of specifications?
6. Explain the term iteration and how it applies to the design process.
7. What is the main function of a progress report to the client?
8. How can attribute listing help a designer to generate ideas?
9. What are the four steps in the creative process?
10. Why should designers carry a notebook at all times?
11. What are some characteristics of a creative person?

12. What is a design layout drawing? How does it differ from a technical detail drawing?

13. What are several advantages of making "cardboard-glue" models?

14. Describe a decision table.

15. Why do a design review?

16. Why are only the first four phases usually done for classroom design projects?

17. Why is the ability to communicate usually rated higher than technical skills by companies looking for new technical personnel?

18. Who are some of the people (occupations) you would most likely contact while doing the design process in school? In industry?

19. How do records kept for patent development differ from a design file?

20. What are some differences between routine and non-routine design projects? Similarities?

21. How does attribute listing help as a checklist for technical detail drawing?

Chapter Twenty-Four Problems

The following problems complement the design process and provided practice to understand and learn the steps before attacking routine and non-routine design projects.

Problem 24-1

Prepare a 5-minute oral presentation on one of the sources of information listed below. Use transparencies for an overhead projector. Suggestions for transparencies (Tx):

Tx 1. Name of source, its location, and name of speaker.
Tx 2. Outline of the talk:
  a. description of the source and its specific location
  b. why source is useful to designers
  c. example of use of source
  d. conclusion
Tx 3. Description of source and its location.
Tx 4. Why source is useful to designers.
Tx 5. Example of use of source.
Tx 6. Conclusion.

Suggested Sources:

1. ASTI (Applied Science and Technology Index)
2. ASTM (American Society for Testing Materials)
3. ANSI (American National Standards Institute)
4. Patents
5. UL (Underwriter's Laboratory)
6. Machinery handbook
7. Handbook (instructor's or your choice)
8. Vendor's catalog
9. Instructor's recommendation

Problem 24-2

Prepare performance and design specifications for one of the items listed below. Well-written specifications can be verified by testing. For example, instead of specifying that a bumper jack will be easy to use, lightweight, and made of metal, well-written "specs" would be the following: easy to use by a licensed driver who is not handicapped, a maximum of 20 pounds of force to operate, weighs less than 10 pounds, and is made of SAE 1035 steel. Include a sketch with notes and dimensions.

1. Screwdriver for use in average household
2. Light switch in average household
3. Can opener for kitchen use
4. Knife for kitchen use
5. Pliers for electrician, or average household
6. Hammer for carpenter, or average household
7. Wood saw
8. Metal saw (hack saw)
9. Instructor's choice

Problem 24-3

Prepare a decision table using criteria and weighting factors for the situations listed. Generate at least three alternatives for each situation.

1. Vehicle for town driving
2. Vehicle for country driving
3. Vehicle for backwoods driving
4. Vacation
5. College to attend
6. Job choice in one city
7. Job choice for different locations (West Coast, East Coast, South, North, etc.)
8. Your choice
9. Instructor's choice

Problem 24-4

Prepare a freehand sketch of a relatively uncomplicated design and then prepare a design development layout drawing of the sketched design. Draw the object to scale, but add notes and dimensions in an informal manner. No title block is needed. Complete information is required. Design suggestions:

1. Wall bracket to support object of your choice. Instructor's choice. Use welded assemblies.
2. Minor modification of a component from:
   a. This text (instructor's choice)
   b. Your choice
   c. Instructor's choice

Problem 24-5

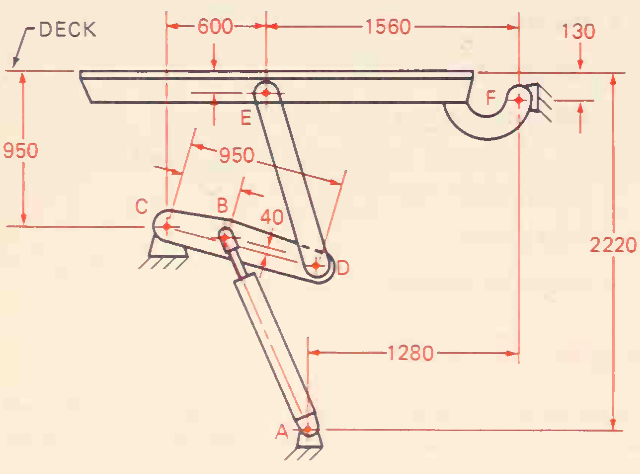
Prepare a kinematic development layout drawing of one of the assemblies drawn below or of an assembly assigned by your instructor.

Suggestions for Kinematic Analyses:

1. Redraw the figures as single straight lines to represent the linkages.
2. Construct radii about fixed points of rotation.
3. Trace, on a separate sheet of paper, the lines representing the linkages whose motions are to be analyzed.
4. Use the lines as underlays to locate the new positions.

Problem 24-5A

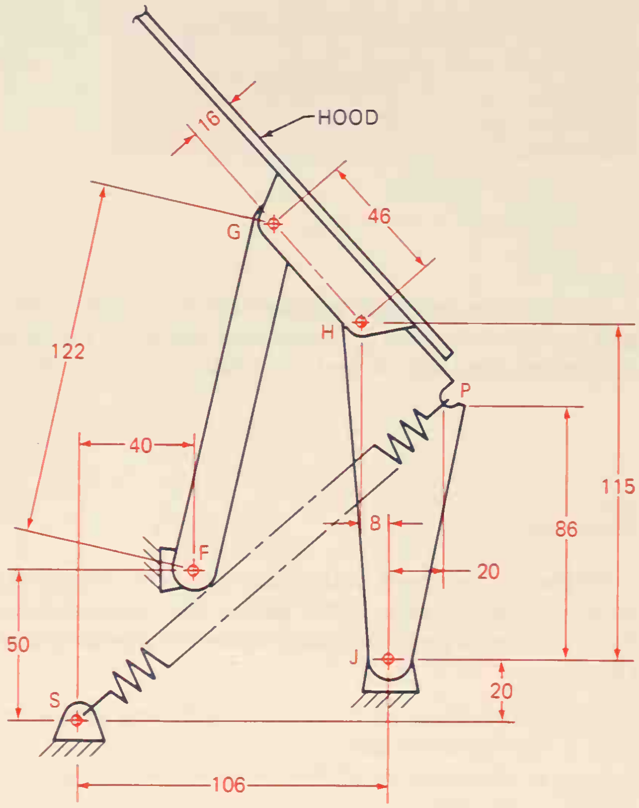
The figure below shows the linkages and hydraulic cylinder to operate a jet-blast deflector EF. The hydraulic cylinder AB causes linkage CD to rotate CCW (counterclockwise) about point C, which causes linkage DE to move the deflector EF in a CW (clockwise) direction. When EF is in the maximum CW position it acts as a shield for personnel standing behind jet aircraft when the jets are warming up for launching from an aircraft carrier. Determine the maximum CW angle that EF rotates and the change in length (stroke) of cylinder AB to obtain the maximum angle. Draw lines EF, DE, CD, and AB when they are in the position for the maximum CW rotation of EF.



Problem 24-5A

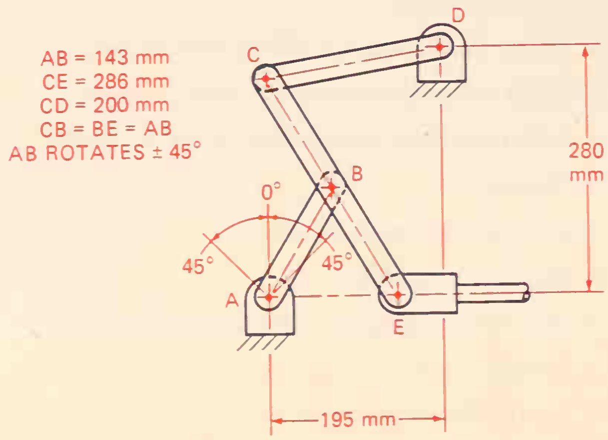
Problem 24-5B

One application of a 4-Bar Linkage is to control the movement of the hood of an automobile: Actually a pair of 4-Bar Linkages support the hood. Linkage GH is attached to the hood as shown in the figure. When the hood closes, GH rotates and translates to a horizontal position. Determine the total CCW (counterclockwise) rotation of the hood from the open to the closed position. Also determine the change in length of the spring SP from the open to closed positions. Draw the lines representing the linkages and the spring in the closed position.



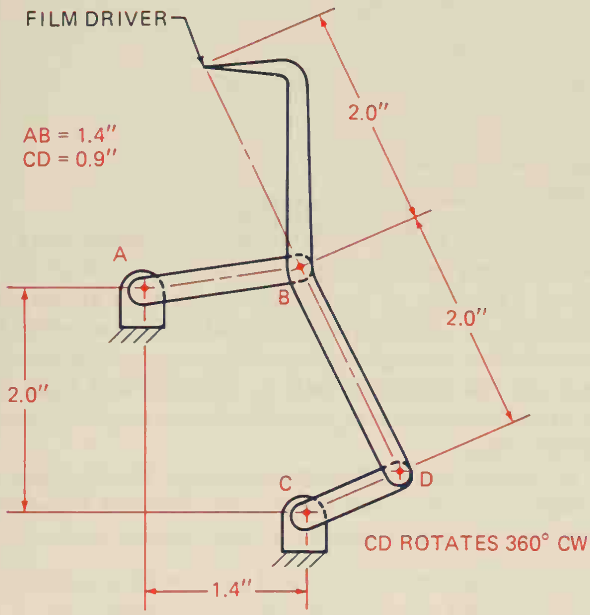
Problem 24-5B

Problem 24-5C



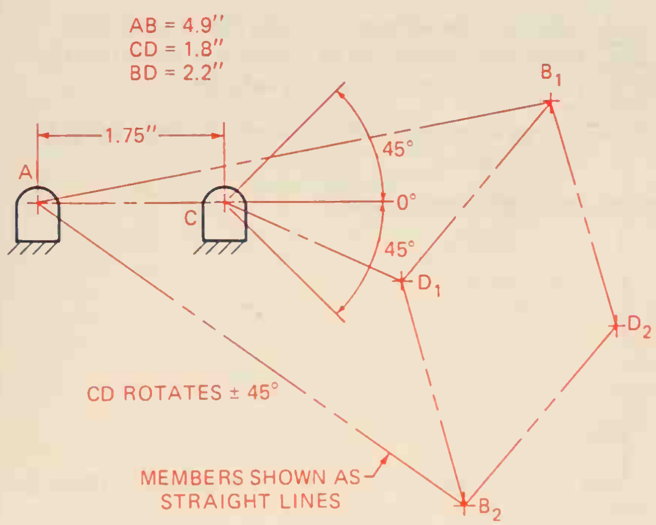
Problem 24-5C. *Straight-Line Mechanism.*

Problem 24-5D



Problem 24-5D. *Straight-Line Mechanism.*

Problem 24-5E



Problem 24-5E. *Straight-Line Mechanism.*

Problem 24-6

The 19-step Kraft Mill Engineering Roadmap listed below summarizes a design process from a company for improving or changing the company's plant facilities. A recent graduate from an engineering program sent the summary to one of her professors to show what she was doing during the first few months on the job.

Kraft Mill Engineering Roadmap

1. PROJECT SCOPE: Define the problem to be resolved, the changes that are required, and the objective to be achieved.
2. SCOPE REVIEW MEETING: Verify that both Maintenance and Operations approve of the project scope.
3. PRELIMINARY DESIGN: Select several options for consideration. Prepare rough cost estimates, sketch general layouts/schematics, and estimate ROI/payback for each option.
4. PRELIMINARY DESIGN REVIEW MEETING: Select one or two options to pursue. Obtain Management's approval to proceed. Determine if project is to be capitalized or expensed.
5. SUBMIT AR OR WO: Write a cost estimate. Use class ±10%, ±20%, or ±40%, as required. Write and submit an AR (Authorization Request) or a WO (work order).
6. RECEIVE APPROVED AR OR WO: No money may be spent until approval is received.

   DETAILED DESIGN: Make detailed layout drawings and flow schematics. Do energy balance. Develop schedule; make time-bar diagram for larger projects. Determine equipment requirements.

8. PROJECT DESIGN REVIEW MEETING: Obtain "buy off" from Operations and Maintenance of the design and layout. Verify schedule, shutdown periods, etc. Decide whether contractors or the mill will provide labor.
9. BIDS: Prepare bid package for material and for labor. Draw up a bidders list. Send to Purchasing Dept. and go out for bids.
10. REVIEW BIDS: Select the best one or two vendors for each portion of the project. Run background check on contractors. Check references of equipment manufacturers.
11. VENDOR APPROVAL MEETING: Obtain approval to purchase equipment and/or hire contractors.
12. PURCHASE ORDERS: Award bids. Write Purchase Orders (P.O.'s).
13. EQUIPMENT TRACKING: Track equipment as it comes into mill. Store in safe place until installation.
14. CONSTRUCTION: Install equipment.

15. PRE-STARTUP: Obtain and file vendor drawings, guarantees, and instruction files. Set up spare parts in the storeroom. Write an operating manual. Develop a start-up plan.
16. PRE-STARTUP: Review startup plan. Set a startup date.
17. STARTUP: Put system into operation.
18. PROJECT REVIEW: Either hold meeting or circulate memo. Restate original project scope. Review the project. Determine that the desired objectives were (or were not) met. Discuss any problems. State final project cost.
19. PROJECT CLOSEOUT: Do necessary paperwork to close out project. Sign the WO as complete, or fill out an AR Capital Job Closure Form.

Note: Some of these events overlap. Depending on the size and type of job, some events may be deleted or some more may need to be added.

Study the 19 steps and do all or any one of the following, as assigned by your instructor:

1. Prepare a planning chart assuming that a 6-month period is required for a particular plant modification, and that you are doing the job.
2. Relate the 19 steps to the design process discussion in this chapter.
3. List and comment on the different people most likely contacted during the 19 steps.
4. Comment on the apparent meaning of some of the terms and acronyms; for example, scope, ROI, capitalized, expensed, AR, WO, ±10% class, ±20% class, ±40% class, time-bar diagram, flow schematic, "buy-off", bid package, background check, PO, tracking, and AR Capital Job Closure Form.

Problem 24-7

1. Contact local vendors of material to obtain current prices of common ones, such as steel shapes (angles, plates, bars, channels, and beams). Note that prices are usually given in dollars per 100 pounds and that price reductions are given for purchasing large quantities (e.g., a full railroad car).
2. Contact vendors of finished components—such as motors, switches, controls, bearings, chain, and similar products—to obtain costs to several categories of buyers.
   a. Private individuals usually pay the full retail price.
   b. Companies that include the finished components in a kit may get a 15% to 30% discount from the vendors because the companies sell the kits to customers.
   c. Companies that include the finished components as an integral part of an assembled machine are called original equipment manufacturers (OEM). They may receive even larger discounts.

Problem 24-8

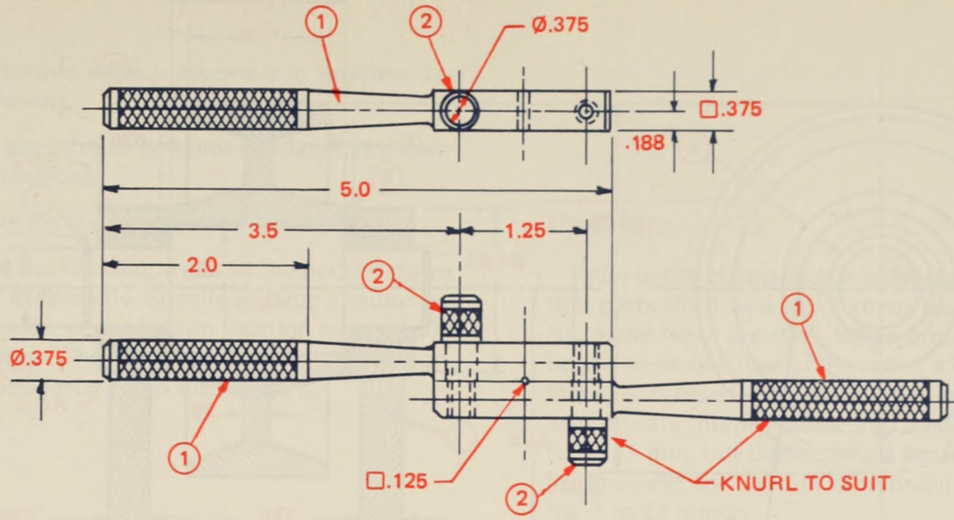
Frequently, professionals are asked to make quick estimates during conversations over lunch or while phoning a client. This type of quick thinking is also an excellent approach to use for checking final results, whether it is homework in an engineering science course or a system in industry. Ask questions such as, does this look right, does this look reasonable, or does the output seem reasonable for the input?

For practicing "back-of-the-envelope" thinking and calculations, do the following in a time period assigned by your instructor and record the assumptions made:

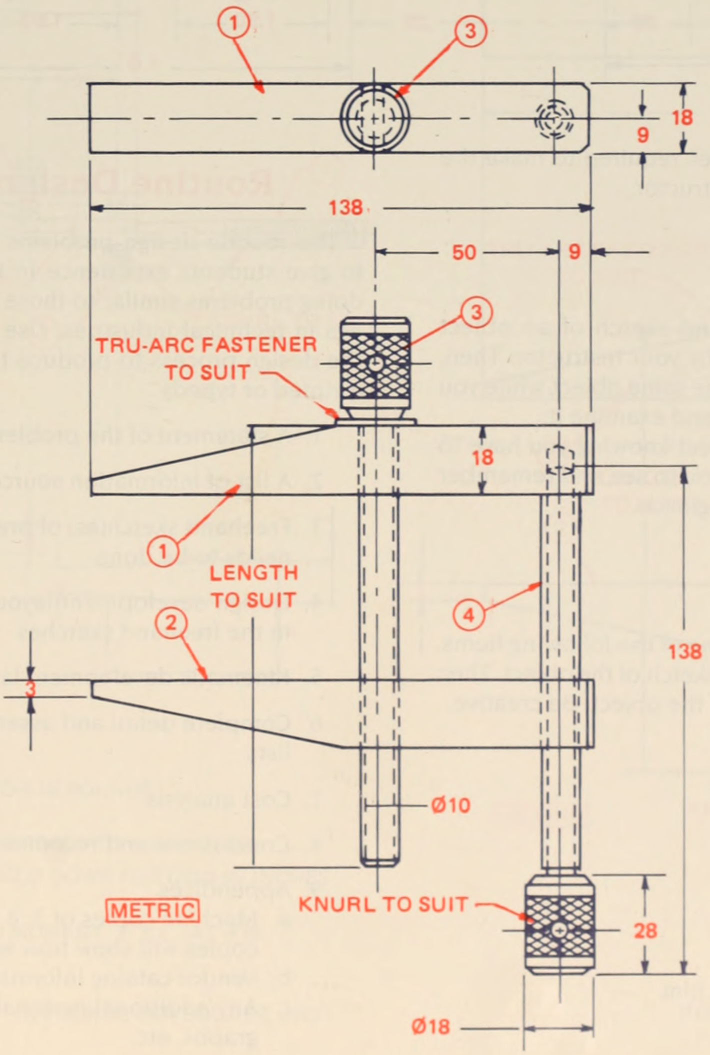
1. Estimate the quantities of food and the cost of lunch for all of the people in your classroom.
2. Estimate the number of gallons of water used by your school in one day. (Perhaps maintenance personnel can verify the accuracy of the estimate.)
3. Estimate the cost of transporting a college football team 1000 miles, and expenses for a 3-day road trip.
4. Estimate the selling price of a new automobile, truck, van, sports car, or motorcycle based on the price per pound of existing vehicles.
5. Estimate selling prices of other products using the approach in 4.
6. Your instructor's choice.

Problem 24-9

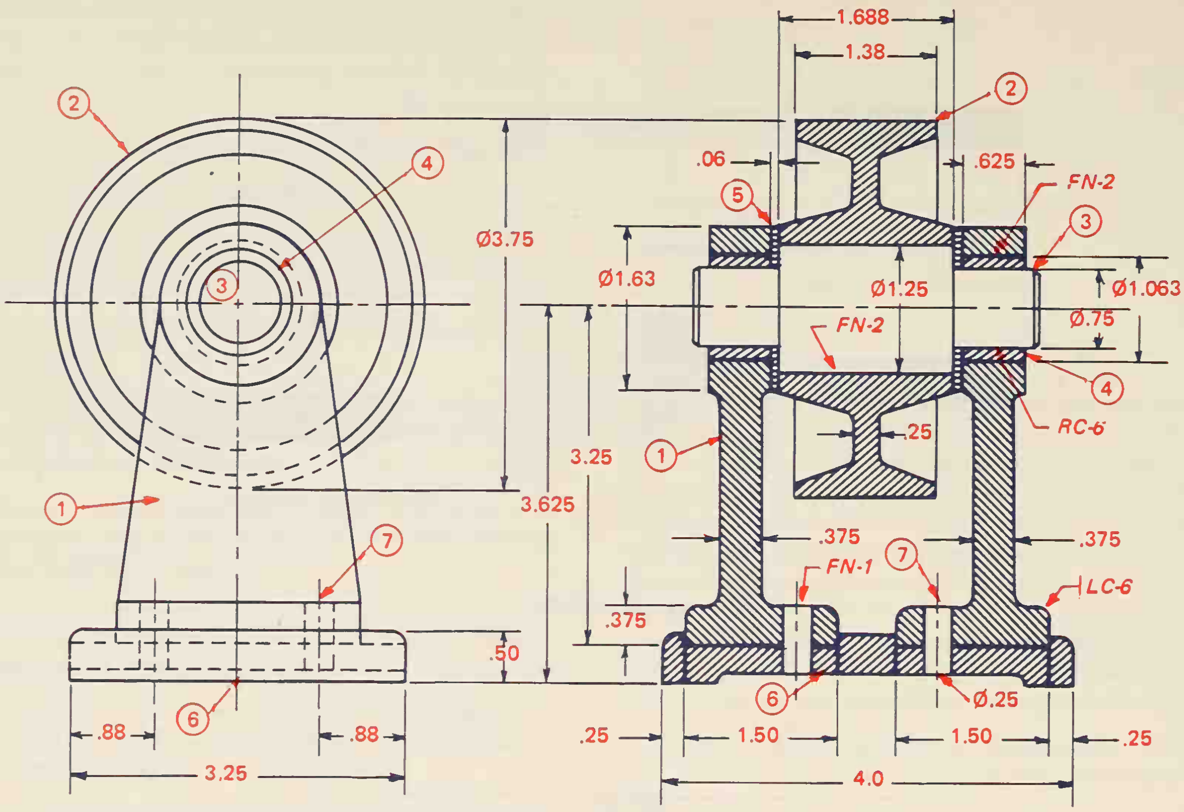
List the manufacturing processes required to make the parts shown in the figures below.



Problem 24-9A



Problem 24-9B



List the manufacturing processes required to make the part or parts assigned by your instructor.

Problem 24-10

From memory, make a freehand sketch of an object shown to you for a limited time by your instructor. Then, do a second freehand sketch of the same object while you have a much longer time to view and examine it.

This practice of viewing an object knowing you have to sketch it from memory will train you to see and remember more than you would at a casual glance.

Problem 24-11

List the obvious attributes of one of the following items. Include a freehand dimensioned sketch of the object. Then list all the not-so-obvious uses of the object. Be creative.

1. Kitchen table
2. Clothespin
3. Bookshelves
   a. Wood
   b. Metal
4. Cardboard milk carton
5. Plastic container for 35 mm film
6. Screwdriver
7. Nail
8. Object assigned by your instructor

Routine Design Problems

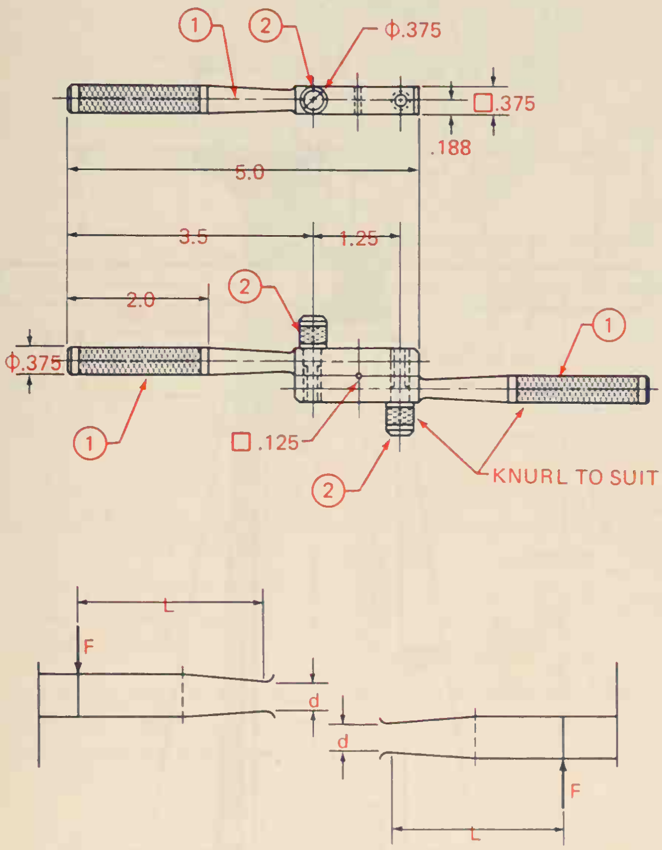
The routine design problems listed here are intended to give students experience in the design process while doing problems similar to those assigned to new employees in technical industries. Use the steps, as needed, in the design process to produce the following short report (printed or typed):

1. A statement of the problem in your own words
2. A list of information sources used
3. Freehand sketch(es) of preliminary ideas of what needs to be done
4. Design development layout drawings of the ideas in the freehand sketches
5. Kinematic development layout drawings, if required
6. Complete detail and assembly drawings with parts lists
7. Cost analysis
8. Conclusions and recommendations
9. Appendices
   a. Machine copies of 3, 4, 5, and 6 above (These copies will show how well drawings reproduce.)
   b. Vendor catalog information
   c. Any additional materials: work order, photographs, etc.
10. A title page and a folder for the report
11. Any additional material assigned by your instructor

Problem 24-12

Refer to the torque wrench assembly in Problem 24-12 and do the following:

1. Make the wrench just two times as large as shown for all dimensions.
2. Select steel for the handles and the fasteners.
3. Determine the bending stress in the necked-down portion of the handle. Specify as large a radius as practical at the necked-down location to avoid stress concentration. The bending stress will depend on the assumed force F and the length L.



F = FORCE BY OPERATOR IN POUNDS (NEED TO ASSUME)

L = ASSUME DISTANCE FROM F TO d IN INCHES

d = DIAMETER OF NECKED DOWN PORTION IN INCHES

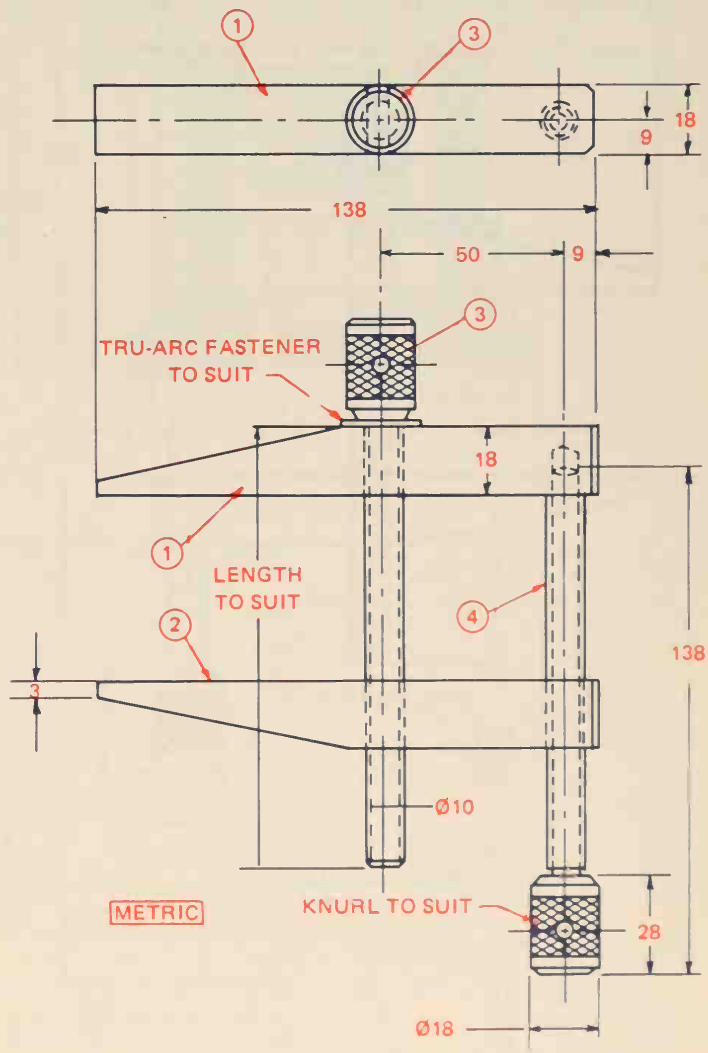
STRESS DUE TO MOMENT F × L AT d IS

$$\text{STRESS} = \frac{(F \times L)(d/2)}{(\pi d^4)/64} \text{ IN POUNDS PER SQUARE INCH}$$

Problem 24-12

Problem 24-13

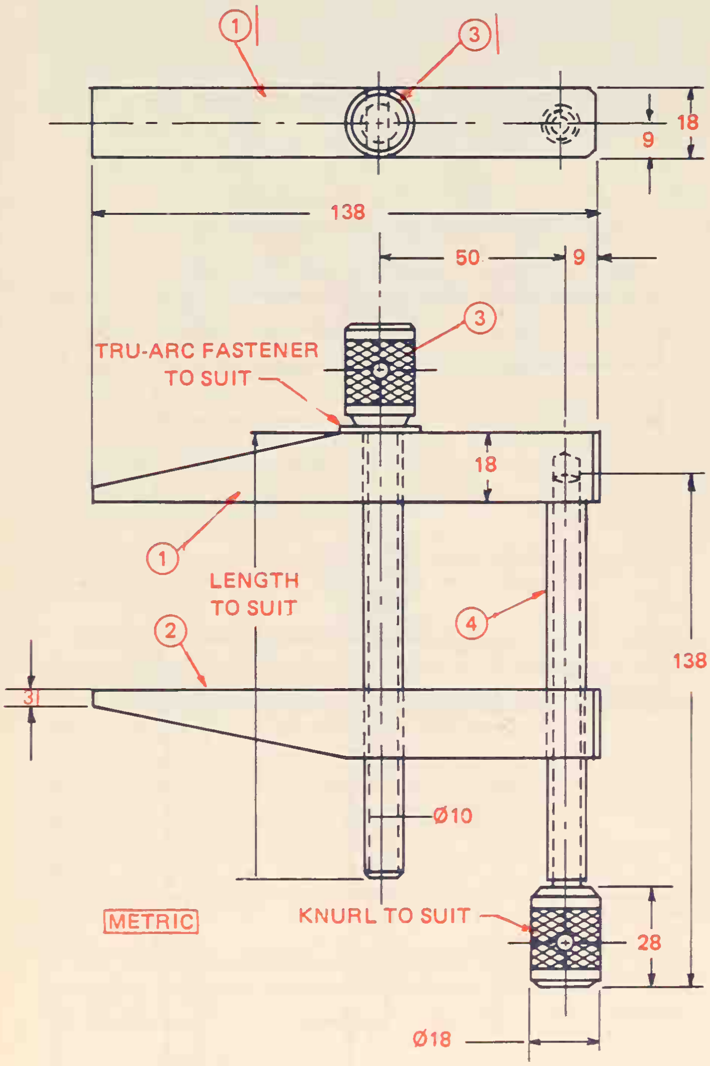
Refer to the clamp shown in Problem 24-13 and assume that parts No. 1 and No. 2 are to be aluminum, and parts No. 3 and No. 4 are steel. When threads in aluminum may be too weak because of the softer metal, a threaded-steel insert is pressed into the aluminum. Use an insert with appropriate threads inside and a nominal outside diameter of 15 mm, but dimensioned for an FN-2 medium drive fit. Increase the 18-mm dimension for parts No. 1 and No. 2 to 25 mm.



Problem 24-13

Problem 24-14

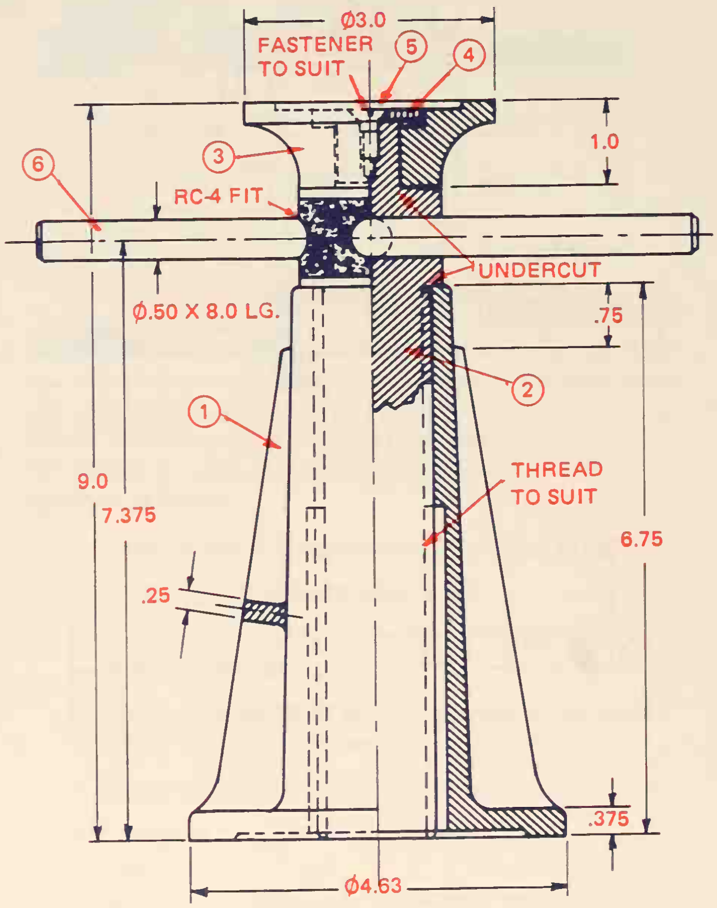
The clamp shown in Problem 24-14 needs to be modified to clamp rectangular assemblies 50 × 300 mm between the two threaded members instead of between the tapered extensions. The thread size should be increased 100% in diameter. Make any other changes that seem appropriate. Select materials. (Note: part No. 4 must function like part No. 3, and the tapered portions of parts No. 1 and No. 2 are no longer needed.)



Problem 24-14

Problem 24-15

Modify the screw jack shown in Problem 24-15 to have an 8-inch vertical movement instead of the apparent 4-inch vertical one.

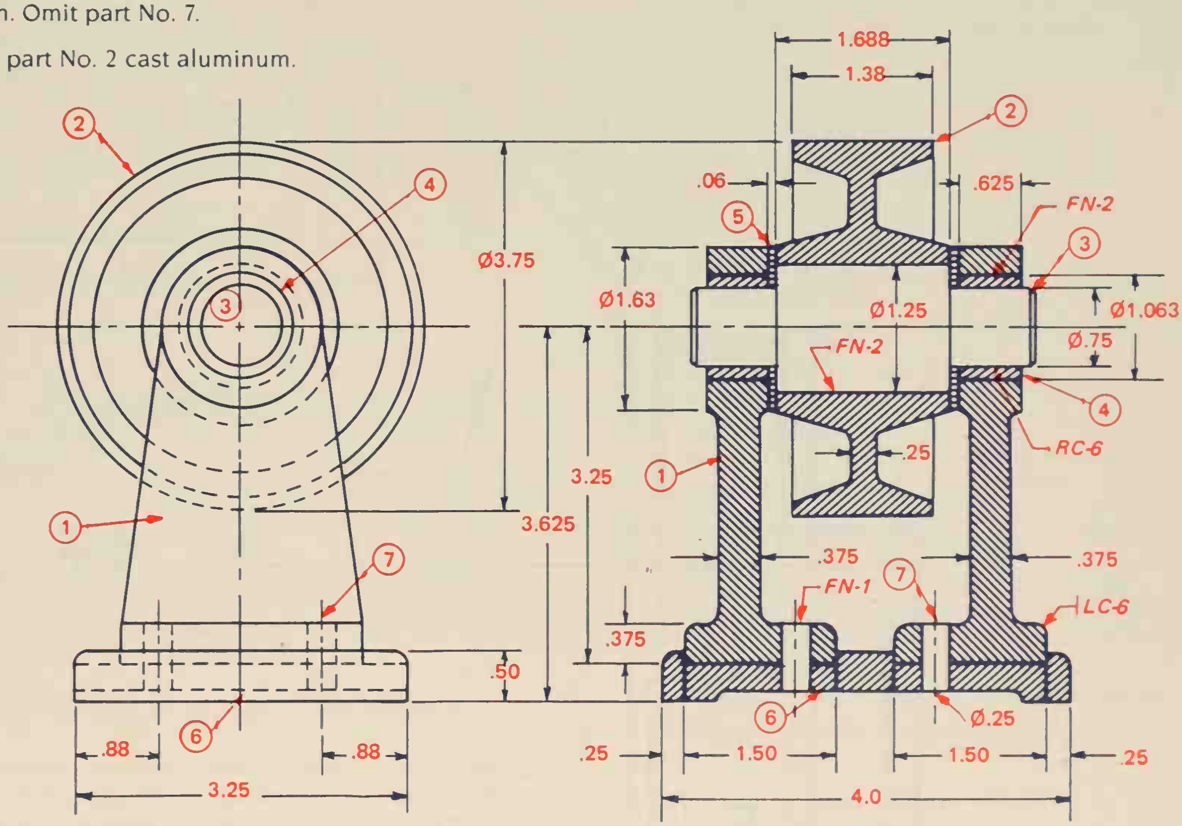


Problem 24-15

Problem 24-16

Modify the roller assembly shown in Problem 24-16 as follows:

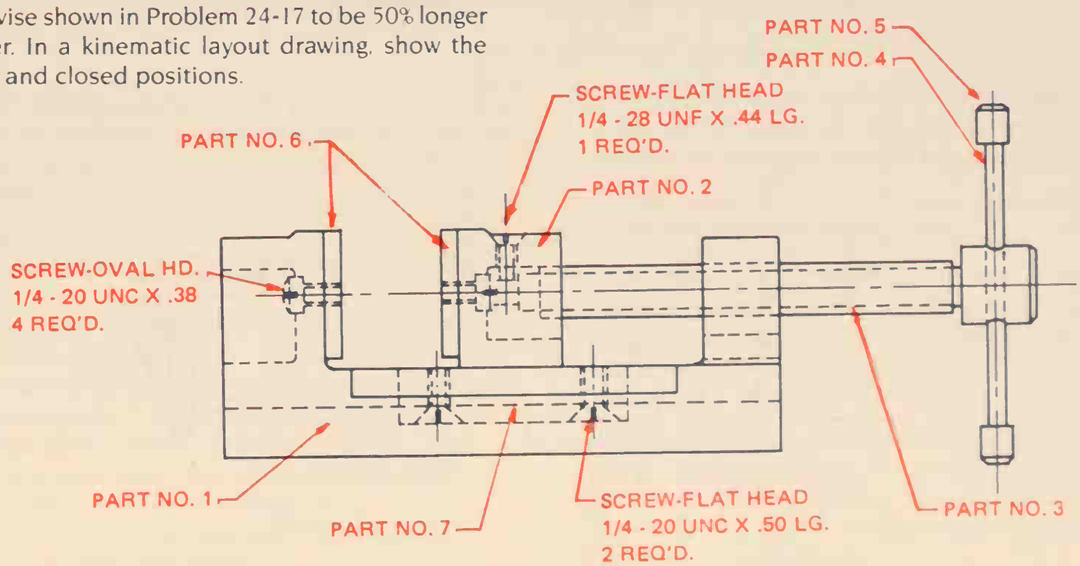
1. Use standard ball bearings in place of the bushings in part No. 1. Use an FN-2 medium drive fit for the bearings pressed into part No. 1.
2. Change parts No. 1 and No. 6 as indicated in the sketch. Omit part No. 7.
3. Make part No. 2 cast aluminum.



Problem 24-16

Problem 24-17

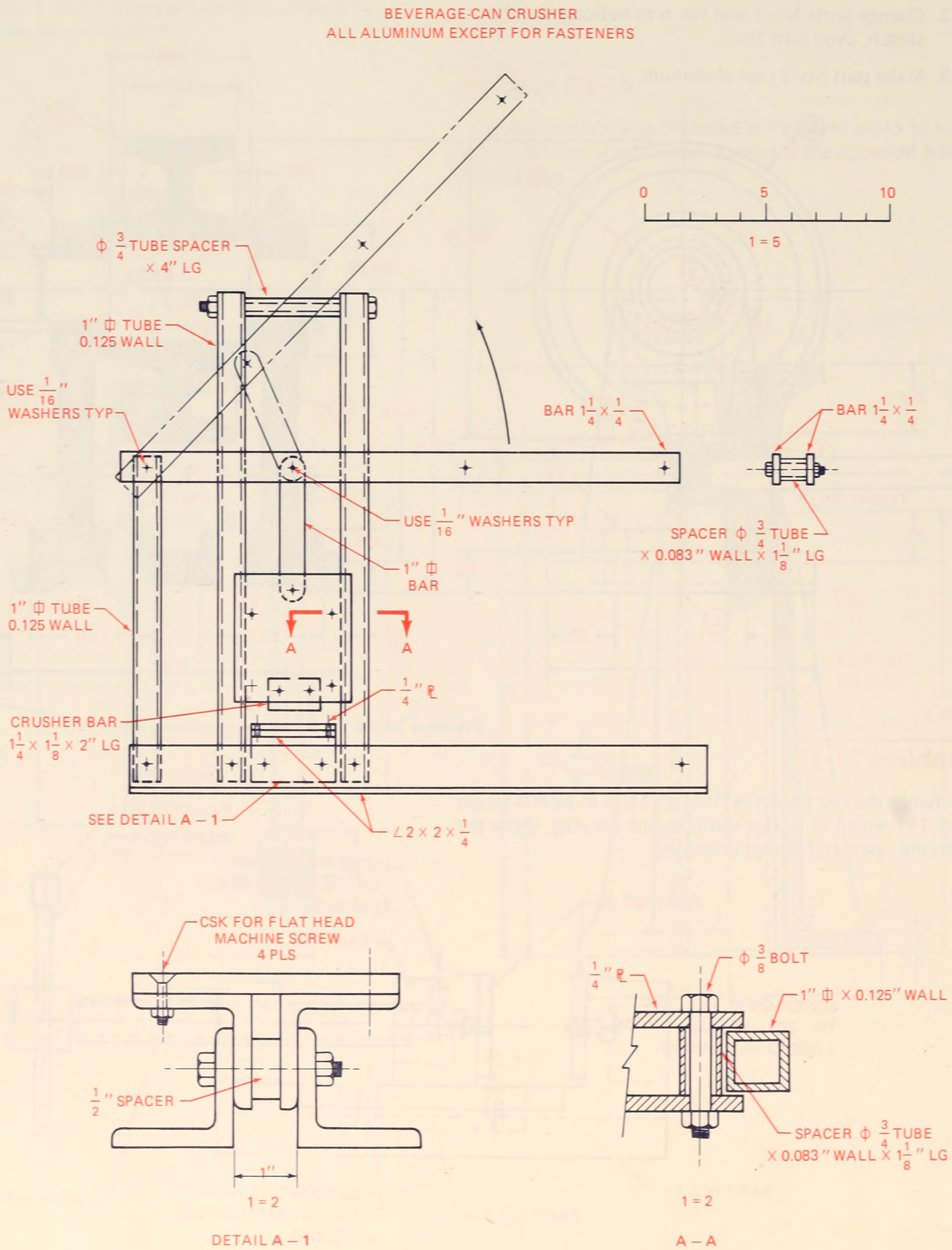
Change the vise shown in Problem 24-17 to be 50% longer and 75% wider. In a kinematic layout drawing, show the extreme open and closed positions.



Problem 24-17

Problem 24-18

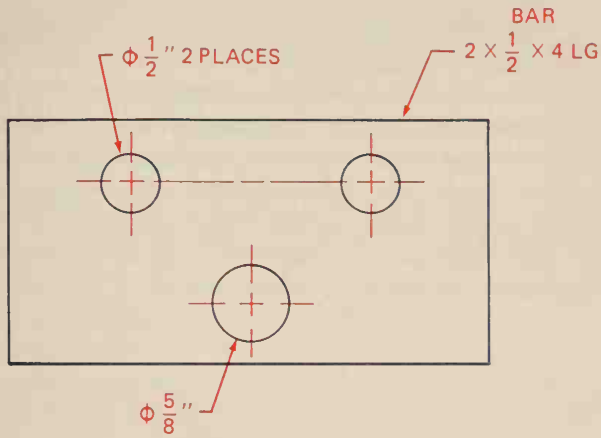
Develop the concept of the beverage can crusher shown in Problem 24-18. Use standard materials and parts as indicated. Include a kinematic layout drawing showing extreme positions of the crusher head.



Problem 24-18

Problem 24-19

Use press-fit drill-bushings with heads to make a leaf type jig, for the hole pattern shown in the part to be drilled.



Problem 24-19

Non-Routine Design Problems

The non-routine design problems listed or described here are intended to give students experience in the design process at least in Phases I-IV, which include Steps 1-11. Where possible, students are encouraged to build prototypes and discuss the other activities in Phase V, which includes Steps 12-14.

The following list includes the general sources for finding real problems.

1. School
   Classroom demonstrators of basic principles of chemistry, physics, statics, dynamics, mechanics of materials, engineering sciences, and manufacturing processes.

2. Handicapped
   a. Designs to help individuals confined to a wheelchair to:
      (i) Reach objects and prepare meals in a kitchen
      (ii) Obtain exercise
      (iii) Obtain access to heights higher than curbs
      (iv) Have access to classroom work surfaces
      (v) Have work surfaces on the wheelchair
   b. Designs to continually flex injured elbows and knee joints to accelerate healing.
   c. Designs to aid communications for individuals who have speech difficulties.

3. Hospitals
   a. Games or devices for children who are confined to a bed and have limited use of their arms.
   b. Devices to help injured individuals to perform simple functions such as dress, read, play games, and eat.

4. Civic Organizations
   a. Designs for YWCA or YMCA
   b. Designs to assist scouting programs such as neighborhood improvement projects

5. Local Industry
   a. Projects for the industry
   b. Projects for the industry's client

6. Private individuals (designs for)
   a. Home improvements
   b. Hobbies
   c. Inventions
   d. Invalid care

7. City (designs for)
   a. Better parking meters
   b. Playgrounds
   c. Park facilities
   d. Signs
   e. Junior Achievement

8. State (designs for)
   a. Signs
   b. National Parks
   c. Recreational facilities

9. National (designs for)
   a. Design contests (Alcoa, Lincoln Arc Welding, Engineering Societies . . .)
   b. Environment

10. International (designs for)
    a. Third World countries
    b. To help Peace Corp volunteers

Specific suggestions for non-routine design problems are as follows:

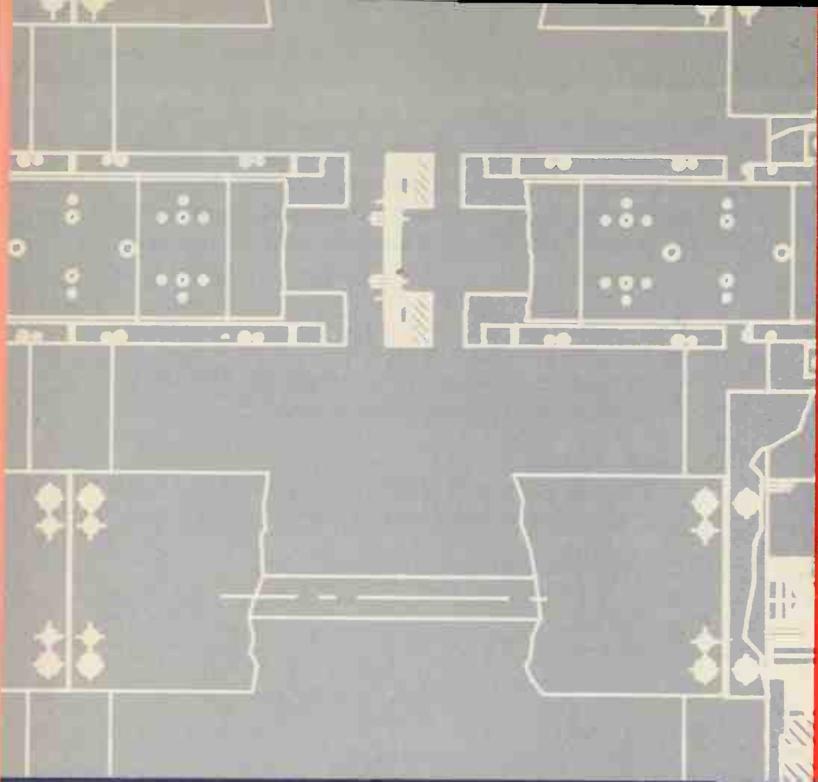
1. Design an inexpensive fruit dryer.

2. Design a device to assist an individual who has no legs, but full use of two arms, to get into a wheelchair from the floor, and back to the floor.

3. Design a device to lift a 150-pound handicapped person out of a swimming pool.

4. Design a means to get rid of moisture in beverage cans that come in truckloads to a recycling center. The driver usually needs to be paid within one-half hour, a realistic price based on the actual metal turned in.

5. Design a motorized vehicle to move one or more employees throughout a large industrial manufacturing plant or warehouse. The vehicle should be cost effective; that is, it should save enough time (money) to justify its use.



APPENDIX A

All technical occupations require the use of mathematics. The drafter is constantly involved with applied mathematics. Much of the mathematics is simply using the basic operations of addition, subtraction, multiplication, and division to compute drawing dimensions. However, a knowledge of the fundamentals of algebra, geometry, and trigonometry, as they relate to drafting applications, is essential. This chapter explains these essential functions in detail.

MECHANICAL DRAFTING MATHEMATICS

Mathematics for Drafters

The drafter is often required to solve problems by using formulas obtained from technical handbooks. Geometry is fundamental to mechanical technology: An engineering drawing is an example of applied geometry. Geometric principles are the bases of many dimension calculations and problem solutions. Trigonometry is used to compute unknown angles and sides of triangles. The drafter and designer often work with triangular configurations. Working dimensions must be determined in which parts of complex shapes are broken down into a series of triangles.

Problems encountered in fully defining details of parts or assemblies to be manufactured are often solved by using a combination of algebra, geometry, and trigonometry.

It is essential that the drafter develop the ability to analyze a problem and relate the mathematical principles that are involved in its solution. Then the problem must be solved in clear, orderly steps based on mathematical fact.

Rounding Decimal Fractions

When working with decimals, the computations and answers may contain more decimal places than are required. The number of decimal places needed depends on the degree of precision required. The degree of precision depends on how the decimal value is going to be used. *Rounding a decimal* means expressing the decimal with fewer decimal places.

Procedure: To round a decimal fraction

- Determine the number of decimal places required in an answer.
- If the digit directly following the last decimal place required is less than 5, drop all digits that follow the required number of decimal places.
- If the digit directly following the last decimal place required is 5 or larger, add one to the last required digit and drop all digits that follow the required number of decimal places.

Example 1: Round 0.68247 in to three decimal places.
The digit following the third decimal place is 4.
0.684④7 in.
Because 4 is less than 5, drop all digits after the third decimal place.
0.682 in Ans

Example 2: Round 12.3876 mm to two decimal places.
The digit following the second decimal place is 7.
12.38⑦6 mm
Because 7 is greater than 5, add 1 to the 8.
12.39 mm Ans

Example 3: Round 3.918256 in to four decimal places.
The digit following the fourth decimal place is 5.
3.9182⑤6 in
Therefore, add 1 to the 2.
3.9183 in Ans

Expressing Common Fractions as Decimal Fractions

Given or computed common = fraction values are often converted to decimal = fraction dimensions.

A common fraction is an indicated division. For example, 7/16 is the same as 7 ÷ 16. Because the numerator and the denominator of a common fraction are both whole numbers, expressing a common fraction as a decimal fraction requires division with whole numbers.

Procedure: To express a common fraction as a decimal fraction divide the numerator by the denominator.

Example: Express 7/8 in as a decimal.
Divide the numerator 7 by the denominator 8.

$$8\overline{)7.000}\quad = 0.875$$

Decimal Equivalent Tables

Generally, fractional engineering drawing dimensions are given in multiples of 64ths of an inch. Decimal equivalent tables are widely used in the manufacturing industry. Many of the equivalents are memorized after using the tables for a period of time. Some of the decimals listed in the table are given to six places. A decimal is rounded to the degree of precision required for a particular application. The amount of computation and the chances of error can be reduced by using the decimal equivalent table shown in Figure A-1.

The following examples illustrate the use of the decimal equivalent table.

Example 1: Find the decimal equivalent of 7/32 in. The decimal equivalent is shown directly to the right of the common fraction.
7/32 in = 0.21875 in Ans

DECIMAL EQUIVALENT TABLE

Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal
1/64	.015625	17/64	.265625	33/64	.515625	49/64	.765625
1/32	.03125	9/32	.28125	17/32	.53125	25/32	.78125
3/64	.046875	19/64	.296875	35/64	.546875	51/64	.796875
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.078125	21/64	.328125	37/64	.578125	53/64	.828125
3/32	.09375	11/32	.34375	19/32	.59375	27/32	.84375
7/64	.109375	23/64	.359375	39/64	.609375	55/64	.859375
1/8	.125	3/8	.375	5/8	.625	7/8	.875
9/64	.140625	25/64	.390625	41/64	.640625	57/64	.890625
5/32	.15625	13/32	.40625	21/32	.65625	29/32	.90625
11/64	.171875	27/64	.421875	43/64	.671875	59/64	.921875
3/16	.1875	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.203125	29/64	.453125	45/64	.703125	61/64	.953125
7/32	.21875	15/32	.46875	23/32	.71875	31/32	.96875
15/64	.234375	31/64	.48438	47/64	.734375	63/64	.984375
1/4	.250	1/2	.500	3/4	.750	1	1.000

Figure A-1 Decimal equivalent table

Example 2: Find the fractional equivalent of 0.8125 in. The fractional equivalent is shown directly to the left of the decimal fraction.
0.8125 in = 13/16 in Ans

Example 3: Find the nearer fractional equivalent of 0.757 in. The decimal 0.757 lies between 0.750 and 0.765625. The difference between 0.757 and 0.750 is 0.007. The difference between 0.757 and 0.765625 is 0.008625. Since 0.007 is less than 0.008625, the 0.750 value is closer to 0.757. The nearer fractional equivalent of 0.757 in is therefore 3/4 in.

Millimetre - Inch Equivalents (Conversion Factors)

Since the English and the metric systems are both used in this country, it is sometimes necessary to express equivalents between systems. Metric-English equivalents other than millimetre-inch are seldom used in mechanical technology.

The relationship between English decimal inch units and metric millimetre units is shown by comparing the scales in Figure A-2.

1 inch (in) = 25.4 millimetres (mm)
1 millimetre (mm) = 0.03937 inch (in)

Procedure: To express a dimension given in inches as an equivalent dimension in millimetres, multiply the inch value by 25.4 mm.

Example: Express 1.278 in millimetres. Round the answer to two decimal places.
Multiply 1.278 by 25.4 mm.
1.278 × 25.4 mm = 32.46 mm Ans

Procedure: To express a dimension given in millimetres as an equivalent dimension in inches, multiply the millimetre value by 0.03937 inch.

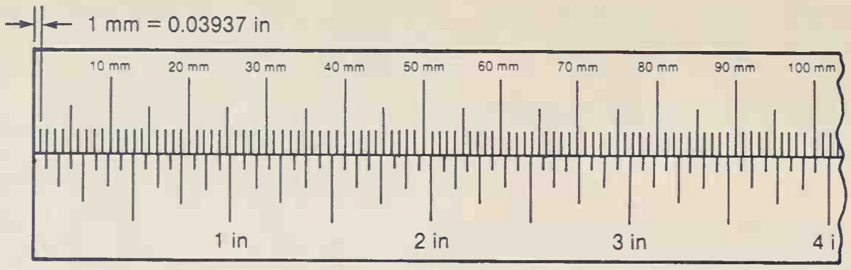


Figure A-2 Decimal inch - millimetre scales

Example: Express 68.74 mm in inches. Round the answer to three decimal places.
Multiply 68.74 by 0.03937 in.
68.74×0.03937 in = 2.706 in Ans

Example: The template shown in Figure A-3 is dimensioned in millimetres. Determine, in inches, the total length of the template. Round the answer to three decimal places. *Do not* express each of the dimensions as inches. Add the dimensions as they are given and express the sum in inches.

87.63 mm + 102.34 mm + 98.75 mm = 288.72 mm
Multiply 288.72 by 0.03937 in:
288.72×0.03937 in = 11.367 in Ans

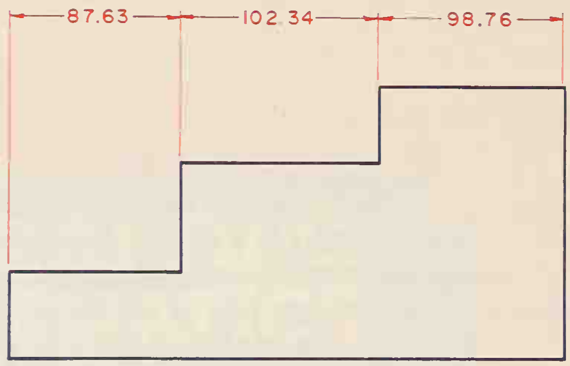


Figure A-3 Template

Evaluating Formulas

By letters and other symbols, generalizations called *formulas* can be stated mathematically. A formula uses symbols to show the relationship between quantities. Problems are often solved by using formulas found in technical manuals and other reference materials.

Procedure: To solve (evaluate) a formula substitute the numerical values for the letter values and solve by following the order of operations of arithmetic. The order of operations follows:

- Do all operations within the grouping symbol first. Parentheses, the fraction bar, and the radical symbol are used to group numbers. If an expression contains parentheses within parentheses or brackets, do the work within the innermost parentheses first.
- Do powers and roots next. The operations are performed in the order in which they occur. If a root consists of two or more operations within the radical symbol, perform all the operations within the radical symbol, then extract the root.
- Do multiplication and division next in the order in which they occur.
- Do addition and subtraction last in the order in which they occur.

Example 1: Determine the outside diameter of a gear with 16 teeth and a circular pitch of 0.7854 in. Use the formula

$$D_O = \frac{P_c(N + 2)}{3.1416}$$

where D_O = outside diameter
P_c = circular pitch
N = number of teeth

Substitute the given numerical values for the letter values.

$$D_O = \frac{0.7854(16 + 2)}{3.1416}$$

Do the work in parentheses.

$$D_O = \frac{0.7854(18)}{3.1416}$$

Multiply.

$$D_O = \frac{14.1372}{3.1416}$$

Divide.

D_O = 4.5000 in Ans

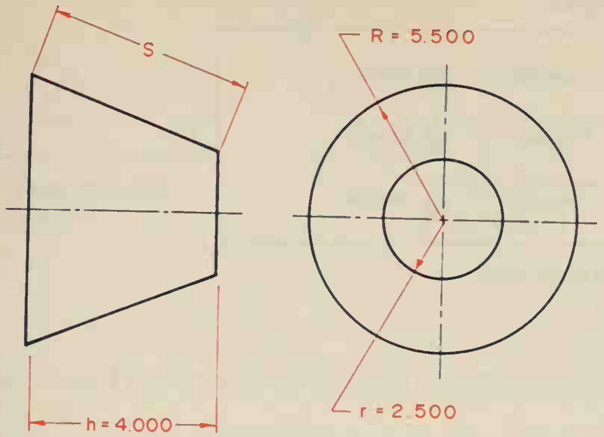


Figure A-4

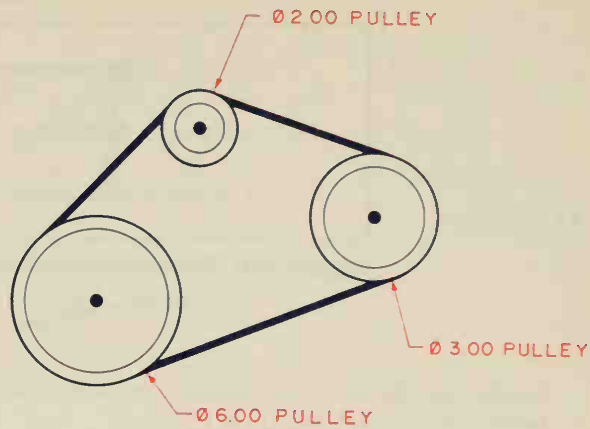


Figure A-5 Pulley system

***Example* 2:** The dimensions in Figure A-4 are given in inches. Refer to the figure and determine slant height(s) by using the formula

$$S = \sqrt{(R - r)^2 + h^2}.$$

Substitute numerical values for letter values.

$S = \sqrt{(5.500 - 2.500)^2 + 4.000^2}$

Do the work within the grouping (radical) symbol. Do the work in parentheses.

$S = \sqrt{3.000^2 + 4.000^2}$

Compute powers within the radical symbol.

$S = \sqrt{9.000 + 16.000}$

Add the values within the radical symbol.

$S = \sqrt{25.000}$

Extract the root.

$S = 5.000$ in Ans

Ratio and Proportion

Ratios

Ratio and proportion are widely used in manufacturing applications, such as computing gear sizes and speeds.

Ratio is the comparison of two *like* quantities. The terms of a ratio are the two numbers that are compared. Both terms of a ratio must be expressed in the same units of measure. Ratios are generally expressed with a colon between the two terms, such as 3:8 (which is read 3 to 8) or as a fraction: 3/8.

The terms of a ratio must be compared in the order in which they are given. The first term is the numerator of a fraction, and the second is the denominator.

***Examples*:**

1. The ratio 2 to 3 = 2 ÷ 3 = 2/3.
2. The ratio 3 to 2 = 3 ÷ 2 = 3/2.
   Generally, a ratio should be expressed in lowest fractional terms.

***Examples*:** A pulley is shown in Figure A-5.

1. The ratio of the 2-in diameter pulley to the 6-in diameter pulley is 2 to 6 = 2/6 = 1/3.
2. The ratio of the 6-in pulley to the 3-in pulley is 6 to 3 = 6/3 = 2/1.

Proportions

A *proportion* is an expression that states the equality of two ratios. Proportions are expressed in the following two ways:

1. 3:4 :: 6:8, which is read: "3 is to 4 as 6 is to 8."
2. 3/4 = 6/8. This form is the usual way to write a proportion.

A proportion consists of four terms. The first and the fourth terms are called *extremes*, and the second and third terms are called the *means*.

***Example*:** 7/16 = 14/32. 7 and 32 are the extremes; 16 and 14 are the means.

In a proportion the product of the means equals the product of the extremes. If the terms are cross multiplied, their products are equal.

***Example*:** 3/4 = 6/8

Cross Multiply. 3/4 × 6/8

$3 \times 8 = 4 \times 6$

$24 = 24$

The method of cross multiplying is used in solving proportions that have an unknown term. After the terms have been cross multiplied, the division principle of equality is applied.

***Example* 1:** $\frac{X}{7.5} = \frac{23.4}{20}$. Solve for the value of X.

Cross multiply.

$20X = 7.5\,(23.4)$

$20X = 175.5$

DECIMAL INCH SCALE

1 circle	= 360 degrees	1 degree	= $\frac{1}{360}$ circle
1 degree	= 60 minutes	1 minute	= $\frac{1}{60}$ degree
1 minute	= 60 seconds	1 second	= $\frac{1}{60}$ minute

Figure A-6 Relationship of degrees, minutes, and seconds

Apply the division principle of equality. Divide both sides of the equation by 20.

$$\frac{20X}{20} = \frac{175.5}{20}$$

X = 8.775 Ans

Example 2: $\frac{80\text{ mm}}{150\text{ mm}} = \frac{70\text{ mm}}{X}$. Solve for the value of X.

Cross multiply.

80X = 150(70 mm)

80X = 10,500 mm

Apply the division principle of equality. Divide both sides of the equation by 80.

$$\frac{80X}{80} = \frac{10,500\text{ mm}}{80}$$

X = 131.25 mm Ans

Arithmetic Operations on Angles Expressed in Degrees, Minutes, and Seconds

The *degree* is the basic unit of angular measure. The symbol ° means degree. A radius rotated one revolution makes a complete circle or 360°. In the English system, computations and measurements are in degrees and minutes. Degrees, minutes, and seconds are used for applications requiring precise angular measurement.

A degree is divided into 60 equal parts called *minutes*. The symbol for minute is ′. A minute is divided into 60 equal parts called *seconds*. The symbol for second is ″. The relationship of degrees, minutes, and seconds is shown in Figure A-6.

Adding Angles Expressed in Degrees, Minutes, and Seconds

Example 1: Determine ∠1 in Figure A-7.

∠1 = 43°50′ + 81°37′

$$\begin{array}{r} 43°50' \\ +\ 81°37' \\ \hline 124°87' \end{array} = 125°27' \text{ Ans}$$

Note: 87′ = 60′ + 27′ = 1°27′; therefore, 124°87′ = 125°27′.

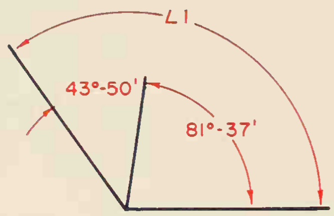


Figure A-7

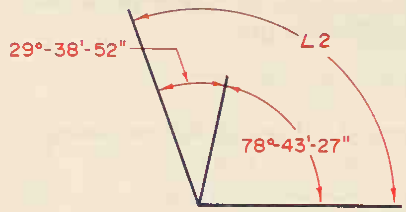


Figure A-8

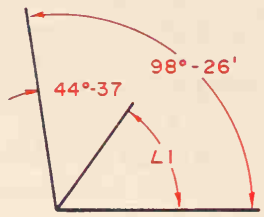


Figure A-9

Example 2: Determine ∠2 in Figure A-8.

∠2 = 78°43′27″ + 29°38′52″

$$\begin{array}{r} 78°43'27'' \\ +\ 29°38'52'' \\ \hline 107°81'79'' \end{array} = 107°82'19'' = 108°22'19'' \text{ Ans}$$

Note: 79″ = 60″ + 19″ = 1′19″; therefore, 107°81′79″ = 107°82′19″.

82′ = 60′ + 22′ = 1°22′; therefore, 107°82′19″ = 108°22′19″.

Subtracting Angles Expressed in Degrees, Minutes, and Seconds

Example 1: Determine ∠1 in Figure A-9.

∠1 = 98°26′ − 44°37′

$$\begin{array}{r} 98°26' = 97°86' \\ -\ 44°37' = 44°37' \\ \hline 53°49' \end{array} \text{ Ans}$$

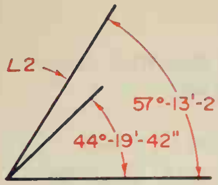


Figure A-10

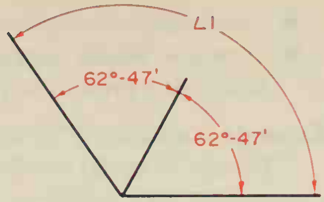


Figure A-11

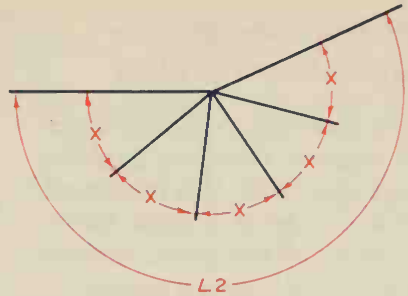


Figure A-12

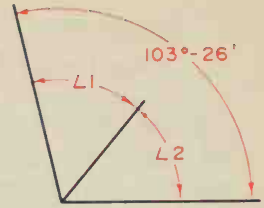


Figure A-13

Note: Since 37' cannot be subtracted from 26', express 1° as 60'.
98°26' = 97° + 1° + 26' = 97° + 60' + 26' = 97°86'.

Example 2: Determine ∠2 in Figure A-10.

∠2 = 57°13'28'' − 44°19'88''

```
  57°13'28'' = 56°73'28'' = 56°72'88''
− 44°19'42'' = 44°19'42'' = 44°19'42''
                            12°53'46'' Ans
```

Note: Since 19' cannot be subtracted from 13', and 42'' cannot be subtracted from 28'', express 1° as 60' and 1' as 60''.
57°13'28'' = 56° + 1° + 13' + 28'' = 56°73'28'' = 56°72' + 1' + 28'' = 56°72'88''.

Multiplying Angles Expressed in Degrees, Minutes, and Seconds

Example 1: Determine ∠1 in Figure A-11.

∠1 = 2(62°47')

```
  62°47'
 ×    2
 124°94' = 125°34' Ans
```

Note: 94' = 1°34'.

Example 2: Refer to Figure A-12 . Determine ∠2 when x = 41°27'42''.

∠2 = 5x = 5(41°27'42'')

```
    41°27'42''
  ×          5
205°135'210'' = 205°138'30'' = 207°18'30'' Ans
```

Note: 210'' = 3'30'' and 138' = 2°18'.

Dividing Angles Expressed In Degrees, Minutes, and Seconds

Example 1: Determine ∠1 and ∠2 in Figure A-13.

∠1 = ∠2 = 103°26' ÷ 2

Divide 103° by 2.

```
    51°
2)103°
  102°
    1°
```

103 ÷ 2 = 51° plus a remainder of 1°

Add the 1° (60') to the 26'.
60' + 26' = 86'.

Divide 86' by 2.

```
   43'
2)86'
```

86' ÷ 2 = 43'

Combine degrees and minutes.
51° + 43' = 51°43' Ans

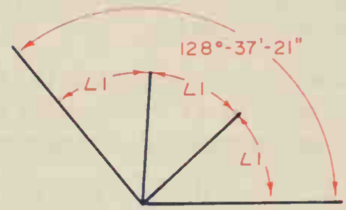


Figure A-14

Example 2: Determine ∠1, ∠2, and ∠3 in Figure A-14.

∠1 = ∠2 − ∠3 = 128°37'21'' ÷ 3

Divide 128' by 3.

```
    42°
3)128°
  126°
    2°
```

128 ÷ 3 = 42° plus a remainder of 2°.

Add the 2° (120') to the 37'.
120' + 37' = 157'

Divide 157' by 3.

```
    52'
3)157'
  156'
    1'
```

157' ÷ 3 = 52' plus a remainder of 1'.

Add the 1' (60'') to the 21''.
60'' + 21'' = 81''.

Divide 81'' by 3.

```
   27''
3)81''
```

81'' ÷ 3 = 27''

Combine.
42° + 52' + 27'' = 42°52'27'' Ans

Degrees, Minutes, Seconds — Decimal Degree Conversion

In the metric system the preferred method of angular measure is decimal degrees. However, degrees, minutes, and seconds are also used. It is important to be able to compute and express angular measurements in both the English and the metric systems and to express angular measure between systems.

Expressing Decimal Degrees As Degrees, Minutes, and Seconds

The measure of an angle given in the form of decimal degrees, such as 41.1938°, must often be expressed as degrees, minutes, and seconds.

Procedure: To express decimal degrees as degrees, minutes, and seconds.

- Multiply the decimal part of the degrees by 60′ in order to obtain minutes.
- If the number of minutes obtained is not a whole number, multiply the decimal part of the minutes by 60″ in order to obtain seconds. Round to the nearer whole second if necessary.
- Combine degrees, minutes, and seconds.

Example: Express 47.1938° as degrees, minutes, and seconds.

Multiply 0.1938 by 60′ to obtain minutes.
60′(0.1938) = 11.6280′
Multiply 0.6280 by 60″ to obtain seconds.
60″(0.6280) = 38″
Round to the nearer whole second.
Combine degrees, minutes, and seconds.
47° + 11′ + 38″ = 47°11′38″ Ans

Expressing Degrees, Minutes, and Seconds As Decimal Degrees.

Often an angle given in degrees and minutes is to be expressed as decimal degrees.

Procedure: To express degrees and minutes as decimal degrees

- Divide the minutes by 60.
- Combine whole degrees and decimal degrees. Round the answer to two places.

Example: Express 76°29′ as decimal degrees.

Divide 29 by 60 to obtain decimal degrees.
29 ÷ 60 = 0.48°
Combine whole degrees with decimal degrees.
76° + 0.48 = 76.48° Ans

When working with English and metric units of measure, it may be necessary to express angles given in degrees, minutes, and seconds as angles in decimal degrees.

Procedure: To express degrees, minutes, and seconds as decimal degrees

- Divide the seconds by 60 in order to obtain decimal minutes.
- Combine whole minutes and decimal minutes.
- Divide the total minutes by 60 in order to obtain decimal degrees.
- Combine whole degrees and decimal degrees. Round the answer to four decimal places.

Example: Express 23°18′44″ as decimal degrees.

Divide 44 by 60 to obtain decimal minutes.
44 ÷ 60 = 0.7333′
Combine whole minutes and decimal minutes.
18′ + 0.7333′ = 18.7333′
Divide 18.7333 by 60 to obtain decimal degrees.
18.7333 ÷ 60 = 0.3122°
Combine whole degrees with decimal degrees.
23° + 0.3122° = 23.3122° Ans

Types of Angles

An *acute angle* is an angle that is less than 90°. Angle 1 in Figure A-15 is acute.

A *right angle* is an angle of 90°. Angle A in Figure A-16 is a right angle.

An *obtuse angle* is an angle greater than 90° but less than 180°. Angle ABC in Figure A-17 is an obtuse angle.

A *straight angle* is an angle of 180°. A straight line is a straight angle. Line EFG in Figure A-18 is a straight angle.

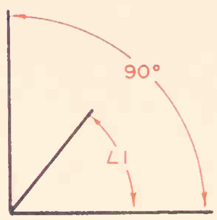


Figure A-15
Acute angle

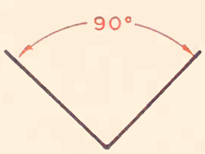


Figure A-16
Right angle

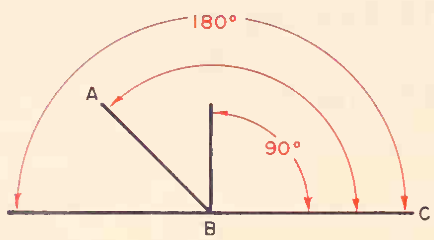


Figure A-17
Obtuse angle

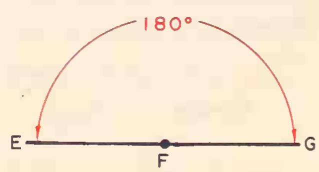


Figure A-18
Straight angle

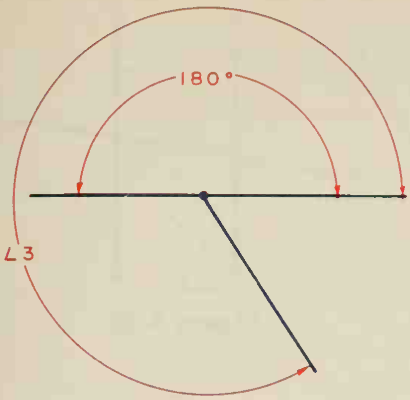


Figure A-19 Reflex angle

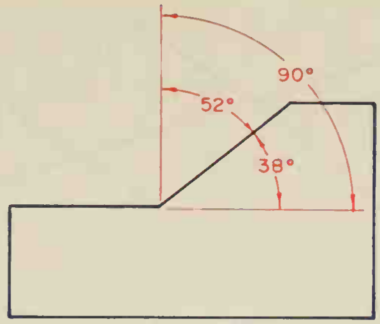


Figure A-20 Complementary angles

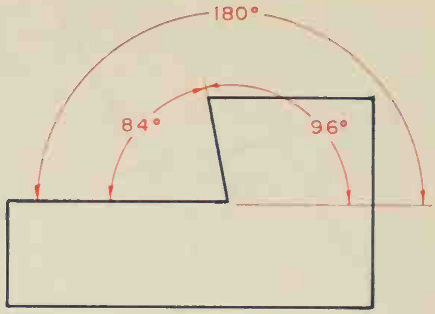


Figure A-21 Supplementary angles

A *reflex angle* is an angle greater than 180° and less than 360°. Angle 3 in Figure A-19 is a reflex angle.

Two angles are *complementary* when their sum is 90°. For example, 38° + 52° = 90°. Therefore, 38° is the complement of 52°, and 52° is the complement of 38°. Refer to Figure A-20.

Two angles are *supplementary* when their sum is 180°. For example, 84° + 96° = 180°. Therefore, 84° is the supplement of 96°, and 96° is the supplement of 84°. Refer to Figure A-21.

Two angles are *adjacent* if they have a common side and a common vertex. A *vertex* is the point where the two lines forming the angle meet. Angles 1 and 2 in Figure A-22 are adjacent since they both contain the common side BC and the common vertex B. Angles 3 and 4 in Figure A-23 are *not* adjacent because they do not have a common vertex.

Angles Formed by a Transversal

A *transversal* is a line that intersects (cuts) two or more lines. Refer to Figure A-24. Line EF is a transversal since it cuts lines AB and CD.

Alternate interior angles are pairs of interior angles on opposite sides of the transversal. The angles have different vertices. For example, angles 3 and 5 and angles 4 and 6 are alternate interior angles.

Corresponding angles are pairs of angles, one interior and one exterior, on the same side of the transversal. The angles have different vertices. For example, angles 1 and 5, 2 and 6, 3 and 7, and 4 and 8 are corresponding angles.

If two parallel lines are intersected by a transversal, then the alternate interior angles are equal.

Refer to Figure A-25. Given: AB || CD. (The symbol || means parallel.) Conclusion: ∠3 = ∠5; therefore ∠5 = 62°; ∠4 = ∠6; therefore ∠6 = 118°.

If two lines are intersected by a transversal and a pair of alternate interior angles are equal, then the lines are parallel. Refer to Figure A-26. Given: ∠1 = 70°, ∠2 = 70°; ∠1 = ∠2. Conclusion: AB || CD.

If two parallel lines are intersected by a transversal, then the corresponding angles are equal. Refer to Figure A-27. Given: AB || CD. Conclusion: ∠1 = ∠5 = 57°, ∠2 = ∠6 = 123°, ∠3 = ∠7 = 57°, ∠4 = ∠8 = 123°.

If two lines are intersected by a transversal and a pair of corresponding angles are equal, then the lines are parallel. Refer to Figure A-28. Given: ∠1 = 95°, ∠2 = 95°; ∠1 = ∠2. Conclusion: AB || CD.

Types of Triangles

A *polygon* is a closed plane figure formed by three or more straight-line segments.

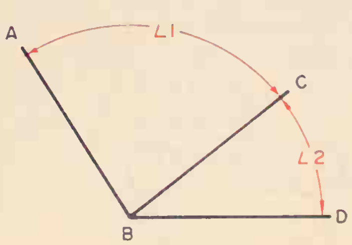


Figure A-22

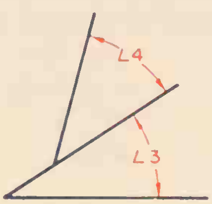


Figure A-23

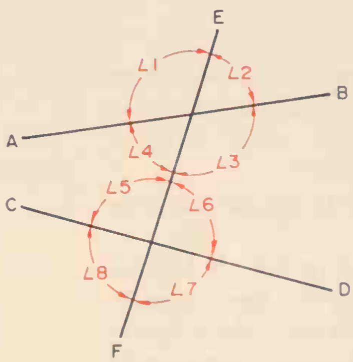


Figure A-24

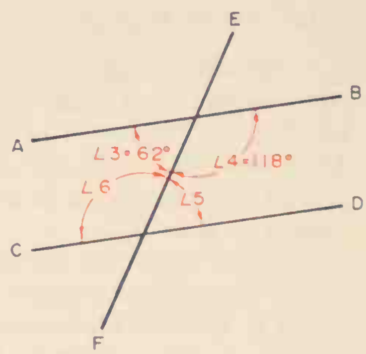


Figure A-25

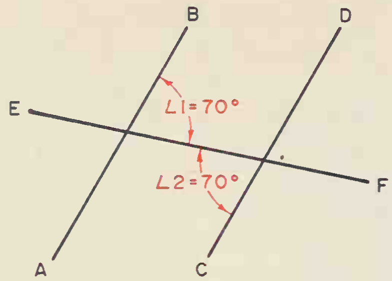


Figure A-26

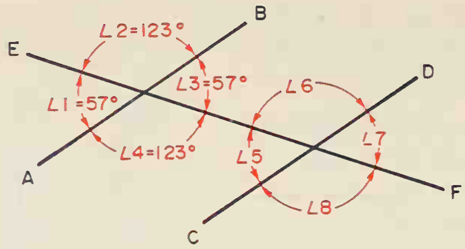


Figure A-27

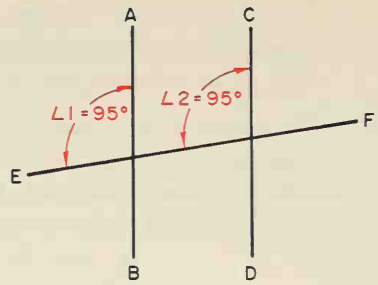


Figure A-28

A *triangle* is a three-sided polygon; it is the simplest kind of polygon.

The sum of the three angles of any triangle equals 180°.

Scalene Triangle

A *scalene triangle* has three unequal sides. It also has three unequal angles. Triangle ABC shown in Figure A-29 is scalene. Sides AB, AC, and BC are unequal, and angles A, B, and C are unequal.

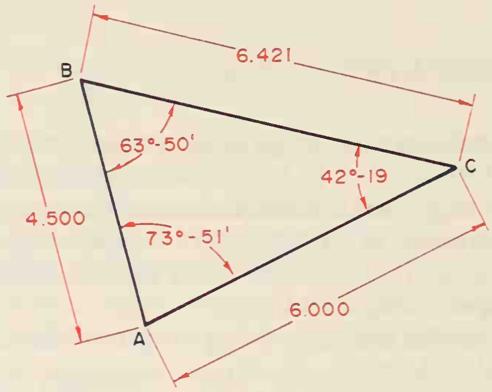


Figure A-29 Scalene triangle

Isosceles Triangle

An *isosceles triangle* has two equal sides, called *legs*, and two equal *base angles* (the angles opposite the legs). In isosceles triangle EFG in Figure A-30, leg EF = leg FG = 27.60 mm and base ∠E base ∠G = 40°.

In an isosceles triangle an altitude to the base bisects the base and the vertex angle.

An *altitude* is a line drawn from a vertex perpendicular to the opposite side.

To *bisect* means to divide into two equal parts.

Isosceles triangle ABC in Figure A-31 is formed by the intersection of center lines between holes A, B, and C. Altitude CD bisects base AB; AD = DB = 6.840 ÷ 2 = 3.420 in. Altitude CD bisects vertex angle ACB; ∠1 = ∠2 = 71°38' ÷ 2 = 35°49'.

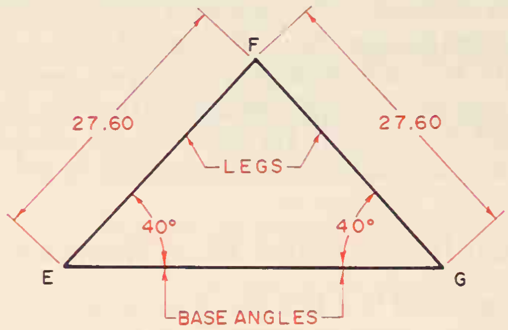


Figure A-30 Isosceles triangle

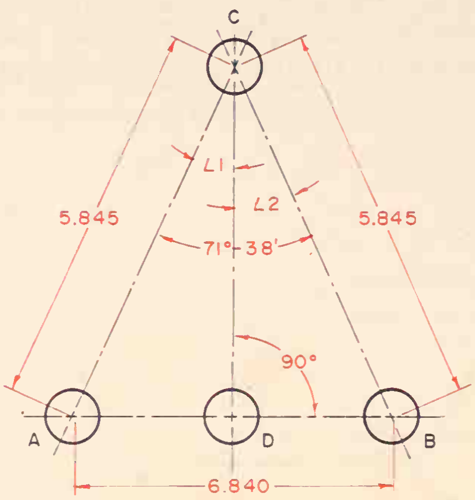


Figure A-31

Equilateral Triangle

An *equilateral triangle* has three equal sides and three equal angles, each equal to 60°. In equilateral triangle DEF in Figure A-32, sides DE = DF = EF = 37.86 mm and ∠D = ∠E = ∠F = 60°.

In an equilateral triangle an altitude to any side bisects the side and the vertex angle.

Equilateral triangle HJK in Figure A-33 is formed by the intersection of center lines between holes H, J, and K. Altitude MJ bisects side HK; HM = MK = 4.500 − 2.250 in. Altitude MJ bisects vertex angle HJK; ∠1 = ∠2 = 60 − 2 = 30°.

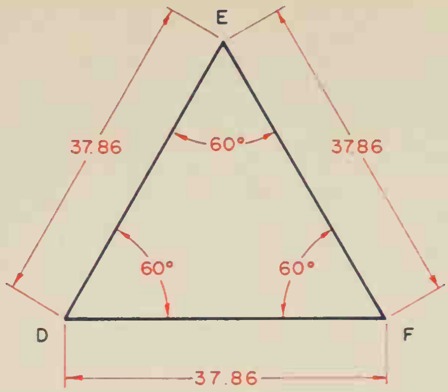


Figure A-32 Equilateral triangle

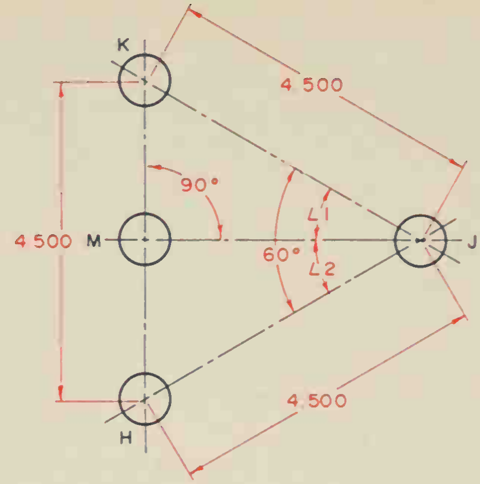


Figure A-33

Right Triangle

A *right triangle* has one right or 90° angle. The side opposite the right angle is called the *hypotenuse*. The other two sides are called *legs*. In right triangle EFG in Figure A-34, ∠E = 90°, and FG is the hypotenuse.

In a right triangle the square of the hypotenuse is equal to the sum of the squares of the other two sides. This principle, called the *Pythagorean Theorem*, is often used for solving drafting problems. As applied to the right triangle with sides *a*, *b*, and *c* (hypotenuse) shown in Figure A-35, the Pythagorean Theorem formula is expressed as *a*, *b*, and *c* (hypotenuse) shown in Figure A-35, the Pythagorean Theorem formula is expressed as $c^2 = a^2 + b^2$.

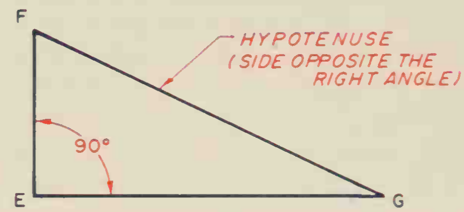


Figure A-34 Right triangle

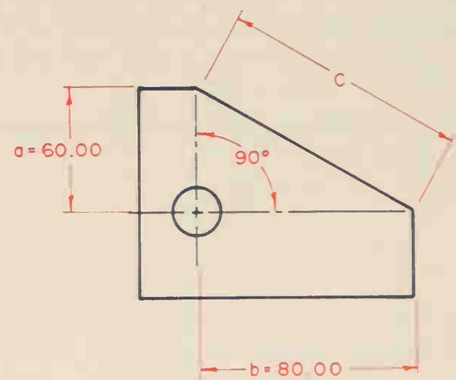


Figure A-35

Example 1: Solve for side *c* when side $a = 60.00$ mm and side $b = 80.00$ mm, as shown in Figure A-35.

$c^2 = a^2 + b^2$

Substitute the given values and solve for *c*.

$c^2 = (60.00\text{ mm})^2 + (80.00\text{ mm})^2$

$c^2 = 3600\text{ mm}^2 + 6400\text{ mm}^2$

$c^2 = 10{,}000\text{ mm}^2$

Add terms. Apply the root principle of equality. Extract the square root of both sides of the equation.

$\sqrt{c^2} = \sqrt{10{,}000\text{ mm}^2}$

$c^2 = 100.00$ mm Ans

Example 2: In right triangle EFG in Figure A-36, side $g = 5.800$ in and hypotenuse $e = 7.200$ in. Determine side *f*.

$e^2 = f^2 + g^2$

Substitute the given values and solve for *f*.

$(7.200\text{ in})^2 = f^2 + (5.800\text{ in})^2$

$51.840\text{ sq in} = f^2 + 33.640\text{ sq in}$

Apply the subtraction principle of equality. Subtract 33.640 sq in from both sides of the equation.

$$\begin{array}{rcl} 51.840\text{ sq in} & = & f^2 + 33.640\text{ sq in} \\ \underline{-\ 33.640\text{ sq in}} & & \underline{-\ 33.640\text{ sq in}} \\ 18.200\text{ sq in} & = & f^2 \end{array}$$

Extract the square root.

$\sqrt{18.200\text{ sq in}} = \sqrt{f^2}$

$4.266\text{ in} = f^2$

$f^2 = 4.266$ in Ans

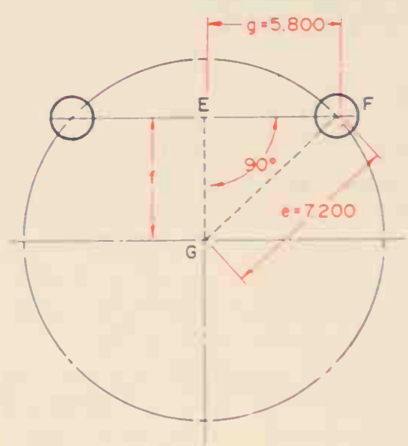


Figure A-36

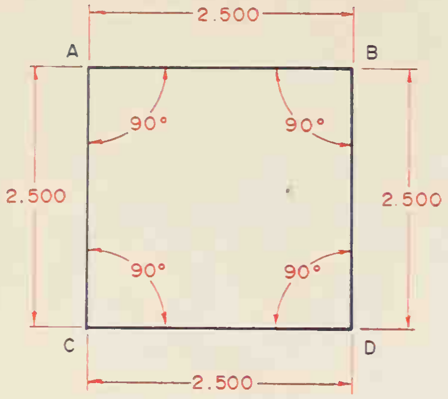


Figure A-37 Square

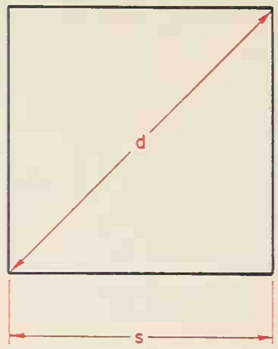


Figure A-38

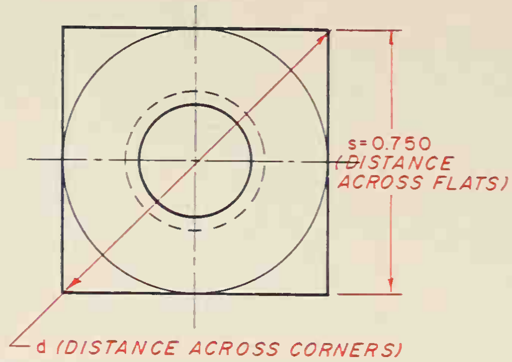


Figure A-39

Common Polygons

The types of polygons most widely used in drafting in addition to triangles are squares, rectangles, parallelograms, and regular hexagons. A *regular polygon* is one with equal sides and equal angles.

In addition to the description and properties of commonly used polygons, formulas are given that simplify computations when working with polygons.

Squares

A *square* is a regular four-sided polygon. Each angle equals 90°. In square ABCD in Figure A-37, AB = BC = CD = AD = 2.500 in, and ∠A = ∠B = ∠C = ∠D = 90°.

The following formulas are used with squares. Refer to Figure A-38.

$a = 1.414s$	where	d = diagonal
$s = 0.7071\ d$		s = side
$A = s^2$ or $0.5d^2$		A = area

Example: A square nut is shown in Figure A-39. Given S (distance across flats) = 0.750 in, determine d (distance across corners). Substitute 0.750 for S in the formula $d = 1.414S$ and solve.

$d = 1.414S$
$d = 1.414(0.750\text{ in})$
$d = 1.061$ in Ans

Rectangles

A rectangle is a four-sided polygon with opposite sides parallel and equal. Each angle is 90°. In rectangle EFGH in Figure A-40, EF ∥ GH, EH ∥ FG; EF = GH = 40.85 mm, EH = FG = 75.20 mm; ∠E = ∠F = ∠G = ∠H = 90°.

The following formulas are used with rectangles. Refer to Figure A-41.

$d = \sqrt{l^2 + w^2}$	where	d = diagonal
$l = \sqrt{d^2 - w^2}$		l = length
$w = \sqrt{d^2 - l^2}$		w = width
$A = lw$		A = area

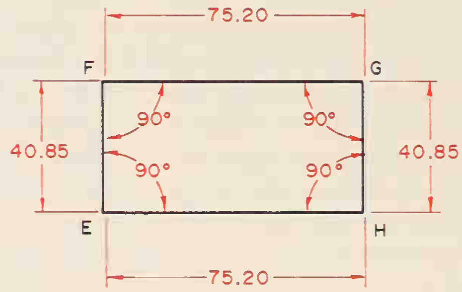


Figure A-40 Rectangle

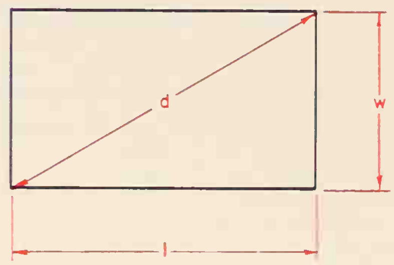


Figure A-41

Example: A rectangular sheet of aluminum is 30 in wide and 42 in long.
Determine:
a. the distance across opposite corners, diagonal d.
b. the area or the sheet in square feet.
a. Substitute the given values in the formula $d = \sqrt{l^2 + w^2}$ and solve.
$d = \sqrt{l^2 + w^2}$
$d = \sqrt{(42\text{ in})^2 + (30\text{ in})^2}$
$d = \sqrt{1764\text{ sq in} + 900\text{ sq in}}$
$d = \sqrt{2664\text{ sq in}}$
$d = 51.614$ in Ans
b. Substitute the values in the formula $A = lw$ and solve. Since 1 sq ft = 144 sq in, 1260 sq in is divided by 144 to obtain square feet.
$A = lw$
$A = 42\text{ in}(30\text{ in})$
$A = 1260$ sq in
1260 sq in ÷ 144 = 8.75 sq ft Ans

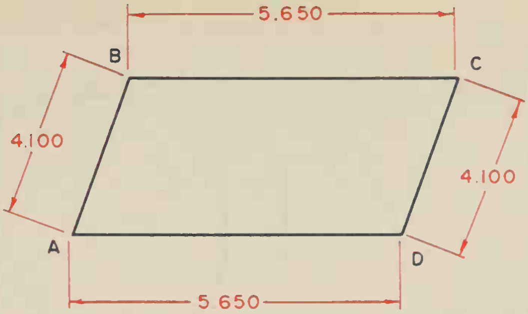


Figure A-42 Parallelogram

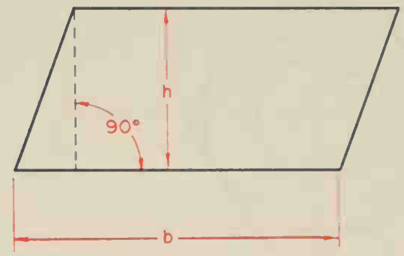


Figure A-43

Parallelograms

A *parallelogram* is a four-sided polygon with opposite sides parallel and equal and opposite angles equal. In parallelogram ABCD in Figure A-42, AB || CD, AD || BC; AB = CD = 4.100 in, AD = BC = 5.650 in; ∠A = ∠C = 70°, ∠B = ∠D = 110°.

The area of a parallelogram is equal to the product of the base and the height or altitude. Refer to Figure A-43.

$A = bh$ where A = area
b = base
h = height or altitude.

Note that h is perpendicular to b.

Example: A sheet-metal detail in the shape of a parallelogram is shown in Figure A-44. Determine the area in square feet. Substitute values in the formula $A = bh$ and solve.

$A = bh$
A= 28 in (40 in)
A = 1120 sq in

Since 1 sq ft. = 144 sq in, 1120 sq in is divided by 144 to obtain square feet.

1120 sq in ÷ 144 = 7.78 sq ft Ans

Regular Hexagons

A *regular hexagon* is a six-sided figure with all sides equal and all angles equal. Each angle equals 120°.

In the regular hexagon ABCDEF shown in Figure A-45, AB = BC = CD = DE = EF = AF = 50.25 mm, and ∠A = ∠B = ∠C = ∠D = ∠E = ∠F = 120°.

The following formulas are used with regular hexagons. Refer to Figure A-46.

$c = 2s$ where s = side
$s = 0.5c$ c = distance across corners
$f = 1.732s$ f = distance across flats
$s = 0.577f$ A = area
$c = 1.155f$
$f \doteq 0.866c$
$A = 2.598s^2 = 0.650c^2 = 0.866f^2$

Example: A hexagonal nut is shown in Figure A-47. Given f (distance across flats) determine:

a. s (length of side)
b. c (distance across corners)

a. Substitute 0.875 for f in the formula $s = 0.577f$ and solve.
$s = 0.577f$
$s = 0.577(0.875 \text{ in})$
$s = 0.505$ in Ans

b. Substitute 0.875 for f in the formula $c = 1.555f$ and solve.
$c = 1.155f$
$c = 1.155(0.875 \text{ in})$
$c = 1.011$ in Ans
$c = 1.155f$

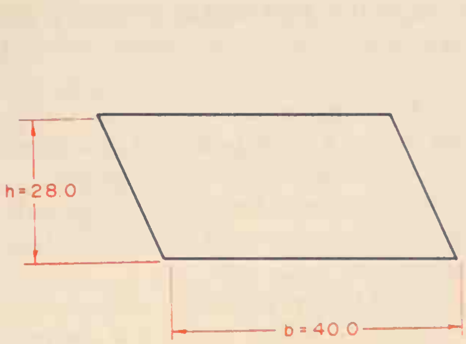


Figure A-44

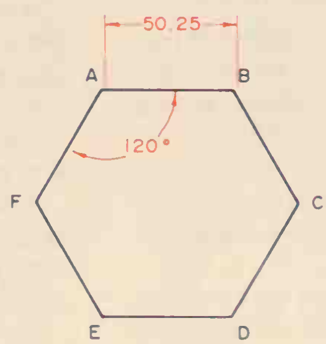


Figure A-45 Regular hexagon

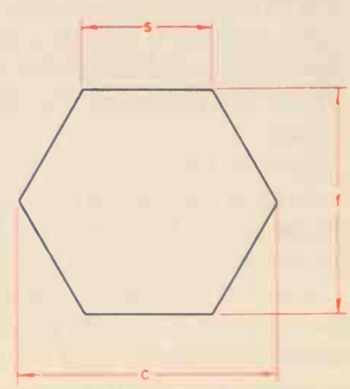


Figure A-46

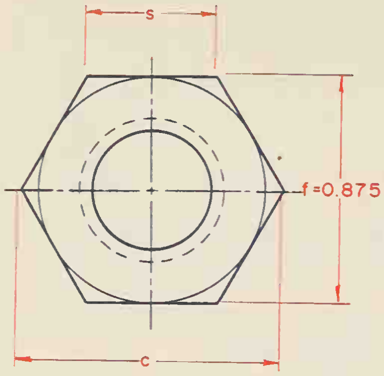


Figure A-47

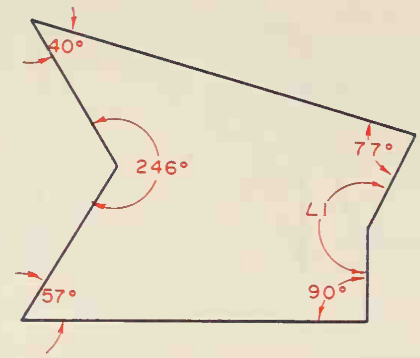


Figure A-48

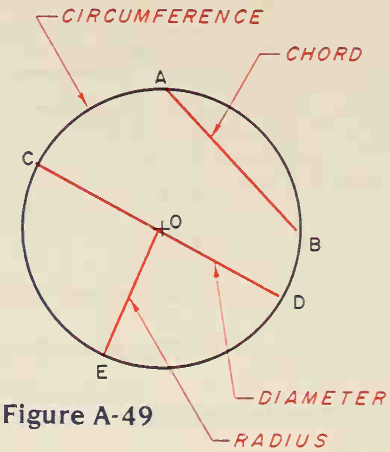


Figure A-49

The following principle is widely applied when determining unknown angles in any type of polygon.

The sum of the interior angles of a polygon of N *sides is equal to* (N - 2) *times* 180°.

Example: Determine ∠1 in the polygon in Figure A-48.
Count the number of sides. The polygon has six sides: N = 6. The sum of the six angles is (N-2) 180° = (6-2) 180° = 4 (180°) = 720°.
Add the five known interior angles and subtract from 720° to find ∠1.
∠1 = 720° − (57° + 246° + 40° + 77° + 90°)
∠1 = 720° − 510°
∠1 = 210° Ans

Definitions of Properties of Circles

The following terms are commonly used to describe the properties of circles. These properties are often applied in mechanical drafting and design situations.

A *circle* is a closed curve of which every point on the curve is equally distant from a fixed point called the center.

Refer to Figure A-49 for the following definitions.

A *circumference* is the length of the curved line which forms the circle.

A *chord* is a straight-line segment that joins two points on the circle. AB is a chord.

A *diameter* is a chord that passes through the center of a circle. CD is a diameter.

A *radius* (plural radii) is a straight-line segment that connects the center of the circle with a point on the circle. The radius is one-half the diameter. OE is a radius.

Refer to Figure A-50 for the following definitions.

An *arc* is that part of a circle between any two points on the circle. The symbol ⌒ written above the letters means arc. $\overset{\frown}{AB}$ is an arc.

A *tangent* to a circle is a straight line that touches the circle at one point only. The point on the circle touched by the tangent is called the *point of tangency* or *tangent point*. CD is a tangent. P is a tangent point.

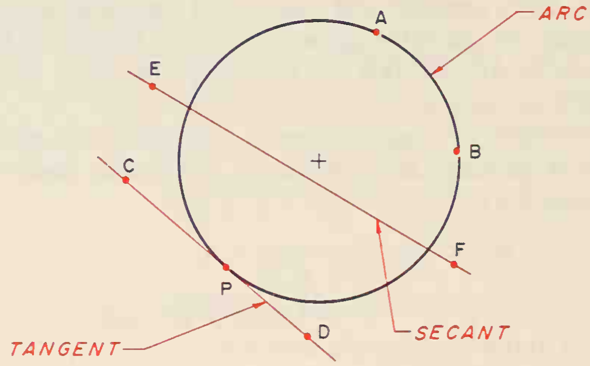


Figure A-50

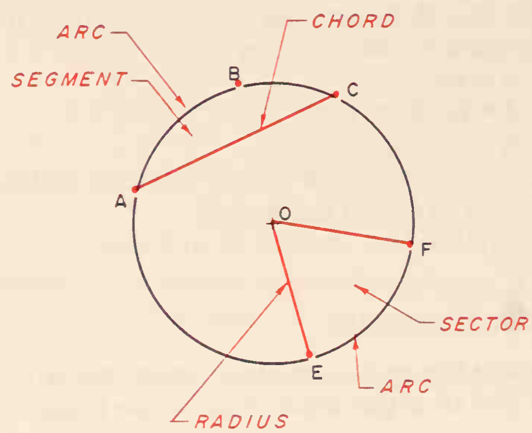


Figure A-51

A *secant* is a straight line that passes through a circle and intersects the circle at two points. EF is a secant.

Refer to Figure A-51 for the following definitions.

A *segment* is that part of a circle bounded by a chord and its arc. The shaded figure ABC is a segment.

A *sector* is that part of a circle bounded by two radii and the arc intercepted by the radii. The shaded figure EOF is a sector.

Refer to Figure A-52 for the following definitions.

A *central angle* is an angle whose vertex is at the center of a circle and whose sides are radii. Angle MON is a central angle.

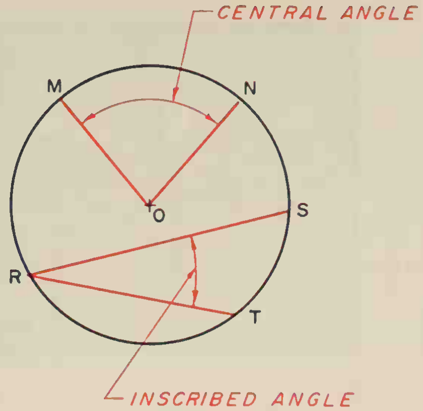


Figure A-52

An *inscribed angle* is an angle whose vertex is on the circle and whose sides are chords. Angle SRT is an inscribed angle.

Geometric Principles of Circle Circumference, Central Angles, Arcs, and Tangents

The circumference of a circle is equal to pi (π) times the diameter. Generally, for the degree of precision required in machining applications, a value of 3.1416 is used for π.

$C = \pi d$ where C = circumference
or π = pi
$C = 2\pi r$ d = diameter
r = radius

Example 1: Compute the circumference of a circle with a 50.70-mm diameter.

$C = \pi d = 3.1416(50.70 \text{ mm}) = 159.28 \text{ mm}$ Ans

Example 2: Determine the radius of a circle with a circumference of 14.860 in.

$$C = 2\pi r$$
$$14.860 \text{ in} = 2(3.1416)r$$
$$r = 2.365 \text{ in Ans}$$

In the same circle or in equal circles, equal chords cut off equal arcs.

Refer to Figure A-53. Given: Circle A = Circle B and chords CD = EF = GH = MS. Conclusion: CD = EF = GH = MS.

In the same circle or in equal circles, equal central angles cut off equal arcs. Refer to Figure A-54. Given: Circle D and $\angle 1 = \angle 2 = \angle 3 = \angle 4$. Conclusion: AB = FG = HK = MP.

In the same circle or in equal circles, two central angles have the same ratio as the arcs that are cut off by the angles.

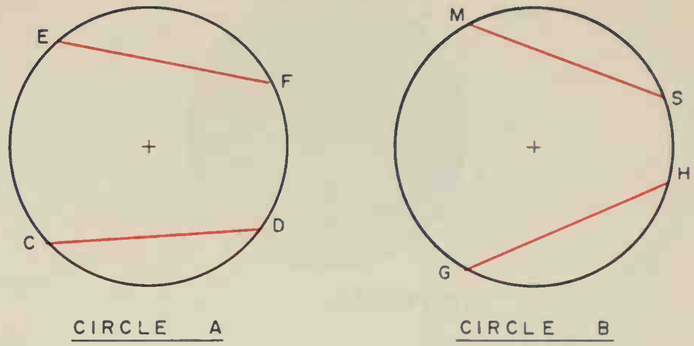


Figure A-53

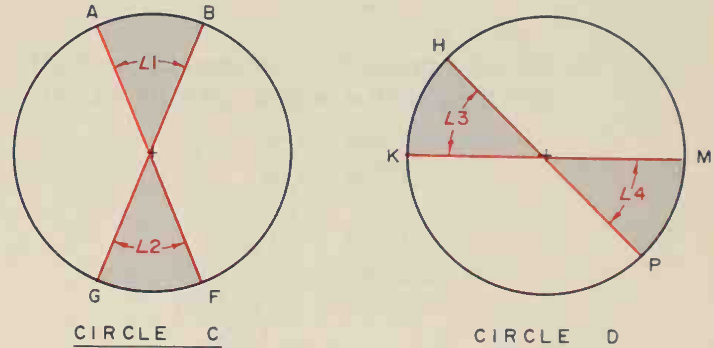


Figure A-54

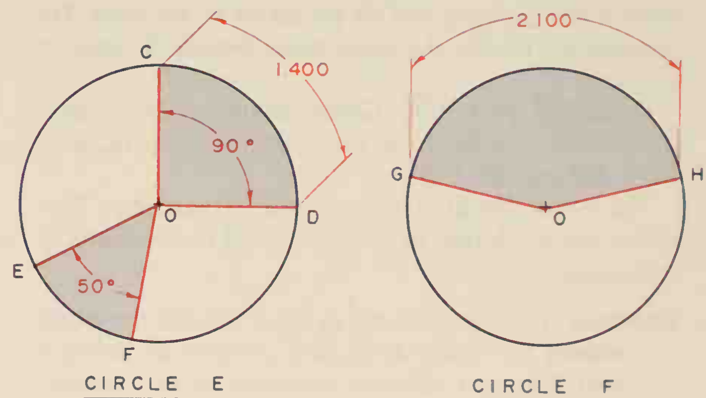


Figure A-55

Example: Refer to Figure A-55. Circle E = Circle F. If $\angle COD = 90°$, $\angle EOF = 50°$, CD = 1.400″, and GH = 2.100″, determine (a) the length of EF and (b) the size of $\angle GOH$. All dimensions are in inches.

a. Set up a proportion between CD and EF with their respective central angles. Solve for EF.

$$\frac{\angle COD}{\angle EOF} = \frac{CD}{EF}$$
$$\frac{90°}{50°} = \frac{1.400''}{EF}$$
$$9EF = 5(1.400'')$$
$$EF = \frac{5(1.400'')}{9}$$
$$EF = 0.778'' \text{ Ans}$$

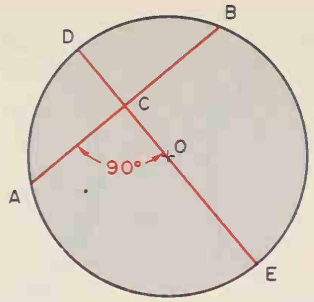


Figure A-56

b. Set up a proportion between CD and GH with their central angles. Solve for $\angle GOH$.

$$\frac{\angle COD}{\angle GOH} = \frac{CD}{GH}$$

$$\frac{90^\circ}{\angle GOH} = \frac{1.400''}{2.100''}$$

$$1.400(\angle GOH) = 90^\circ(2.100)$$

$$\angle GOH = \frac{90^\circ(2.100)}{1.400}$$

$$\angle GOH = 135^\circ \text{ Ans}$$

A line drawn from the center of a circle perpendicular to a chord bisects the chord and the arc cut off by the chord. The perpendicular bisector of a chord passes through the center of a circle.

Refer to Figure A-56. Given: Diameter DE is perpendicular to chord AB. Conclusion: AC = BC and AD = BD and AE = BE.

The use of this principle with the Pythagorean Theorem has wide practical application in mechanical technology.

Example: Holes A, B, C are to be drilled in the plate shown in Figure A-57. The centers of holes A and C lie on a 280-mm diameter circle. The center of hole B lies on the intersection of chord AC and segment OB, which is perpendicular to AC. Compute working dimensions F, G, and H. All dimensions are in millimetres.

Compute dimension F: Applying the principle, AC is bisected by OB.

$$AB = BC = 250 \text{ mm} \div 2 = 125 \text{ mm}$$

$$F = 200 \text{ mm} - 125 \text{ mm} = 75 \text{ mm Ans}$$

Compute dimension G.

$$G = 200 \text{ mm} + 125 \text{ mm} = 325 \text{ mm Ans}$$

Compute dimension H. In right triangle ABO, AB = 125 mm, AO = 280 mm ÷ 2 = 140 mm. Compute OB by applying the Pythagorean Theorem.

$$AO^2 = OB^2 + AB^2$$

$$(140 \text{ mm})^2 = OB^2 + (125 \text{ mm})^2$$

$$OB = 63.05 \text{ mm}$$

Hence, $H = 180 \text{ mm} + 63.05 \text{ mm} = 243.05 \text{ mm}$ Ans

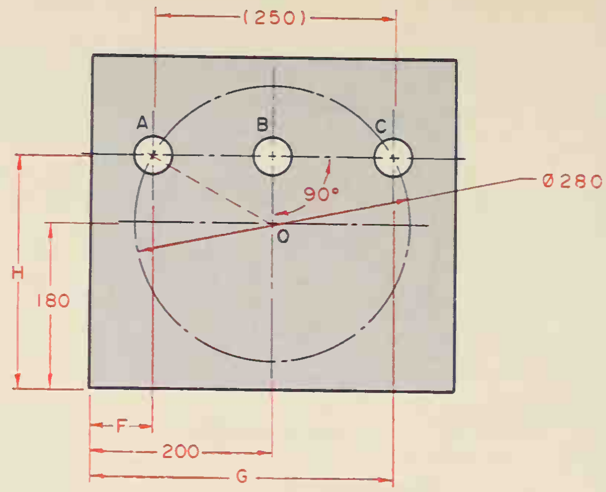


Figure A-57

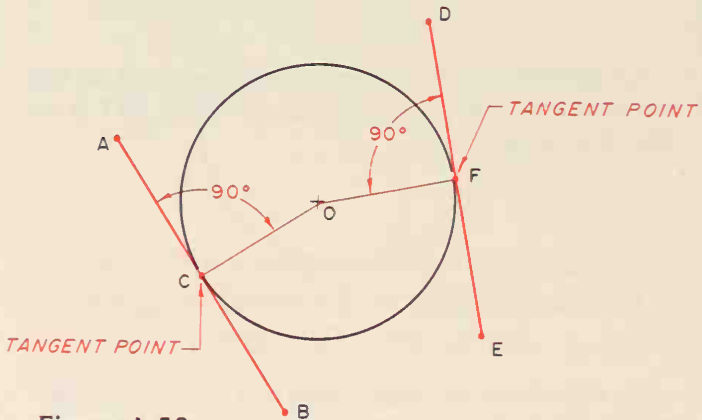


Figure A-58

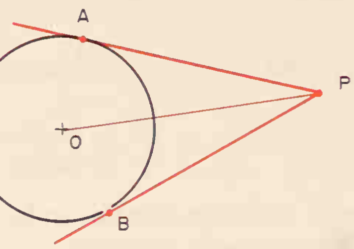


Figure A-59

A line perpendicular to a radius at its extremity is tangent to the circle. A tangent is perpendicular to a radius at its tangent point.

Refer to Figure A-58.

Example 1:

Given: Line AB is perpendicular to a radius CO at point C. Conclusion: Line AB is a tangent.

Example 2:

Given: Tangent DE passes through point F of radius FO. Conclusion: Tangent DE is perpendicular to radius FO.

Two tangents drawn to a circle from a point outside the circle are equal. The angle at the outside point is bisected by a line drawn from the point to the center of the circle.

Refer to Figure A-59.

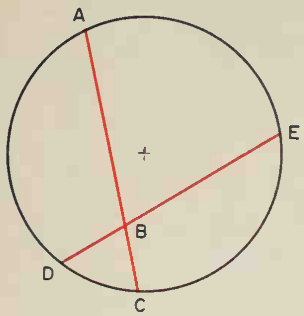


Figure A-60

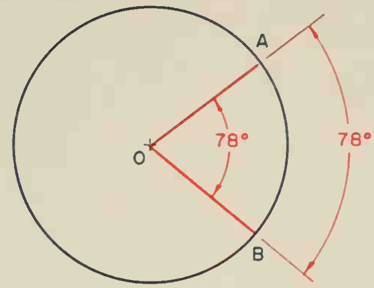


Figure A-61

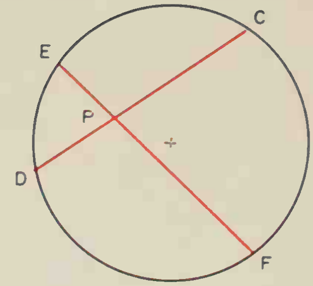


Figure A-62

Example 1:

Given: Tangents AP and BP are drawn to the circle from point P. Conclusion: AP = BP

Example 2:

Given: Line OP extending from outside point P to center O. Conclusion: ∠APO = ∠BPO

If two chords intersect inside a circle, the product of the two segments of one chord is equal to the product of the two segments of the other chord.

Refer to Figure A-60.

Example 1:

Given: Chords AC and DE intersect at point B. Conclusion: AB(BC) = BD(BE).

Example 2: If AB = 7.5 in. BC = 2.8 in. and BD = 2.1 in. determine the length of BE.

AB(BC) = BD(BE)
7.5(2.8) = 2.1(BE)
21.0 = 2.1BE
BE = 10.0 in Ans

Geometric Principles of Angles Formed Inside a Circle

A central angle is equal to its intercepted arc. (An *intercepted arc* is an arc cut off by a central angle.) Refer to Figure A-61. Given: AB = 78°. Conclusion: ∠AOB = 78°.

An angle formed by two chords intersecting inside a circle is equal to one-half the sum of its two intercepted arcs.

Refer to Figure A-62.

Example 1: Given: Chords CD and EF intersect at point P.
Conclusion: ∠EPD = ½ (CF + DE).

Example 2: If CF = 106° and ED = 42°, determine ∠EPD. ∠EPD = ½ (106° + 42° = 74° Ans

An inscribed angle is equal to one-half of its intercepted arc. Refer to Figure A-63. Given: AC = 105°. Conclusion: ∠ABC = ½AC = ½(105°) = 52°30'.

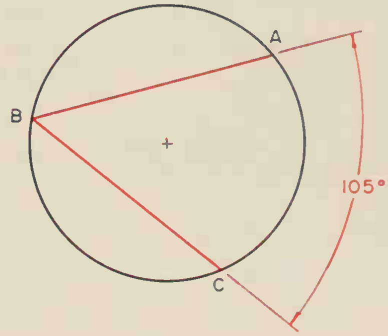


Figure A-63

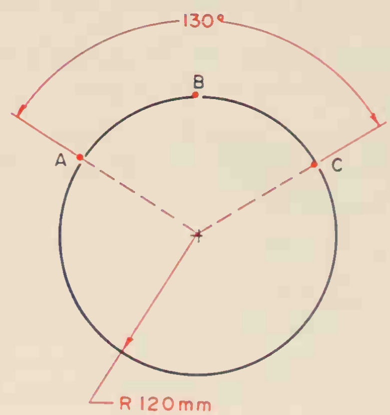


Figure A-64

Arc Length Formula

Consider a complete circle as an arc of 360°. The ratio of the number of degrees of an arc to 360° is the fractional part of the circumference that is used to find the length of an arc. *The length of an arc equals the ratio of the number of degrees of the arc to 360° times the circumference.*

$$\text{Arc Length} = \frac{\text{Arc Degrees}}{360°}(2\pi r)$$

or

$$\text{Arc Length} = \frac{\text{Central Angle}}{360°}(2\pi r)$$

Example: Refer to Figure A-64. ABC = 130° and the radius is 120 mm. Determine the arc length ABC.

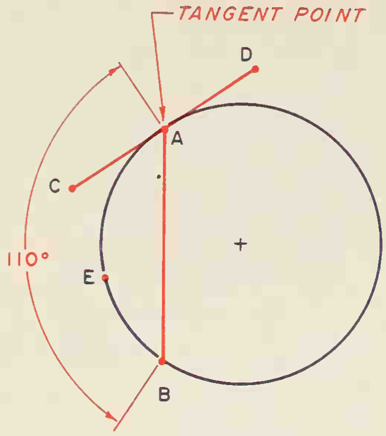


Figure A-65

$$\text{Arc Length} = \frac{\text{Arc Degrees}}{360°}(2\pi r)$$
$$= \frac{130°}{360°}[2(3.1416)(120\text{ mm})]$$
$$= 272.271\text{ mm Ans}$$

Geometric Principles of Angles Formed on a Circle and Angles Formed Outside a Circle

An angle formed by a tangent and a chord at the tangent point is equal to one-half of its intercepted arc.

Example 1: Refer to Figure A-65. Tangent CD meets chord AB at tangent point A and AEB = 110°. Determine ∠CAB.

∠CAB = ½ AEB = ½ (110°) = 55° Ans

Example 2: Refer to Figure A-66. The centers of three holes lie on line ABC. Line ABC is tangent to circle O at hole-center B. The hole-center D, of a fourth hole, lies on the circle. Determine ∠ABD. A central angle is equal to its intercepted arc.

DEB = ∠DOB = 132°

An angle formed by a tangent and a chord is equal to one-half of its intercepted arc.

∠ABD = ½ DEB = ½ (132°) = 66° Ans

An angle formed at a point outside a circle by two secants, two tangents, or a secant and a tangent is equal to one-half the difference of the intercepted arcs.

Two Secants

Refer to Figure A-67.

Example 1:

Given: Secants AP and DP meet at point P and intercept BC and AD. Conclusion: ∠P = ½ (AD − BC).

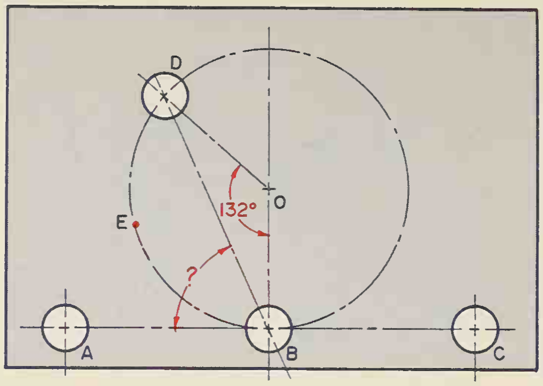


Figure A-66

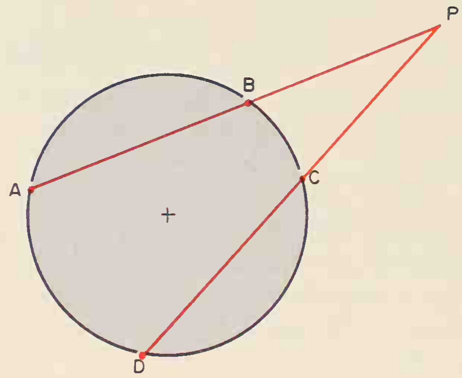


Figure A-67

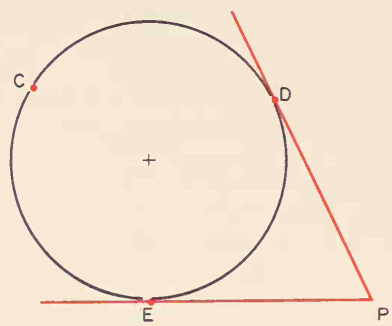


Figure A-68

Example 2: If AD = 85°40′ and BC = 39°17′, find ∠P.

∠P = ½ (AD − BC) = ½ (85°40′ − 39°17′) = ½ (46°23′) = 23°11′30″ Ans

Two Tangents

Refer to Figure A-68.

Example 1:

Given: Tangents DP and EP meet at point P and intercept DE and DCE. Conclusion: ∠P = ½ (DCE − DE).

Example 2: If DCE = 253°37′ and DE = 106°23′, determine ∠P.

∠P = ½ (DCE − DE) = ½ (253°37′ − 106°23′) = ½ (147°14′) = 73°37′ Ans

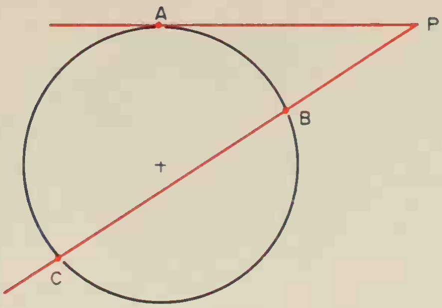


Figure A-69

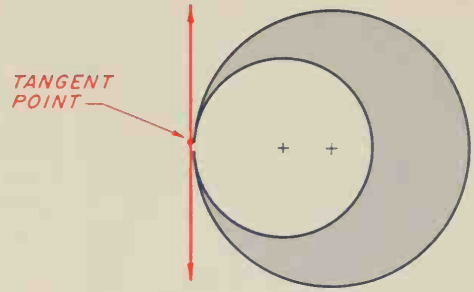


Figure A-70 Internally tangent circles

A Tangent and a Secant

Example 1: Refer to Figure A-69. Given: Tangent AP and secant CP meet at point P and intercept AC and AB. Conclusion: $\angle P = \frac{1}{2}(AC - AB)$.

Example 2: If AC – 126°38′ and AB = 68°58′, determine $\angle P$.

$$\angle P = \tfrac{1}{2}(AC - AB) = \tfrac{1}{2}(126°38' - 68°58')$$
$$= \tfrac{1}{2}(57°40') = 28°50' \text{ Ans}$$

Internally and Externally Tangent Circles

Two circles that are tangent to the same line at the same point are tangent to each other. Circles are either internally tangent or externally tangent.

Two circles are *internally tangent* if both circles are on the same side of the common tangent line. Refer to Figure A-70.

Two circles are *externally tangent* if the circles are on opposite sides of the common tangent line. Refer to Figure A-71.

If two circles are either internally tangent or externally tangent, a line connecting the centers of the circles passes through the point of tangency and is perpendicular to the tangent line.

Internally Tangent Circles

Example 1: Refer to Figure A-72. Given: Circle D and Circle E are internally tangent at point C. D is the center of Circle D, and E is the center of Circle E. Line AB is tangent to both circles at point C.
Conclusion: An extension of line DE passes through tangent point C and line CDE is perpendicular to tangent line AB.

This principle is often used as the basis for computing dimensions of parts on which two or more radii blend to give a smooth curved surface. This type of application is illustrated by the following example.

Example 2: A part is to be drawn as shown in Figure A-73. The proper locations of the two radii will

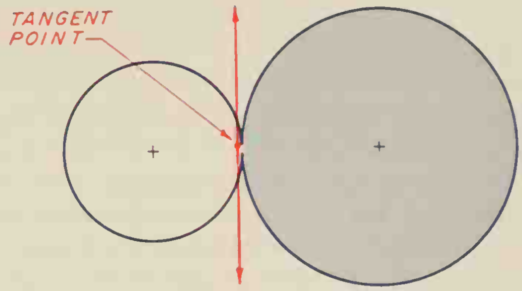


Figure A-71 Externally tangent circles

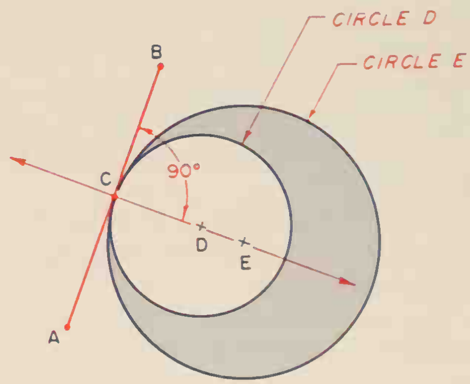


Figure A-72

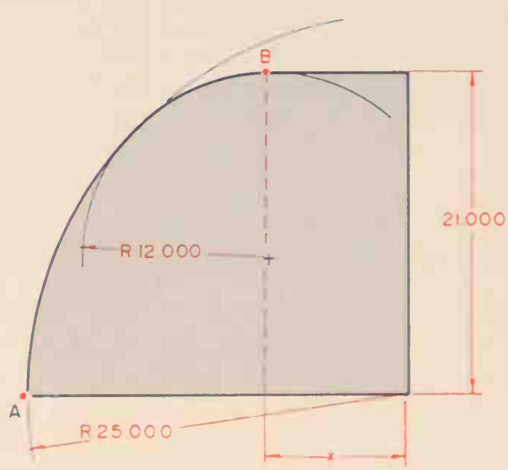


Figure A-73

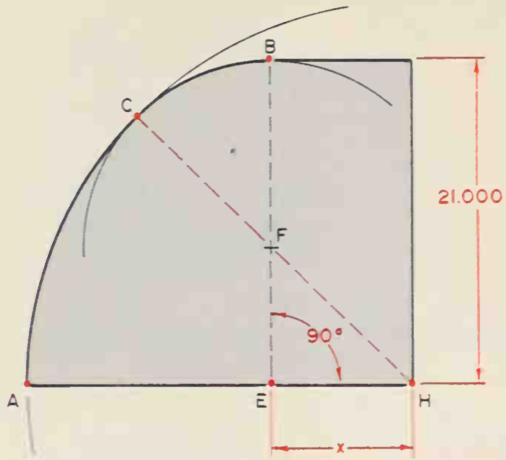


Figure A-74

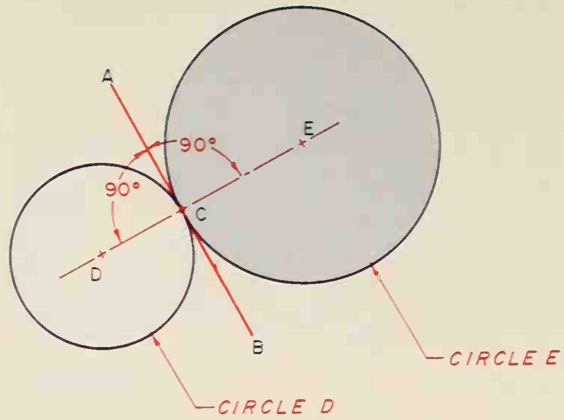


Figure A-75

result in a smooth curve from point A to point B. Note that the curve from A to B is not an arc of one circle, but is made up of two circles of different sizes. In order to completely dimension the part the location to the center of the 12.000-in radius (dimension x) must be determined. Compute x. All dimensions are in inches. Refer to Figure A-74. The 12.000-in radius arc and the 25.000-in radius arc are internally tangent. A line connecting arc centers F and H passes through tangent point C. Tangent point C is the endpoint of the 25.000-in radius: (FH = 25.000-in. Tangent point C is the endpoint of the 12.000-in radius: CF = 12.000-in.

FH = 25.000-in − 12.000-in = 13.000-in.

Since BFE is vertical and AEH is horizontal, ∠FEH = 90°. In right triangle FEH, FH = 13.000-in, FE = 21.000-in - BF = 9.000-in.

Apply the Pythagorean Theorem to compute EH.

$$
\begin{aligned}
FH^2 &= EH^2 + FE^2\\
(13.000 \text{ in})^2 &= EH^2 + (9.000 \text{ in})^2\\
169.000 \text{ sq in} &= EH^2 + 81.000 \text{ sq in}\\
169.000 \text{ sq in} - 81.000 \text{ sq in} &= EH^2\\
88.000 \text{ sq in} &= EH^2\\
\sqrt{88.000 \text{ sq in}} &= EH\\
9.381 \text{ in} &= EH\\
x &= EH,\\
x &= 9.381 \text{ in Ans}
\end{aligned}
$$

Externally Tangent Circles

***Example* 1:** Refer to Figure A-75. Given: Circle D and Circle E are externally tangent at point C. D is the center of Circle D, and E is the center of Circle E. Line AB is tangent to both circles at point C. Conclusion: Line DE passes through tangent point C, and line DE is perpendicular to tangent line AB at point C.

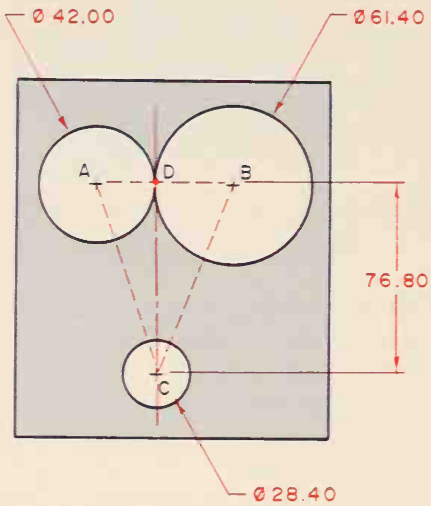


Figure A-76

***Example* 2:** Three holes are to be bored in the steel plate of Figure A-76. The 42.00-mm and 61.40-mm diameter holes are tangent at point C. CD is the common tangent line. Determine the distances between hole centers (AB, AC, and BC). All dimensions are in millimetres. Compute AB. AB connects the centers of two tangent circles: AB passes through tangent point D.

AB = AD + DB = 21.00 mm + 30.70 mm = 51.70 mm Ans

Compute AC and BC. Since AB connects the centers of two tangent circles, AB is perpendicular to tangent line DC. Triangle ADC and triangle BDC are right triangles. Apply the Pythagorean Theorem.

In right triangle ADC, AD = 21.00 mm and DC = 76.80 mm.

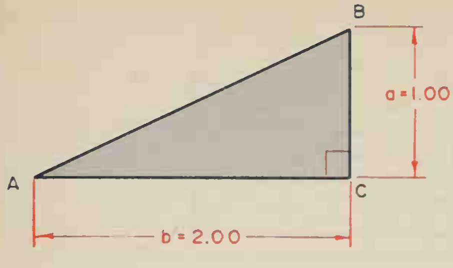


Figure A-77

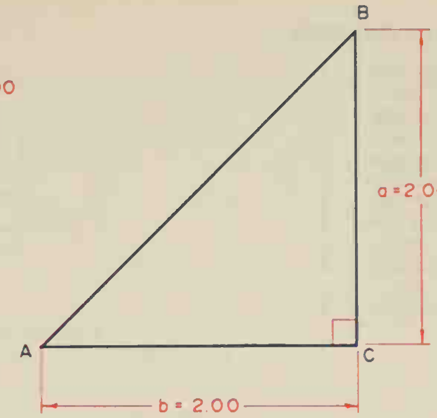


Figure A-78

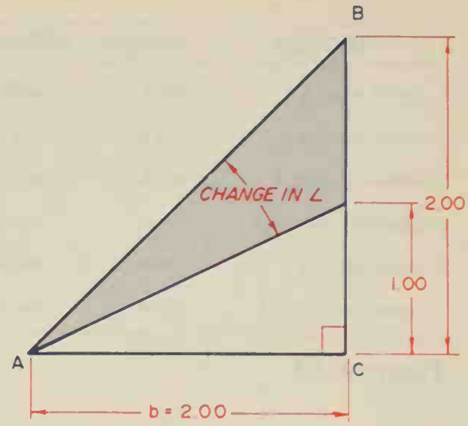


Figure A-79

$$AC^2 = AD^2 + DC^2$$
$$AC^2 = (21.00\ mm)^2 + (76.80\ mm)^2$$
$$AC^2 = 441.00\ mm^2 + 5898.24\ mm^2$$
$$AC^2 = 6339.24\ mm^2$$
$$AC = 79.62\ mm \text{ Ans}$$

In right triangle BDC, DB = 30.70 mm and DC = 76.80 mm.

$$BC^2 = DB^2 + DC^2$$
$$BC^2 = (30.70\ mm)^2 + (76.80\ mm)^2$$
$$BC^2 = 942.49\ mm^2 + 5898.24\ mm^2$$
$$BC^2 = 6840.73\ mm^2$$
$$BC = \sqrt{6840.73\ mm^2}$$
$$BC = 82.71\ mm \text{ Ans}$$

Trigonometry: Trigonometric Functions

Trigonometry is the branch of mathematics used to compute unknown angles and sides of triangles. Many drafting problems that cannot be solved by the use of geometry alone are easily solved by trigonometry.

Ratio of Right Triangle Sides

In a right triangle the ratio of two sides of the triangle determines the sizes of the angles, and the angles determine the ratio of two sides. Refer to the triangles in Figures A-77 - A-79. The size of angle A is determined by the ratio of side a to side b. When side a = 1 in and side b = 2 in (Figure A-77), the ratio of a to b is 1:2 or 1/2. If side a is increased to 2 in and side b remains 2 in (Figure A-78), the ratio of a to b is 1:1 or 1/1. Observe the increase in angle A (Figure A-79) as the ratio changed from 1/2 to 1/1.

Note: The symbol for a right angle is ∟, which is shown at the vertex of the angle.

Identifying Right Triangles by Name

The sides of a right triangle are named opposite side, adjacent side, and hypotenuse. The *hypotenuse* (hyp) is always the side opposite the right angle. It is always the longest side of a right triangle. The positions of the opposite and adjacent sides depend on the reference angle. The *opposite side* (opp side) is opposite the reference angle, and the *adjacent side* (adj side) is next to the reference angle.

In the triangle in Figure A-80 showing ∠A as the reference angle, side b is the adjacent side, and side a is the opposite side. In the triangle in Figure A-81

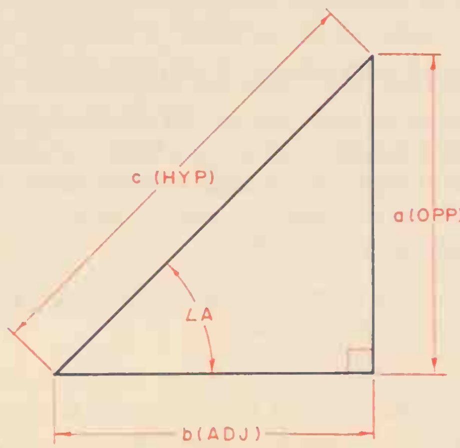


Figure A-80

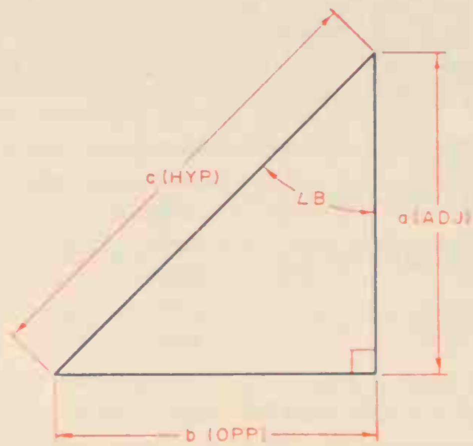


Figure A-81

FUNCTION	SYMBOL	DEFINITION OF FUNCTION
sine of angle *A*	sin *A*	$\sin A = \frac{\text{opp side}}{\text{hyp}} = \frac{a}{c}$
cosine of angle *A*	cos *A*	$\cos A = \frac{\text{adj side}}{\text{hyp}} = \frac{b}{c}$
tangent of angle *A*	tan *A*	$\tan A = \frac{\text{opp side}}{\text{adj side}} = \frac{a}{b}$
cotangent of angle *A*	cot *A*	$\cot A = \frac{\text{adj side}}{\text{opp side}} = \frac{b}{a}$
secant of angle *A*	sec *A*	$\sec A = \frac{\text{hyp}}{\text{adj side}} = \frac{c}{b}$
cosecant of angle *A*	csc *A*	$\csc A = \frac{\text{hyp}}{\text{opp side}} = \frac{c}{a}$

Figure A-82

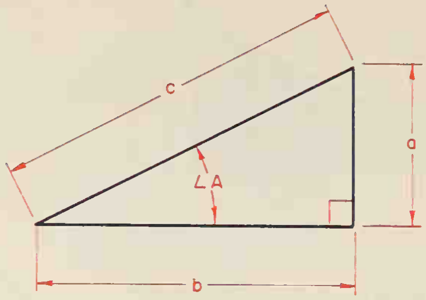


Figure A-83

showing ∠B as the reference angle, side *b* is the opposite side, and side *a* is the adjacent side. It is important to be able to identify the opposite and adjacent sides of right triangles with reference to any angle regardless of the positions of the triangles.

Trigonometric Functions: Ratio Method

There are two methods of defining trigonometric functions: the unity or unit circle method, and the ratio method. Only the ratio method is presented here.

Since a triangle has three sides and a ratio is the comparison of any two sides, there are six different ratios. The names of the ratios are *sine, cosine, tangent, cotangent, secant,* and *cosecant.*

The six trigonometric functions are defined in the table in Figure A-82 in relation to the triangle shown in Figure A-83. The reference angle is A, and adjacent side is *b*, the opposite side is *a*, and the hypotenuse is *c*.

To properly use trigonometric functions it is essential to know that the function of an angle depends upon the ratio of the sides and not upon the size of the triangle. Similar triangles are alike in shape but different in size. The functions of similar triangles are the same regardless of the sizes of the triangles, since the sides of similar triangles are proportional. For example, in the similar triangles shown in Figure A-84, the functions of angle A are the same for the three triangles. The equality of the tangent function is shown. Each of the other five functions has equal values for the three similar triangles.

Note: The symbol △ means triangle.

$$\text{In } \triangle ABC, \tan \angle A = \frac{0.500}{1.000} = 0.500$$

$$\text{In } \triangle ADE, \tan \angle A = \frac{0.800}{1.600} = 0.500$$

$$\text{In } \triangle AFG, \tan \angle A = \frac{1.200}{2.400} = 0.500$$

In a right triangle the reference angle is greater than 0° and less than 90°. Values for the six trigonometric functions from 0° to 90° are available in degree-minute and decimal-degree tables. Scientific electronic calculators provide a quick and convenient determination of trigonometric functions. It is assumed that users of this text will use calculators; therefore, trigonometric function tables are not provided. However, if a calculator is not used, supplementary trigonometric function tables are generally readily available. Conversion between decimal-minutes and decimal-degree angular measure may be required. If necessary, refer to the section Degrees, Minutes, Seconds — Decimal Degree Conversion.

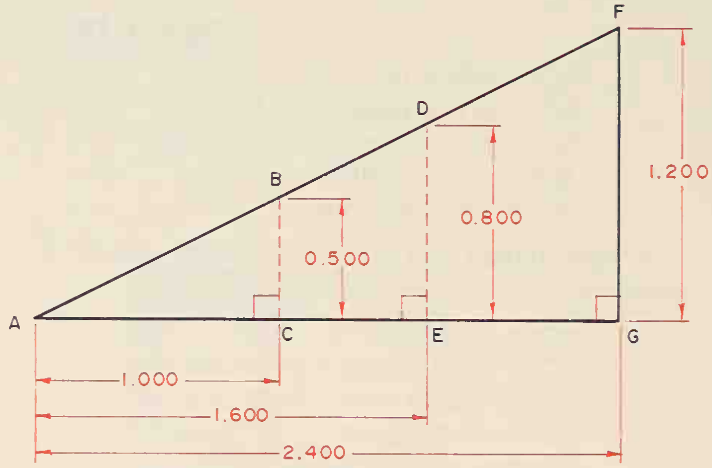


Figure A-84

Trigonometry: Basic Calculations of Angles

In order to solve for an unknown angle of a right triangle when neither acute angle is shown, at least two sides must be known. An understanding of the procedures required for solving for unknown angles is essential to the drafter.

Procedure: *To determine an unknown angle when two sides of a right triangle are known*

- Identify two given sides as adjacent, opposite, or hypotenuse in relation to the desired angle.
- Determine the functions that are ratios of the sides identified in relation to the desired angle.

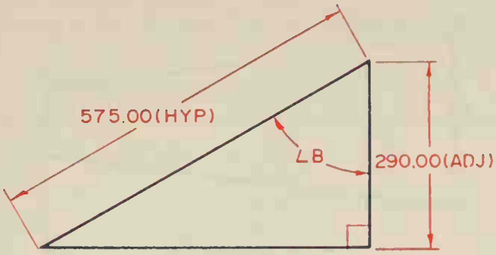


Figure A-85

Note: Two of the six trigonometric functions are ratios of the two known sides. Either of the two functions can be used. Both produce the same value for the unknown, except for cotangents, secants, and cosecants of angles less than 15° and tangents, secants, and cosecants of angles greater than 75°.

- Choose one of the two functions, substitute the given sides in the ratio, and divide.
- Using either a calculator or a trigonometric function table, determine the angle that corresponds to the quotient obtained.

Example 1: Determine ∠B of the triangle in Figure A-85. All dimensions are in millimetres.
In relation to ∠B, the 290.000-mm side is the adjacent side and the 575.00-mm side is the hypotenuse. Determine the two functions whose ratios consist of the adjacent side and the hypotenuse:

$$\text{secant } \angle B = \frac{\text{hypotenuse}}{\text{adjacent side}},$$

and

$$\text{cosine } \angle B = \frac{\text{adjacent side}}{\text{hypotenuse}}.$$

Either function can be used. Choosing the cosine function:

$$\cos \angle B = \frac{\text{adj side}}{\text{hyp}}$$
$$\cos \angle B = \frac{290.00}{575.00}$$
$$\cos \angle B = 0.50435$$
$$\angle B = 59.72° \text{ or } 59°43' \text{ Ans}$$

Example 2: Determine ∠1 and ∠2 of the triangle in Figure A-86. All dimensions are in inches.
Calculate either ∠1 or ∠2. Choose any two of the three given sides. In relation to ∠1, the 3.420-in side is the opposite side. The 5.845-in side is the hypotenuse. Determine the two functions whose ratios consist of the opposite side and the hypotenuse:

$$\angle 1 = \frac{\text{opposite side}}{\text{hypotenuse}}.$$

and

$$\text{cosecant } \angle 1 = \frac{\text{hypotenuse}}{\text{opposite side}}.$$

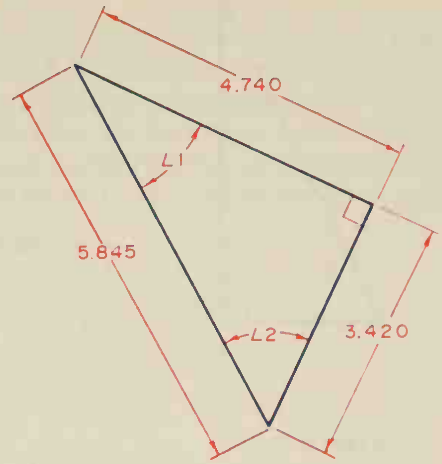


Figure A-86

Either function can be used. Choosing the sine function:

$$\sin \angle 1 = \frac{\text{opp side}}{\text{hyp}}$$
$$\sin \angle 1 = \frac{3.420}{5.845}$$
$$\sin \angle 1 = 0.58512$$
$$\angle 1 = 35°49' \text{ Ans}$$
$$\angle 2 = 90° - 35°49'$$
$$\angle 2 = 54°11' \text{ Ans}$$

Trigonometry: Basic Calculations of Sides

Procedure: *To determine an unknown side when an acute angle and one side of a right triangle are known*

- Identify the given side and the unknown side as adjacent, opposite, or hypotenuse in relation to the given angle.
- Determine the trigonometric functions that are ratios of the sides identified in relation to the given angle.
  Note: Two of the six functions will be found as ratios of the two identified sides. Either of the two functions can be used. Both produce the same value for the unknown, except for cotangents, secants, and cosecants of angles less than 15° and tangents, secants, and cosecants of angles greater than 75°. If the unknown side is made the numerator of the ratio, the problem is solved by multiplication. If the unknown side is made the denominator of the ratio, the problem is solved by division.
- Using either a calculator or a trigonometric function table, find the function of the given angle and substitute this value.
- Solve as a proportion for the unknown side.

Example: Determine side of the triangle in Figure A-87. All dimensions are in inches.

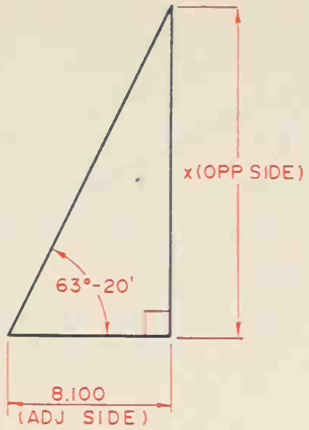


Figure A-87

In relation to the 63°20′ angle, the 8.100-in side is the adjacent side and side x is the opposite side. Determine the two functions whose ratios consist of the adjacent and opposite sides:

$$\text{tangent } 63°20' = \frac{\text{opposite side}}{\text{adjacent side}}$$

and

$$\text{cotangent } 63°20' = \frac{\text{adjacent side}}{\text{opposite side}}.$$

Either function can be used. Choosing the tangent function:

$$\tan 63°20' = \frac{\text{opp side}}{\text{adj side}}$$

$$\tan 63°20' = \frac{x}{8.100}$$

$$1.9912 = \frac{x}{8.100}$$

Solve as a proportion.

$$\frac{1.9912}{1} = \frac{x}{8.100}$$

$$x = 1.9912\,(8.100)$$

$$x = 16.129 \text{ in Ans}$$

Trigonometry: Common Drafting Applications

Method of Solution

The following examples are simple practical applications of right-angle trigonometry, although they may not be given directly in the form of right triangles. To solve the examples it is necessary to project auxiliary lines to produce a right triangle. The unknown, or a dimension required to compute the unknown, is part of the triangle. The auxiliary lines may be projected between given points or from given points. The lines may be projected parallel or perpendicular to center lines, tangents, or other reference lines.

It is important to study carefully the procedures and the use of auxiliary lines as they are applied to the following examples. The same basic method is used in solving many similar drafting problems. A knowledge of both geometric principles and trigonometric functions and the ability to relate and apply them to specific situations are required in solving many applied problems.

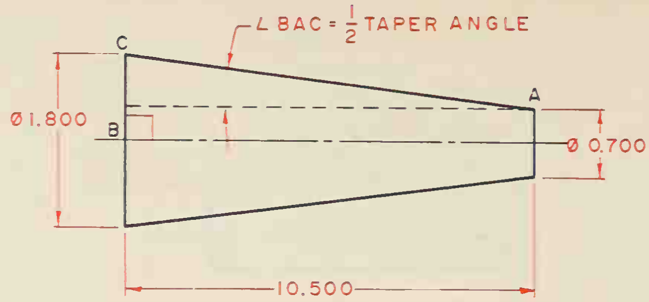


Figure A-88

Tapers and Bevels

Example 1: Determine the included taper angle of the shaft in Figure A-88. All dimensions are in inches.

The problem must be solved by using a figure in the form of a right triangle. Therefore, project line AB from point A parallel to the center line. Right △ABC is formed in which ∠BAC is one-half the included taper angle.

Side AB = 10.500″

$$\text{Side BC} = \frac{1.800'' - 0.700''}{2} = 0.550''$$

Using sides AB and BC, solve for ∠BAC.

$$\tan \angle BAC = \frac{BC}{AB} = \frac{0.500}{10.500} = 0.05238$$

$$\angle BAC = 3°0'$$

The included taper angle = 2(3°0′) = 6°0′ Ans

Example 2: Determine diameter x of the part shown in Figure A-89. All dimensions are in millimetres.

Project line DE from point D parallel to the centerline in order to form right △DEF.

Side DE = 21.80 mm − 7.50 mm = 14.30 mm.

∠EDF = 32.5°

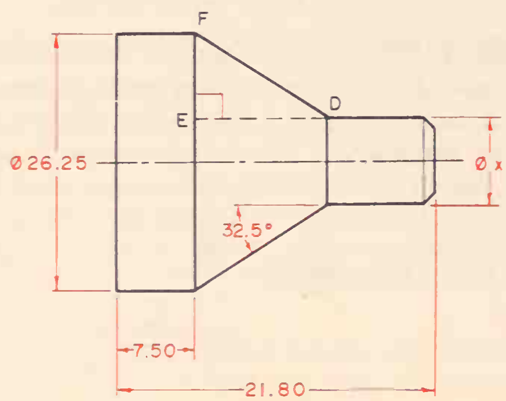


Figure A-89

Using side DE and $\angle EDF$, solve for side EF.

$$\tan \angle EDF = \frac{EF}{DE}$$

$$\tan 32.5^\circ = \frac{EF}{14.30}$$

$$EF = 0.63707(14.30)$$

$$EF = 9.11 \text{ mm}$$

$$\text{Dia } x = 26.25 \text{ mm} - 2(9.11 \text{ mm}) = 8.03 \text{ mm Ans}$$

Isosceles Triangle Applications: Distance Between Holes and V-Slots

The solutions to many practical trigonometry problems are based on recognizing figures as isosceles triangles. In an isosceles triangle an altitude to the base bisects the base and the vertex angle.

***Example* 1:** In Figure A-90 five holes are equally spaced on a 5.200-in diameter circle. Determine the straight-line distance between centers of two consecutive holes.

Project radii from center O to hole centers A and B. Project a line from A to B. $\angle AOB = \frac{360^\circ}{5} = 72^\circ$.

Since OA = OB, $\triangle AOB$ is isosceles. Project line OC perpendicular to AB from center O. Line OC bisects $\angle AOB$ and side AB. In right $\triangle AOC$, $\angle AOC = \frac{72^\circ}{2} = 36^\circ$. $AO = \frac{5.200 \text{ in}}{2} = 2.600$ in.

Solve for side AC.

$$\sin \angle AOC = \frac{AC}{AO}$$

$$\sin 36^\circ = \frac{AC}{2.600}$$

$$0.58779 = \frac{AC}{2.600}$$

$$AC = 0.58779(2.600)$$

$$AC = 1.528 \text{ in}$$

$$AB = 2(1.528 \text{ in}) = 3.056 \text{ in Ans}$$

***Example* 2:** Determine dimension x of the V-slot in Figure A-91. All dimensions are in inches.

Connect a line between points R and T.

Sides RS = TS; therefore, $\triangle RST$ is isosceles.

Project line SM from point S perpendicular to RT.

Side RT and $\angle RST$ are bisected. In right $\triangle RSM$,

$$\angle RSM = \frac{62^\circ 40'}{2} = 31^\circ 20'.$$

$$RM = \frac{3.800 \text{ in}}{2} = 1.900 \text{ in}.$$

Solve for distance MS.

$$\cot \angle RSM = \frac{MS}{RM}$$

$$\cot 31^\circ 20' = \frac{MS}{1.900}$$

$$1.6426 = \frac{MS}{1.900}$$

$$MS = 1.6426(1.900)$$

$$MS = 3.121 \text{ in}$$

$$x = MS = 3.121 \text{ in Ans}$$

Tangents to Circles Applications: Angle Cuts and Dovetails

***Example*:** An internal dovetail is shown in Figure A-92. Two pins or balls are used to check the dovetail for both location and angular accuracy. Calculate check dimension x. All dimensions are in inches.

Project line HO from point H to the pin center O; HO bisects the 72°20' angle. Project a radius from point O to the point of tangency K; $\angle HKO$ is a right angle, since a radius is perpendicular to a tangent at the point of tangency. In right $\triangle HOK$, $\angle KHO = \frac{72^\circ 20'}{2} = 36^\circ 10'$, $KO = \frac{1.000 \text{ in}}{2}$ $= 0.500$ in

Solve for side HK.

$$\cot \angle KHO = \frac{HK}{KO}$$

$$\cot 36^\circ 10' = \frac{HK}{0.500}$$

$$1.3680 = \frac{HK}{0.500}$$

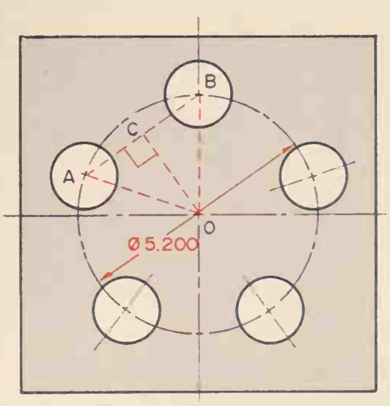


Figure A-90

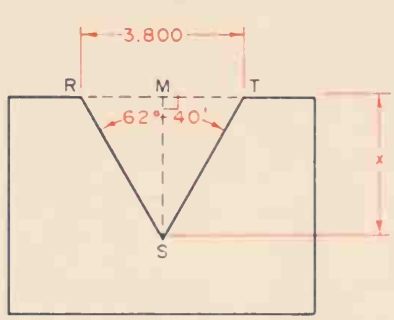


Figure A-91

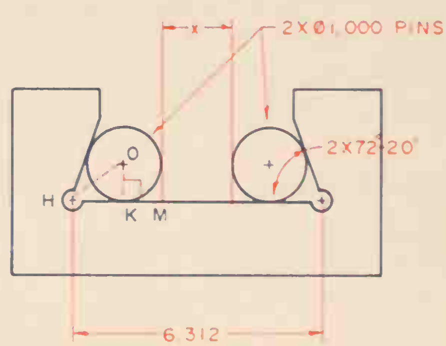


Figure A-92

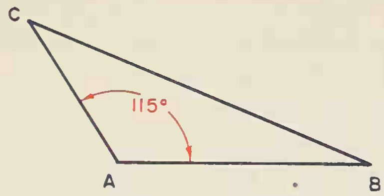


Figure A-93

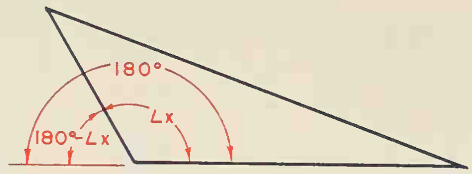


Figure A-94

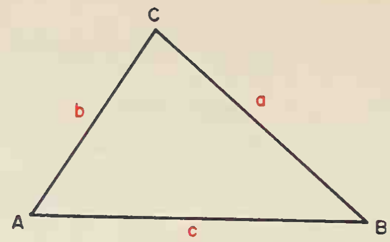


Figure A-95

$$HK = 0.500(1.3680)$$
$$HK = 0.684 \text{ in}$$
$$KM = \text{pin radius} = 0.500 \text{ in}$$
$$HM = HK + KM = 0.684 \text{ in} + 0.500 \text{ in} = 1.184. \text{ in}$$
$$x = 6.312 \text{ in} - 2(HM) = 6.312 \text{ in} - 2(1.184 \text{ in}) = 3.944 \text{ in Ans}$$

Trigonometry: Oblique Triangles — Law of Sines and Law of Cosines

An *oblique triangle* is one that does not contain a right angle. Drafting and design problems often involve oblique triangles. These problems can be reduced to a series of right triangles, but the process can be cumbersome and time consuming. Two formulas, the *law of sines* and the *law of cosines*, can be used to simplify such computations. In order to use either formula, three parts of an oblique triangle must be known; at least one part must be a side.

An oblique triangle can contain an angle greater than 90°, such as oblique triangle ABC in Figure A-93. Therefore, sine and cosine functions of angles between 90° and 180° must be determined.

Sine Functions of Angles Between 90° and 180°

The sine of an angle greater than 90° and less than 180° equals the sine of the supplement of the angle. If the value of $\angle x$ is between 90° and 180°, as shown in Figure A-94, $\sin \angle x = \sin(180° - \angle x)$.

Examples:

1. $\sin 115° = \sin(180° - 115°) = \sin 65° = 0.90631$ Ans
2. $\sin 90°42' = \sin(180° - 90°42') = \sin 89°18' = 0.99992$ Ans
3. $\sin 176.25° = \sin(180° - 176.25°) = \sin 3.75° = 0.06540$ Ans

Law of Sines

The law of sines states that, in any triangle, the sides are proportional to the sines of the opposite angles. That is (see Figure A-95)

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

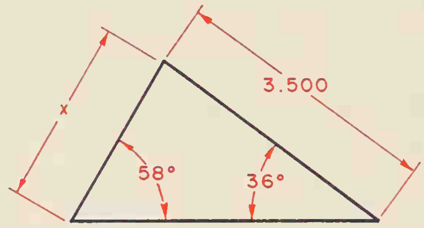


Figure A-96

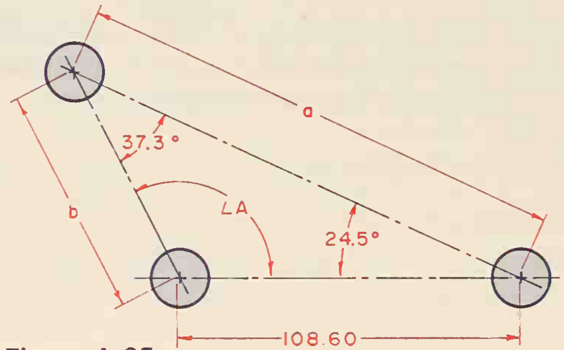


Figure A-97

The law of sines is used to solve the following kinds of problems:

- Problems where any two angles and any one side of an oblique triangle are known.
- Problems where any two sides and an angle opposite one of the given sides of an oblique triangle are known.

Solving Oblique Triangle Problems Given Two Angles and a Side

Example 1: Given two angles and a side, determine side x of the oblique triangle in Figure A-96. (All dimensions are in inches.)

Set up a proportion and solve for x.

$$\frac{x}{\sin 36°} = \frac{3.500}{\sin 58°}$$
$$\frac{x}{0.58779} = \frac{3.500}{0.84805}$$
$$0.84805x = 3.500(0.58779)$$
$$x = \frac{3.500(0.58779)}{0.84805}$$
$$x = 2.426 \text{ in Ans}$$

Example 2: Given two angles and a side of the oblique triangle formed by the intersection of hole centerlines shown in Figure A-97. All dimensions

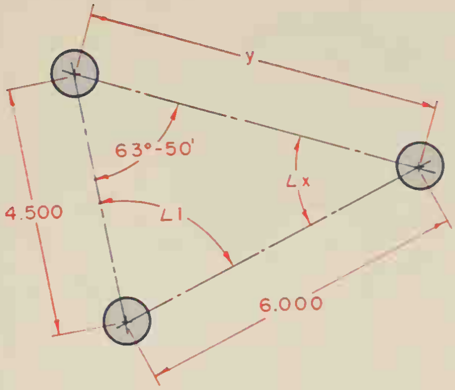


Figure A-98

are in millimetres.

a. Determine ∠A.
b. Determine side a.

a. Determine ∠A.

$$\angle A = 180° - (37.3° + 24.5°) = 118.2° \text{ Ans}$$

b. Determine side a. Set up a proportion and solve for side a.

$$\frac{a}{\sin 118.2°} = \frac{108.60}{\sin 37.3°}$$
$$\sin 118.2° = \sin(180° - 118.2°) = \sin 61.8° = 0.88130$$
$$\sin 37.3° = 0.60599$$
$$\frac{a}{0.88130} = \frac{108.60}{0.60599}$$
$$a = 157.94 \text{ mm Ans}$$

Solving Oblique Triangle Problems Given Two Sides and an Angle Opposite One of the Given Sides

***Example* 1:** Given two sides and an opposite angle of the oblique triangle formed by the intersection of hole center lines shown in Figure A-98. (All dimensions are in inches.)

a. Determine $\angle x$.
b. Determine side y.

a. Determine $\angle x$.

$$\frac{4.500}{\sin \angle x} = \frac{6.000}{\sin 63°50'}$$
$$\frac{4.500}{\sin \angle x} = \frac{6.000}{0.89752}$$
$$6.000(\sin \angle x) = 4.500(0.89752)$$
$$\sin \angle x = \frac{4.500(0.89752)}{6.000}$$
$$\sin \angle x = 0.67314$$
$$\angle x = 42°18' \text{ Ans}$$

b. Determine side y.

$$\angle 1 = 180° - (63°50' + \angle x) =$$
$$180° - (63°50' + 42°18') = 180° - 106°8' = 73°52'$$
$$\frac{6.000}{\sin 63°50'} = \frac{y}{\sin 73°52'}$$

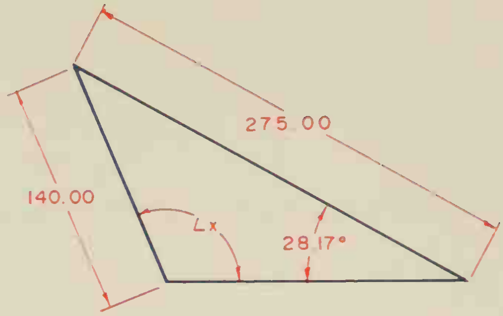


Figure A-99

$$\frac{6.000}{0.89752} = \frac{y}{0.96062}$$
$$0.89752y = 6.000(0.96054)$$
$$y = \frac{6.000(0.96054)}{0.89752}$$
$$y = 6.422 \text{ in Ans}$$

***Example* 2:** Given two sides and an opposite angle, determine $\angle x$ of the oblique triangle shown in Figure A-99. (All dimensions are in millimetres.)

$$\frac{140.00}{\sin 28.17°} = \frac{275.00}{\sin \angle x}$$
$$\frac{140.00}{0.47209} = \frac{275.00}{\sin \angle x}$$
$$\sin \angle x = 0.92731$$

The angle that corresponds to the sine function 0.92731 is 68°. Because $\angle x$ is greater than 90°, $\angle x$ = the supplement of 68°. $\angle x = 180° - 68° = 112°$. Ans

Cosine Functions of Angles Between 90° and 180°

The cosine of an angle greater than 90° and less than 180° equals the negative cosine of the supplement of the angle. If the value of $\angle x$ is between 90° and 180°, $\cos \angle x = -\cos(180° - \angle x)$. A negative function of an angle does *not* mean that the angle is negative: it is a negative function of a positive angle. For example, $-\cos 65°$ does *not* mean $\cos(-65°)$.

***Examples*:**

1. $\cos 115° = -\cos(180° - 115°) = -\cos 65° = -0.42262$.
   Note: Determine the cosine of 65° and prefix a negative sign:
   $\cos 65° = 0.42262$: $-\cos 65° = 0.42262$.
2. $\cos 90°42' = -\cos(180° - 90°42') = -\cos 89°18' = -0.01222$.
3. $\cos 176.25° = -\cos(180° - 176.25°) = -\cos 3.75° = -0.99786$.

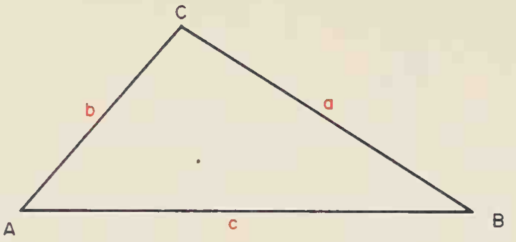


Figure A-100

Law of Cosines

The law of cosines states that, in any triangle, the square of any side is equal to the sum of the squares of the other two sides minus twice the product of these two sides multiplied by the cosine of their included angle. That is (see Figure A-100)

$$a^2 = b^2 + c^2 - 2bc(\cos A)$$
$$b^2 = a^2 + c^2 - 2ac(\cos B)$$
$$c^2 = a^2 + b^2 - 2ab(\cos C)$$

The equations can be rearranged in this form:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$
$$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$$
$$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$$

The law of cosines is used to solve the following kinds of problems:

- Problems where two sides and the included angle of an oblique triangle are known.
- Problems where three sides of an oblique triangle are known.

Solving Oblique Triangle Problems Given Two Sides and the Included Angle

Example 1: Internally and externally tangent circles are shown in Figure A-101. Determine dimension y, the distance between hole centers A and C.
All dimensions are in inches.
In oblique △ABC:

$$AB = \frac{3.000}{2} - \frac{0.930}{2} = 1.035$$
$$BC = \frac{3.000}{2} + \frac{1.500}{2} = 2.250$$

The 82° angle is the included angle between AB and BC. Substitute values in their appropriate places in the formula and solve for dimension y.

$$y^2 = 1.035^2 + 2.250^2 - 2(1.035)(2.250)(\cos 82°)$$
$$y^2 = 1.0712 + 5.0625 - 2(1.035)(2.250)(0.13917)$$
$$y^2 = 6.1337 - 0.6482$$
$$y^2 = 5.4855$$
$$y = 2.342 \text{ in Ans}$$

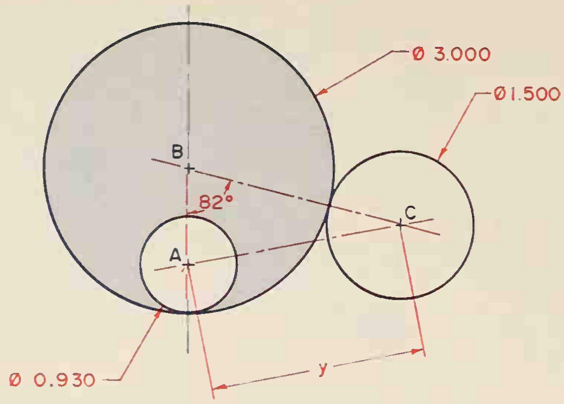


Figure A-101

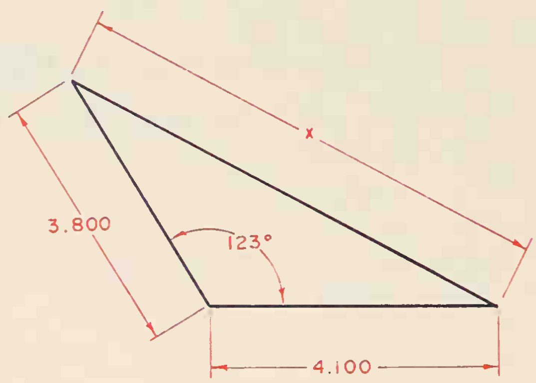


Figure A-102

Example 2: Given two sides and the included angle, determine side x of the oblique triangle in Figure A-102. All dimensions are in inches. Substitute values to solve for x.

$$x^2 = 3.800^2 + 4.100^2 - 2(3.800)(4.100)(\cos 123°)$$

Since the given angle is greater than 90°, the cosine of the angle is equal to the negative cosine of its supplement. Therefore,

$$\cos 123° = -\cos(180° - 123°) = -\cos 57° = -0.54464$$

This negative value must be used in computing side x.

$$x^2 = 3.800^2 + 4.100^2 - 2(3.800)(4.100)(-0.54464)$$
$$x^2 = 31.250 - (-16.971)$$

Recall that subtracting a negative value is the same as adding a positive value.

$$x^2 = 31.250 + 16.971$$
$$x^2 = 48.221$$
$$x = 6.944 \text{ in Ans}$$

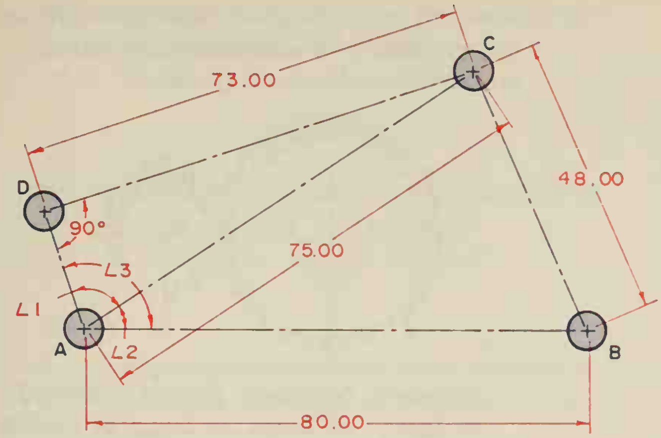


Figure A-103

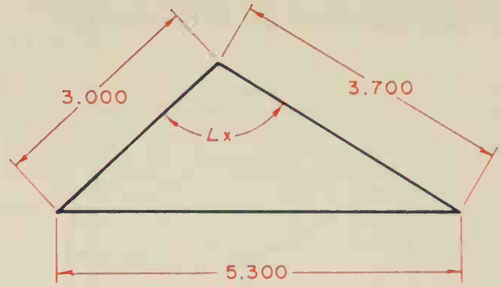


Figure A-104

Solving Oblique Triangle Problems Given Three Sides

Example 1: Four pins are located on a fixture at A, B, C, and D as shown in Figure A-103. Compute ∠3.

All dimensions are in millimetres.

∠3 = ∠1 + ∠2. Compute ∠1 in the right △ADC. Compute ∠2 in oblique △ABC. In right △ADC, AC = 75.00, DC = 73.00.

$$\sin \angle 1 = \frac{DC}{AC}$$

$$\sin \angle 1 = \frac{73.00}{75.00} = 0.97333$$

$$\angle 1 = 76.73^\circ$$

In oblique △ABC, AC = 75.00, AB = 80.00, BC = 48.00.

Substitute values in their appropriate places in the formula.

$$\cos \angle 2 = \frac{75.00^2 + 80.00^2 - 48.00^2}{2(75.00)(80.00)}$$

$$\cos \angle 2 = \frac{5625 + 6400 - 2304}{12{,}000} = 0.81008$$

$$\angle 2 = 35.90^\circ$$

$$\angle 3 = \angle 1 + \angle 2 = 76.73^\circ + 35.90^\circ = 112.63^\circ \text{ Ans}$$

Example 2: Given three sides, determine ∠*x* of the oblique triangle in Figure A-104. All dimensions are in inches.

Substitute values in the formula.

$$\cos \angle x = \frac{3.000^2 + 3.700^2 - 5.300^2}{2(3.000)(3.700)}$$

$$\cos \angle x = \frac{9.000 + 13.690 - 28.090}{22.200}$$

$$\cos \angle x = \frac{22.690 - 28.090}{22.200}$$

$$\cos \angle x = \frac{-5.400}{22.200}$$

$$\cos \angle x = -0.24324$$

Since cos ∠*x* is a negative value, ∠*x* is equal to the supplement of the angle found. The angle corresponding to the cosine function 0.24324 is 75°55′. Therefore, the angle whose cosine function is −0.24324 is equal to 180° − 75°55′ = 104°05′. Therefore, ∠*x* = 104°05′ Ans

Review

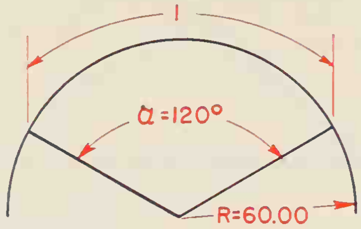
Solutions to the following problems require the application of mathematical operations, procedures, and principles presented in this appendix.

1. Round 4.02463 inches to three decimal places.
2. Round 59.6841 mm to two decimal places.
3. Using the decimal equivalent table,
   a. find the decimal equivalent of 57/64 in;
   b. find the fractional equivalent of 0.4375 in;
   c. find the nearer fractional equivalent of 0.706 in.
4. Express 0.983 in in millimetres. Round the answer to two decimal places.
5. Express 70.15 mm in inches. Round the answer to three decimal places.

   Problems 6-11 involve working with formulas that have been obtained from technical handbooks. For each problem substitute the given numerical values for letters in the formula and solve for the unknown. Where necessary, round answers to two decimal places.

6. $A = \pi(ab - cd)$. Solve for A when $\pi = 3.1416$, $a = 5.000$ in, $b = 3.000$ in, $c = 4.000$ in, and $d = 2.000$ in.
7. $A = \frac{\pi(R^2 - r^2)}{2}$. Solve for A when $\pi = 3.1416$, $R = 7.000$ in, and $r = 3.000$ in.
8. $V = \frac{(2a + c)bh}{6}$. Solve for V when $a = 9.000$ in, $b = 7.000$ in, $c = 11.000$ in, and $h = 8.000$ in.

9. All dimensions are in millimetres.



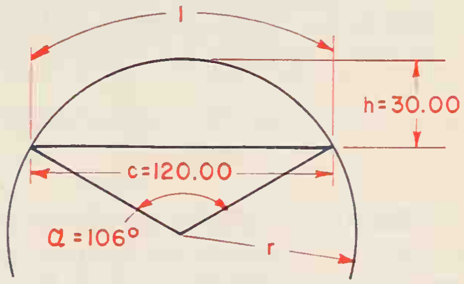
a. Find the length of this arc (l).

$$l = \frac{3.1416\, R\, \alpha}{180°}$$

b. Find the area of this sector (A).

$$A = \frac{1}{2} Rl$$

10. All dimensions are in millimetres.



a. Find the radius of this circle.

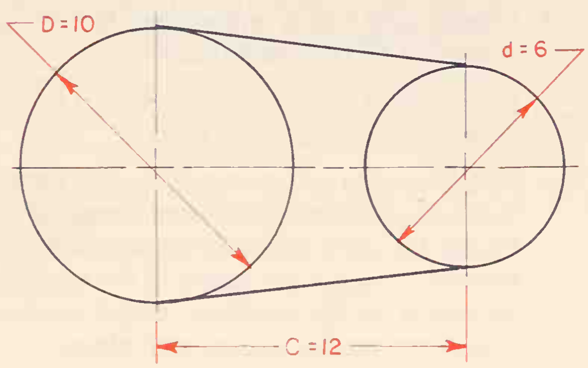
$$r = \frac{c^2 + 4h^2}{8h}$$

b. Find the length of the arc (l).

$l = 0.0175 r\alpha$

11. All dimensions are in inches. Find the belt length on the pulleys.

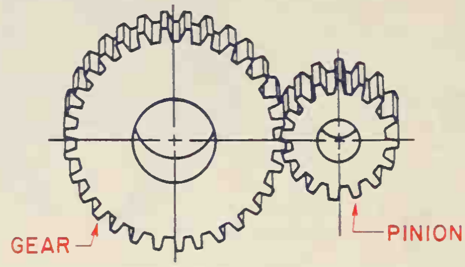
$$\text{Length of belt} = 2C + \frac{11D + 11d}{7} + \frac{(D - d)^2}{4C}$$



12. Of two gears that mesh, the one which has the greater number of teeth is called the gear, and the one which has the fewer teeth is called the pinion. The proportion that expresses the relationship of gear teeth and speeds is

$$\frac{\text{Number of teeth on gear}}{\text{Number of teeth on pinion}} = \frac{\text{Speed of pinion}}{\text{Speed of gear}}$$

For each problem, a - e, determine the unknown value x. Where necessary, round answer to one decimal place.



	Number of Teeth on Gear	Number of Teeth on Pinion	Speed of Gear (rpm)	Speed of Pinion (rpm)
a	48	20	120	x
b	32	24	x	210
c	35	x	160	200
d	x	15	150	250
e	54	28	80	x

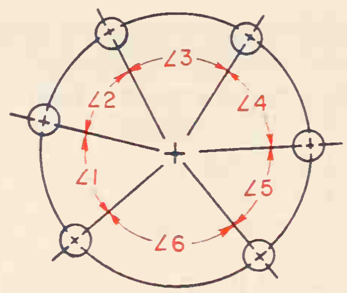
13. Add the angles in each of these problems.
    a. 23°43′ + 71°12′ + 19°27′
    b. 9°33′46″ + 37°12′19″

14. Subtract the angles in each of these problems.
    a. 63°23′ − 32°58′
    b. 54°32′13″ − 19°13′42″

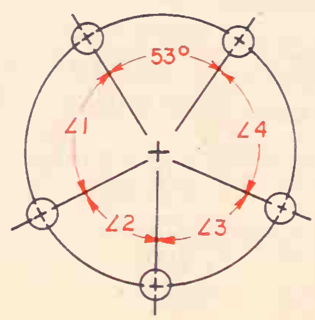
15. Multiply the angles in each of these problems.
    a. 2(43°43′)
    b. 5(22°10′13″)

16. Divide the angles in each of these problems.
    a. 105°20′ ÷ 4
    b. 110°51′5″ ÷ 5

17. In the figure,
    ∠1 = ∠2 = ∠3 = ∠4 = ∠5 = 53°41′
    Determine ∠6.



18. In the figure,
    ∠1 = ∠2 = ∠3 = ∠4
    Determine ∠1.



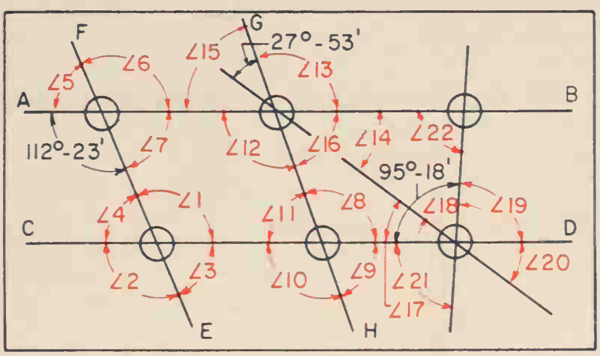
19. Express each of the following decimal-degrees as degrees and minutes.
a. 76.95°   b. 117.70°

20. Express the following decimal-degrees as degrees, minutes, and seconds.
a 7.9250°   b. 37.9365°

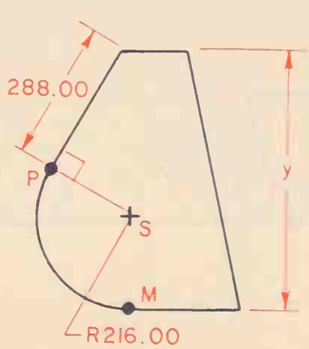
21. Express each of the following degrees and minutes as decimal-degrees. Round the answer to two decimal places.
a. 93°18′   b. 79°59′

22. Express each of the following degrees, minutes, and seconds as decimal-degrees. Round the answer to four decimal places.
a. 53°10′45″   b. 176°27′18″

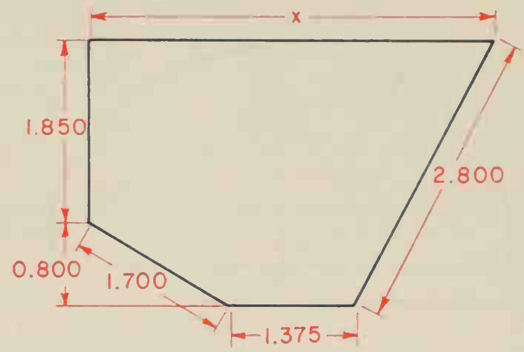
23. Centerlines AB || CD and EF || GH. Determine the values of ∠1 – ∠2.



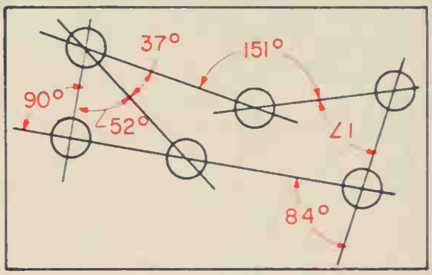
24. Determine dimension y. All dimensions are in millimetres.



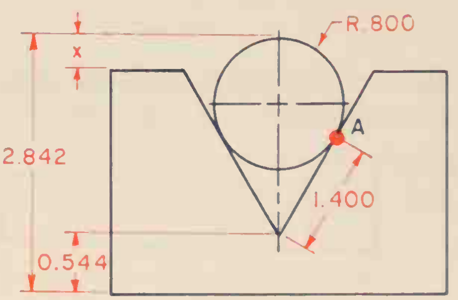
25. Determine dimension x. All dimensions are in inches.



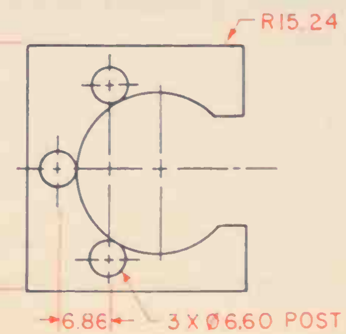
26. Determine ∠1.



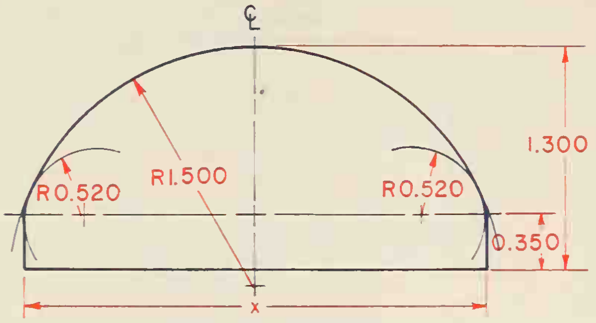
27. Point A is a tangent point. All dimensions are in inches. Determine dimension x.



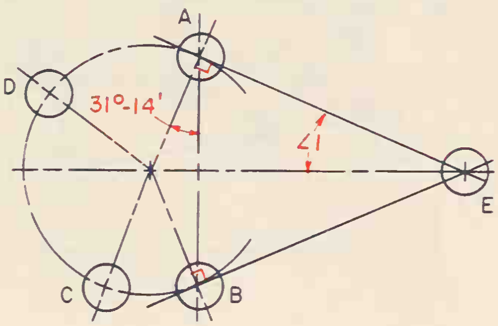
28. Determine dimension y. All dimensions are in millimetres.



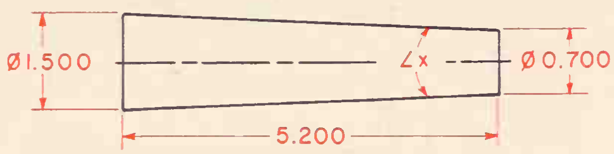
29. Determine dimension x. All dimensions are in inches.



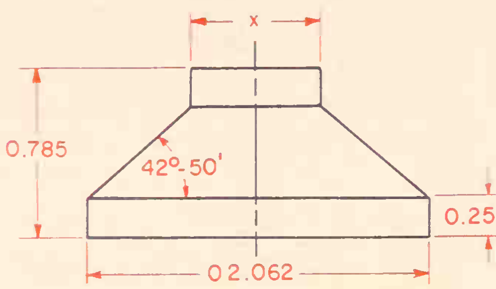
30. AC is a diameter. Determine ∠1.



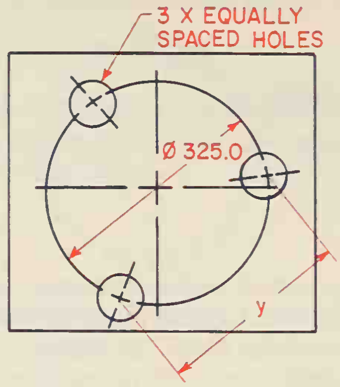
31. Determine the included taper angle x. All dimensions are in inches.



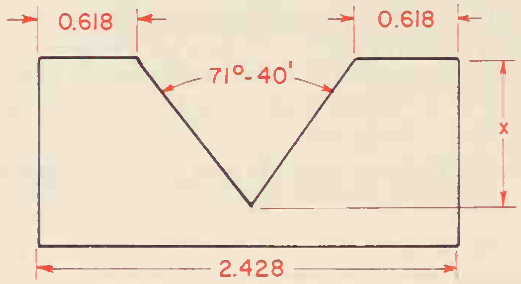
32. Determine diameter x. All dimensions are in inches.



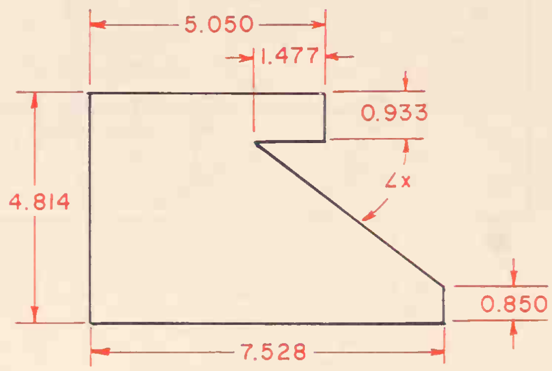
33. Determine center distance y. All dimensions are in millimetres.



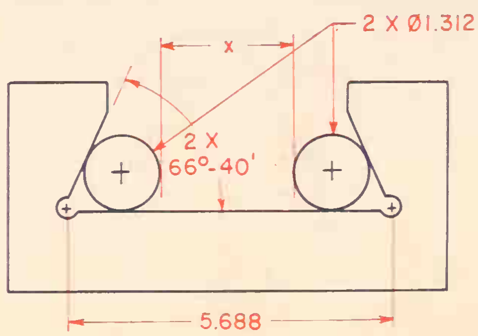
34. Determine depth of cut x. All dimension are in inches.



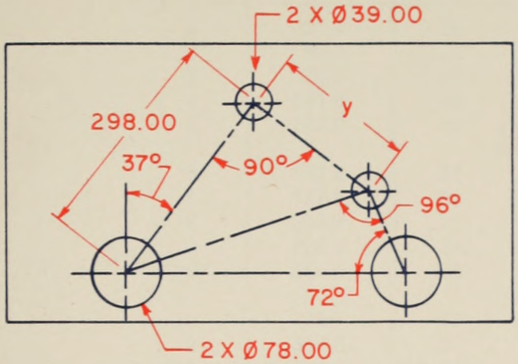
35. Determine ∠x. All dimension are in inches.



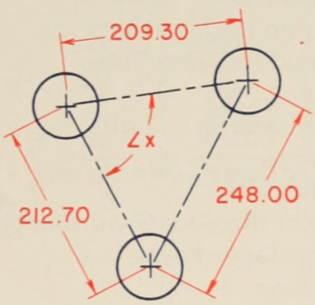
36. Determine gage dimension x. All dimensions are in inches.



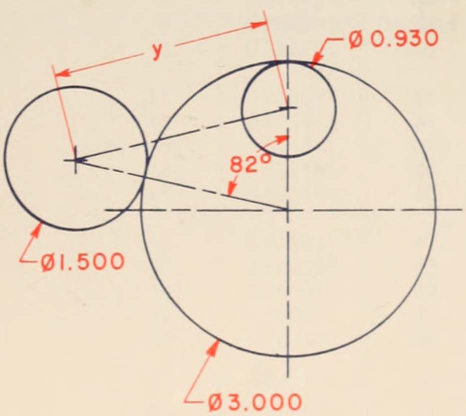
37. Determine dimension *y*. All dimensions are in millimetres.



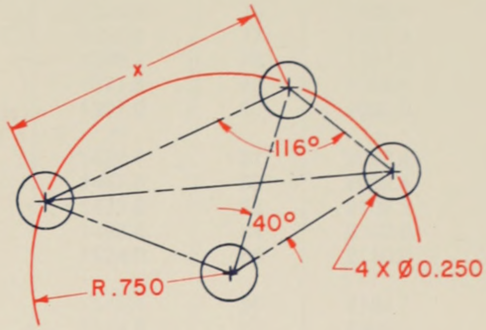
38. Determine ∠*x*. All dimensions are in millimetres.



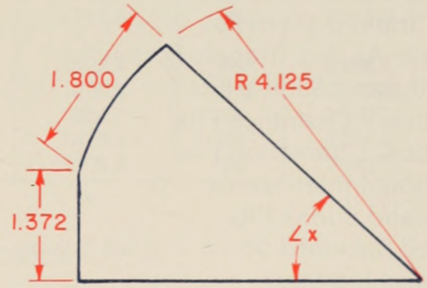
39. Determine dimension *y*. All dimensions are in inches.



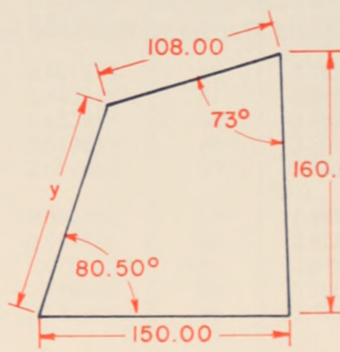
40. Determine dimension *x*. All dimensions are in inches.



41. Determine ∠*x*. All dimensions are in inches.



42. Determine dimension *y*. All dimensions are in millimetres.



Appendix B
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INCHES TO MILLIMETRES

in.	mm	in.	mm	in.	mm	in.	mm
1	25.4	26	660.4	51	1295.4	76	1930.4
2	50.8	27	685.8	52	1320.8	77	1955.8
3	76.2	28	711.2	53	1346.2	78	1981.2
4	101.6	29	736.6	54	1371.6	79	2006.6
5	127.0	30	762.0	55	1397.0	80	2032.0
6	152.4	31	787.4	56	1422.4	81	2057.4
7	177.8	32	812.8	57	1447.8	82	2082.8
8	203.2	33	838.2	58	1473.2	83	2108.2
9	228.6	34	863.6	59	1498.6	84	2133.6
10	254.0	35	889.0	60	1524.0	85	2159.0
11	279.4	36	914.4	61	1549.4	86	2184.4
12	304.8	37	939.8	62	1574.8	87	2209.8
13	330.2	38	965.2	63	1600.2	88	2235.2
14	355.6	39	990.6	64	1625.6	89	2260.6
15	381.0	40	1016.0	65	1651.0	90	2286.0
16	406.4	41	1041.4	66	1676.4	91	2311.4
17	431.8	42	1066.8	67	1701.8	92	2336.8
18	457.2	43	1092.2	68	1727.2	93	2362.2
19	482.6	44	1117.6	69	1752.6	94	2387.6
20	508.0	45	1143.0	70	1778.0	95	2413.0
21	533.4	46	1168.4	71	1803.4	96	2438.4
22	558.8	47	1193.8	72	1828.8	97	2463.8
23	584.2	48	1219.2	73	1854.2	98	2489.2
24	609.6	49	1244.6	74	1879.6	99	2514.6
25	635.0	50	1270.0	75	1905.0	100	2540.0

The above table is exact on the basis: 1 in. = 25.4 mm

MILLIMETRES TO INCHES

mm	in.	mm	in.	mm	in.	mm	in.
1	0.039370	26	1.023622	51	2.007874	76	2.992126
2	0.078740	27	1.062992	52	2.047244	77	3.031496
3	0.118110	28	1.102362	53	2.086614	78	3.070866
4	0.157480	29	1.141732	54	2.125984	79	3.110236
5	0.196850	30	1.181102	55	2.165354	80	3.149606
6	0.236220	31	1.220472	56	2.204724	81	3.188976
7	0.275591	32	1.259843	57	2.244094	82	3.228346
8	0.314961	33	1.299213	58	2.283465	83	3.267717
9	0.354331	34	1.338583	59	2.322835	84	3.307087
10	0.393701	35	1.377953	60	2.362205	85	3.346457
11	0.433071	36	1.417323	61	2.401575	86	3.385827
12	0.472441	37	1.456693	62	2.440945	87	3.425197
13	0.511811	38	1.496063	63	2.480315	88	3.464567
14	0.551181	39	1.535433	64	2.519685	89	3.503937
15	0.590551	40	1.574803	65	2.559055	90	3.543307
16	0.629921	41	1.614173	66	2.598425	91	3.582677
17	0.669291	42	1.653543	67	2.637795	92	3.622047
18	0.708661	43	1.692913	68	2.677165	93	3.661417
19	0.748031	44	1.732283	69	2.716535	94	3.700787
20	0.787402	45	1.771654	70	2.755906	95	3.740157
21	0.826772	46	1.811024	71	2.795276	96	3.779528
22	0.866142	47	1.850394	72	2.834646	97	3.818898
23	0.905512	48	1.889764	73	2.874016	98	3.858268
24	0.944882	49	1.929134	74	2.913386	99	3.897638
25	0.984252	50	1.968504	75	2.952756	100	3.937008

The above table is approximate on the basis: 1 in. = 25.4 mm, 1/25.4 = 0.039370078740+

Table 1

INCH/METRIC – EQUIVALENTS					
Fraction	Decimal Equivalent Customary (in.)	Decimal Equivalent Metric (mm)	Fraction	Decimal Equivalent Customary (in.)	Decimal Equivalent Metric (mm)
1/64	.015625	0.3969	33/64	.515625	13.0969
1/32	.03125	0.7938	17/32	.53125	13.4938
3/64	.046875	1.1906	35/64	.546875	13.8906
1/16	.0625	1.5875	9/16	.5625	14.2875
5/64	.078125	1.9844	37/64	.578125	14.6844
3/32	.09375	2.3813	19/32	.59375	15.0813
7/64	.109375	2.7781	39/64	.609375	15.4781
1/8	.1250	3.1750	5/8	.6250	15.8750
9/64	.140625	3.5719	41/64	.640625	16.2719
5/32	.15625	3.9688	21/32	.65625	16.6688
11/64	.171875	4.3656	43/64	.671875	17.0656
3/16	.1875	4.7625	11/16	.6875	17.4625
13/64	.203125	5.1594	45/64	.703125	17.8594
7/32	.21875	5.5563	23/32	.71875	18.2563
15/64	.234375	5.9531	47/64	.734375	18.6531
1/4	.250	6.3500	3/4	.750	19.0500
17/64	.265625	6.7469	49/64	.765625	19.4469
9/32	.28125	7.1438	25/32	.78125	19.8438
19/64	.296875	7.5406	51/64	.796875	20.2406
5/16	.3125	7.9375	13/16	.8125	20.6375
21/64	.328125	8.3384	53/64	.828125	21.0344
11/32	.34375	8.7313	27/32	.84375	21.4313
23/64	.359375	9.1281	55/64	.859375	21.8281
3/8	.3750	9.5250	7/8	.8750	22.2250
25/64	.390625	9.9219	57/64	.890625	22.6219
13/32	.40625	10.3188	29/32	.90625	23.0188
27/64	.421875	10.7156	59/64	.921875	23.4156
7/16	.4375	11.1125	15/16	.9375	23.8125
29/64	.453125	11.5094	61/64	.953125	24.2094
15/32	.46875	11.9063	31/32	.96875	24.6063
31/64	.484375	12.3031	63/64	.984375	25.0031
1/2	.500	12.7000	1	1.000	25.4000

From Drafting for Trades and Industry—Basic Skills. Nelson. Delmar Publishers Inc.

Table 2

METRIC EQUIVALENTS

LENGTH

U.S. to Metric	Metric to U.S.
1 inch = 2.540 centimetres	1 millimetre = .039 inch
1 foot = .305 metre	1 centimetre = .394 inch
1 yard = .914 metre	1 metre = 3.281 feet or 1.094 yards
1 mile = 1.609 kilometres	1 kilometre = .621 mile

AREA

U.S. to Metric	Metric to U.S.
1 inch^2 = 6.451 centimetre^2	1 millimetre^2 = .00155 inch^2
1 foot^2 = .093 metre^2	1 centimetre^2 = .155 inch^2
1 yard^2 = .836 metre^2	1 metre^2 = 10.764 foot^2 or 1.196 yard^2
1 acre^2 = 4,046.873 metre^2	1 kilometre^2 = .386 mile^2 or 247.04 acre^2

VOLUME

U.S. to Metric	Metric to U.S.
1 inch^3 = 16.387 centimetre^3	1 centimetre^3 = 0.61 inch^3
1 foot^3 = .028 metre^3	1 metre^3 = 35.314 foot^3 or 1.308 yard^3
1 yard^3 = .764 metre^3	1 litre = .2642 gallons
1 quart = .946 litre	1 litre = 1.057 quarts
1 gallon = .003785 metre^3	1 metre^3 = 264.02 gallons

WEIGHT

U.S. to Metric	Metric to U.S.
1 ounce = 28.349 grams	1 gram = .035 ounce
1 pound = .454 kilogram	1 kilogram = 2.205 pounds
1 ton = .907 metric ton	1 metric ton = 1.102 tons

VELOCITY

U.S. to Metric	Metric to U.S.
1 foot/second = .305 metre/second	1 metre/second = 3.281 feet/second
1 mile/hour = .447 metre/second	1 kilometre/hour = .621 mile/second

ACCELERATION

U.S. to Metric	Metric to U.S.
1 inch/second^2 = .0254 metre/second^2	1 metre/second^2 = 3.278 feet/second^2
1 foot/second^2 = .305 metre/second^2	

FORCE

N (newton) = basic unit of force, kg-m/s^2. A mass of one kilogram (1 kg) exerts a gravitational force of 9.8 N (theoretically 9.80665 N) at mean sea level.

Table 3

MULTIPLIERS FOR DRAFTERS

Multiply	By	To Obtain
Acres	43,560	Square feet
Acres	4047	Square metres
Acres	1.562×10^{-3}	Square miles
Acres	4840	Square yards
Acre–feet	43,560	Cubic feet
Atmospheres	76.0	Cms. of mercury
Atmospheres	29.92	Inches of mercury
Atmospheres	33.90	Feet of water
Atmospheres	10,333	Kgs./sq. metre
Atmospheres	14.70	Lbs./sq. inch
Atmospheres	1.058	Tons/sq. ft.
Board feet	144 sq. in. × 1 in.	Cubic inches
British Thermal Units	0.2520	Kilogram–calories
British Thermal Units	777.5	Foot–lbs.
British Thermal Units	3.927×10^{-4}	Horsepower–hrs.
British Thermal Units	107.5	Kilogram–metres
British Thermal Units	2.928×10^{-4}	Kilowatt–hrs.
B.T.U./min.	12.96	Foot–lbs./sec.
B.T.U./min.	0.02356	Horsepower
B.T.U./min.	0.01757	Kilowatts
B.T.U./min.	17.57	Watts
Cubic centimetres	3.531×10^{-5}	Cubic feet
Cubic centimetres	6.102×10^{-2}	Cubic inches
Cubic centimetres	10^{-6}	Cubic metres
Cubic centimetres	1.308×10^{-6}	Cubic yards
Cubic centimetres	2.642×10^{-4}	Gallons
Cubic centimetres	10^{-3}	Litres
Cubic centimetres	2.113×10^{-3}	Pints (liq.)
Cubic centimetres	1.057×10^{-3}	Quarts (liq.)
Cubic feet	2.832×10^{4}	Cubic cms.
Cubic feet	1728	Cubic inches
Cubic feet	0.02832	Cubic metres
Cubic feet	0.03704	Cubic yards
Cubic feet	7.48052	Gallons
Cubic feet	28.32	Litres
Cubic feet	59.84	Pints (liq.)
Cubic feet	29.92	Quarts (liq.)
Cubic feet/min.	472.0	Cubic cms./sec.
Cubic feet/min.	0.1247	Gallons/sec.
Cubic feet/min.	0.4720	Litres/sec.
Cubic feet/min.	62.43	Pounds of water/min.
Cubic feet/sec.	0.646317	Millions gals./day
Cubic feet/sec.	448.831	Gallons/min.
Cubic inches	16.39	Cubic centimetres
Cubic inches	5.787×10^{-4}	Cubic feet
Cubic inches	1.639×10^{-5}	Cubic metres
Cubic inches	2.143×10^{-5}	Cubic yards
Cubic inches	4.329×10^{-3}	Gallons
Cubic inches	1.639×10^{-2}	Litres
Cubic inches	0.03463	Pints (liq.)
Cubic inches	0.01732	Quarts (liq.)
Cubic metres	10^{6}	Cubic centimetres
Cubic metres	35.31	Cubic feet
Cubic metres	61.023	Cubic inches
Cubic metres	1.308	Cubic yards
Cubic metres	264.2	Gallons
Cubic metres	10^{3}	Litres
Cubic metres	2113	Pints (liq.)
Cubic metres	1057	Quarts (liq.)
Degrees (angle)	60	Minutes
Degrees (angle)	0.01745	Radians
Degrees (angle)	3600	Seconds
Degrees/sec.	0.01745	Radians/sec.
Degrees/sec.	0.1667	Revolutions/min.
Degrees/sec.	0.002778	Revolutions/sec.
Fathoms	6	Feet
Feet	30.48	Centimetres
Feet	12	Inches
Feet	0.3048	Metres
Foot–pounds	1.286×10^{-3}	British Thermal Units
Foot–pounds	5.050×10^{-7}	Horsepower–hrs.
Foot–pounds	3.241×10^{-4}	Kilogram–calories
Foot–pounds	0.1383	Kilogram–metres
Foot–pounds	3.766×10^{-7}	Kilowatt–hrs.
Foot–pounds/min.	1.286×10^{-3}	B.T.U./min.
Foot–pounds/min.	0.01667	Foot–pounds/sec.
Foot–pounds/min.	3.030×10^{-5}	Horsepower
Foot–pounds/min.	3.241×10^{-4}	Kg.–calories/min.
Foot–pounds/min.	2.260×10^{-5}	Kilowatts
Foot–pounds/sec.	7.717×10^{-2}	B.T.U./min.
Foot–pounds/sec.	1.818×10^{-3}	Horsepower
Foot–pounds/sec.	1.945×10^{-2}	Kg.–calories/min.
Foot–pounds/sec.	1.356×10^{-3}	Kilowatts
Gallons	3785	Cubic centimetres
Gallons	0.1337	Cubic feet
Gallons	231	Cubic inches
Gallons	3.785×10^{-3}	Cubic metres
Gallons	4.951×10^{-3}	Cubic yards
Gallons	3.785	Litres
Gallons	8	Pints (liq.)
Gallons	4	Quarts (liq.)
Gallons–Imperial	1.20095	U.S. gallons
Gallons–U.S.	0.83267	Imperial gallons
Gallons water	8.3453	Pounds of water
Horsepower	42.44	B.T.U./min.
Horsepower	33,000	Foot–lbs./min.
Horsepower	550	Foot–lbs./sec.
Horsepower	1.014	Horsepower (metric)
Horsepower	10.70	Kg.–calories/min.
Horsepower	0.7457	Kilowatts
Horsepower	745.7	Watts
Horsepower–hours	2547	B.T.U.
Horsepower–hours	1.98×10^{6}	Foot–lbs.
Horsepower–hours	641.7	Kilogram–calories
Horsepower–hours	2.737×10^{5}	Kilogram–metres
Horsepower–hours	0.7457	Kilowatt–hours
Kilometres	10^{5}	Centimetres
Kilometres	3281	Feet
Kilometres	10^{3}	Metres
Kilometres	0.6214	Miles
Kilometres	1094	Yards
Kilowatts	56.92	B.T.U./min.
Kilowatts	4.425×10^{4}	Foot–lbs./min.
Kilowatts	737.6	Foot–lbs./sec.
Kilowatts	1.341	Horsepower
Kilowatts	14.34	Kg.–calories/min.
Kilowatts	10^{3}	Watts
Kilowatt–hours	3415	B.T.U.
Kilowatt–hours	2.655×10^{6}	Foot–lbs.
Kilowatt–hours	1.341	Horsepower–hrs.
Kilowatt–hours	860.5	Kilogram–calories
Kilowatt–hours	3.671×10^{5}	Kilogram–metres
$\frac{\text{Lumber Width (in.)} \times \text{Thickness (in.)}}{12}$	Length (ft.)	Board feet
Metres	100	Centimetres
Metres	3.281	Feet
Metres	39.37	Inches

Table 4

MULTIPLIERS FOR DRAFTERS (cont'd)

Multiply	By	To Obtain
Metres	10^{-3}	Kilometres
Metres	10^{3}	Millimetres
Metres	1.094	Yards
Metres/min.	1.667	Centimetres/sec.
Metres/min.	3.281	Feet/min.
Metres/min.	0.05468	Feet/sec.
Metres/min.	0.06	Kilometres/hr.
Metres/min.	0.03728	Miles/hr.
Metres/sec.	196.8	Feet/min.
Metres/sec.	3.281	Feet/sec.
Metres/sec.	3.6	Kilometres/hr.
Metres/sec.	0.06	Kilometres/min.
Metres/sec.	2.237	Miles/hr.
Metres/sec.	0.03728	Miles/min.
Microns	10^{-6}	Metres
Miles	5280	Feet
Miles	1.609	Kilometres
Miles	1760	Yards
Miles/hr.	1.609	Kilometres/hr.
Miles/hr.	0.8684	Knots
Minutes (angle)	2.909×10^{-4}	Radians
Ounces	16	Drams
Ounces	437.5	Grains
Ounces	0.0625	Pounds
Ounces	28.349527	Grams
Ounces	0.9115	Ounces (troy)
Ounces	2.790×10^{-5}	Tons (long)
Ounces	2.835×10^{-5}	Tons (metric)
Ounces (troy)	480	Grains
Ounces (troy)	20	Pennyweights (troy)
Ounces (troy)	0.08333	Pounds (troy)
Ounces (troy)	31.103481	Grams
Ounces (troy)	1.09714	Ounces (avoir.)
Ounces (fluid)	1.805	Cubic inches
Ounces (fluid)	0.02957	Litres
Ounces/sq. inch	0.0625	Lbs./sq. inch
Pounds	16	Ounces
Pounds	256	Drams
Pounds	7000	Grains
Pounds	0.0005	Tons (short)
Pounds	453.5924	Grams
Pounds	1.21528	Pounds (troy)
Pounds	14.5833	Ounces (troy)
Pounds (troy)	5760	Grains
Pounds (troy)	240	Pennyweights (troy)
Pounds (troy)	12	Ounces (troy)
Pounds (troy)	373.24177	Grams
Pounds (troy)	0.822857	Pounds (avoir.)
Pounds (troy)	13.1657	Ounces (avoir.)
Pounds (troy)	3.6735×10^{-4}	Tons (long)
Pounds (troy)	4.1143×10^{-4}	Tons (short)
Pounds (troy)	3.7324×10^{-4}	Tons (metric)
Quadrants (angle)	90	Degrees
Quadrants (angle)	5400	Minutes
Quadrants (angle)	1.571	Radians
Radians	57.30	Degrees
Radians	3438	Minutes
Radians	0.637	Quadrants
Radians/sec.	57.30	Degrees/sec.
Radians/sec.	0.1592	Revolutions/sec.
Radians/sec.	9.549	Revolutions/min.
Radians/sec./sec.	573.0	Revs./min./min.
Radians/sec./sec.	0.1592	Revs./sec./sec.
Reams	500	Sheets
Revolutions	360	Degrees
Revolutions	4	Quadrants
Revolutions	6.283	Radians
Revolutions/min.	6	Degrees/sec.
Square yards	2.066×10^{-4}	Acres
Square yards	9	Square feet
Square yards	0.8361	Square metres
Square yards	3.228×10^{-7}	Square miles
Temp. (°C.) + 273	1	Abs. temp. (°C.)
Temp. (°C.) + 17.78	1.8	Temp. (°F.)
Temp. (°F.) + 460	1	Abs. temp. (°F.)
Temp. (°F.) − 32	5/9	Temp. (°C.)
Watts	0.05692	B.T.U./min.
Watts	44.26	Foot−pounds/min.
Watts	0.7376	Foot−pounds/sec.
Watts	1.341×10^{-3}	Horsepower
Watts	0.01434	Kg.−calories/min.
Watts	10^{-3}	Kilowatts
Watt−hours	3.415	B.T.U.
Watt−hours	2655	Foot−pounds
Watt−hours	1.341×10^{-3}	Horsepower−hrs.
Watt−hours	0.8605	Kilogram−calories
Watt−hours	367.1	Kilogram−metres
Watt−hours	10^{-3}	Kilowatt−hours
Yards	91.44	Centimetres
Yards	3	Feet
Yards	36	Inches
Yards	0.9144	Metres

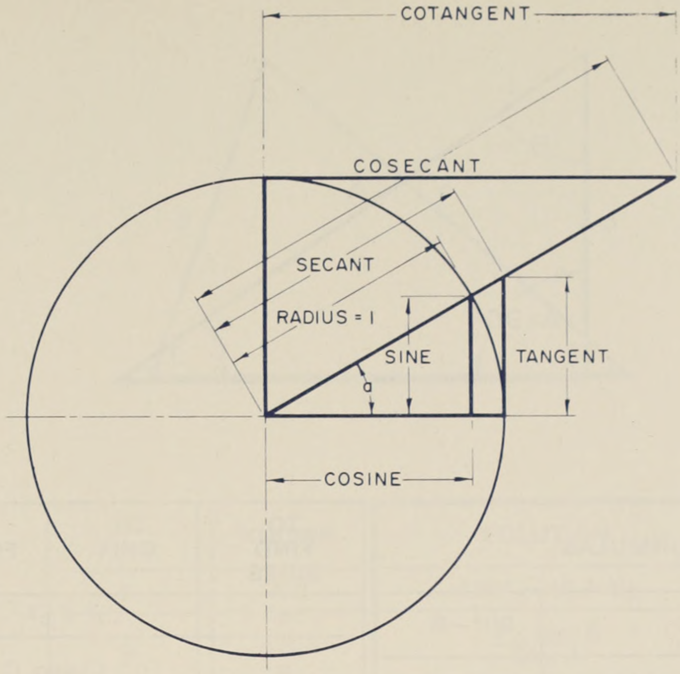
Table 4 (Cont'd)

Table 5

CIRCUMFERENCES AND AREAS OF CIRCLES
From 1/64 to 50, Diameter

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
1/64	.04909	.00019	8	25.1327	50.2655	17	53.4071	226.980	26	81.6814	530.929
1/32	.09818	.00077	8⅛	25.5254	51.8485	17⅛	53.7998	230.330	26⅛	82.0741	536.047
1/16	.19635	.00307	8¼	25.9181	53.4562	17¼	54.1925	233.705	26¼	82.4668	541.188
⅛	.39270	.01227	8⅜	26.3108	55.0883	17⅜	54.5852	237.104	26⅜	82.8595	546.355
3/16	.58905	.02761	8½	26.7035	56.7450	17½	54.9779	240.528	26½	83.2522	551.546
¼	.78540	.04909	8⅝	27.0962	58.4262	17⅝	55.3706	243.977	26⅝	83.6449	556.761
5/16	.98175	.07670	8¾	27.4889	60.1321	17¾	55.7633	247.450	26¾	84.0376	562.002
⅜	1.1781	.11045	8⅞	27.8816	61.8624	17⅞	56.1560	250.947	26⅞	84.4303	567.266
7/16	1.3744	.15033	9	28.2743	63.6173	18	56.5487	254.469	27	84.8230	572.555
½	1.5708	.19635	9⅛	28.6670	65.3967	18⅛	56.9414	258.016	27⅛	85.2157	577.869
9/16	1.7671	.24850	9¼	29.0597	67.2007	18¼	57.3341	261.587	27¼	85.6084	583.207
⅝	1.9635	.30680	9⅜	29.4524	69.0292	18⅜	57.7268	265.182	27⅜	86.0011	588.570
11/16	2.1598	.37122	9½	29.8451	70.8822	18½	58.1195	268.803	27½	86.3938	593.957
¾	2.3562	.44179	9⅝	30.2378	72.7597	18⅝	58.5122	272.447	27⅝	86.7865	599.369
13/16	2.5525	.51849	9¾	30.6305	74.6619	18¾	58.9049	276.117	27¾	87.1792	604.806
⅞	2.7489	.60132	9⅞	31.0232	76.5886	18⅞	59.2976	279.810	27⅞	87.5719	610.267
15/16	2.9452	.69029				19	59.6903	283.529	28	87.9646	615.752
1	3.1416	.78540	10	31.4159	78.5398	19⅛	60.0830	287.272	28⅛	88.3573	621.262
1⅛	3.5343	.99402	10⅛	31.8086	80.5156	19¼	60.4757	291.039	28¼	88.7500	626.797
1¼	3.9270	1.2272	10¼	32.2013	82.5159	19⅜	60.8684	294.831	28⅜	89.1427	632.356
1⅜	4.3197	1.4849	10⅜	32.5940	84.5408	19½	61.2611	298.648	28½	89.5354	637.940
1½	4.7124	1.7671	10½	32.9867	86.5902	19⅝	61.6538	302.489	28⅝	89.9281	643.548
1⅝	5.1051	2.0739	10⅝	33.3794	88.6641	19¾	62.0465	306.354	28¾	90.3208	649.181
1¾	5.4978	2.4053	10¾	33.7721	90.7626	19⅞	62.4392	310.245	28⅞	90.7135	654.838
1⅞	5.8905	2.7612	10⅞	34.1648	92.8856	20	62.8319	314.159	29	91.1062	660.520
2	6.2832	3.1416	11	34.5575	95.0332	20⅛	63.2246	318.099	29⅛	91.4989	666.226
2⅛	6.6759	3.5466	11⅛	34.9502	97.2053	20¼	63.6173	322.062	29¼	91.8916	671.957
2¼	7.0686	3.9761	11¼	35.3429	99.4020	20⅜	64.0100	326.051	29⅜	92.2843	677.713
2⅜	7.4613	4.4301	11⅜	35.7356	101.623	20½	64.4027	330.064	29½	92.6770	683.493
2½	7.8540	4.9087	11½	36.1283	103.869	20⅝	64.7954	334.101	29⅝	93.0697	689.297
2⅝	8.2467	5.4119	11⅝	36.5210	106.139	20¾	65.1881	338.163	29¾	93.4624	695.127
2¾	8.6394	5.9396	11¾	36.9137	108.434	20⅞	65.5808	342.250	29⅞	93.8551	700.980
2⅞	9.0321	6.4918	11⅞	37.3064	110.753				30	94.2478	706.858
3	9.4248	7.0686	12	37.6991	113.097	21	65.9735	346.361	30⅛	94.6405	712.761
3⅛	9.8175	7.6699	12⅛	38.0918	115.466	21⅛	66.3662	350.496	30¼	95.0332	718.689
3¼	10.2102	8.2958	12¼	38.4845	117.859	21¼	66.7589	354.656	30⅜	95.4259	724.640
3⅜	10.6029	8.9462	12⅜	38.8772	120.276	21⅜	67.1516	358.841	30½	95.8186	730.617
3½	10.9956	9.6211	12½	39.2699	122.718	21½	67.5442	363.050	30⅝	96.2113	736.618
3⅝	11.3883	10.3206	12⅝	39.6626	125.185	21⅝	67.9369	367.284	30¾	96.6040	742.643
3¾	11.7810	11.0447	12¾	40.0553	127.676	21¾	68.3296	371.542	30⅞	96.9967	748.693
3⅞	12.1737	11.7932	12⅞	40.4480	130.191	21⅞	68.7223	375.825	31	97.3894	754.768
4	12.5664	12.5664	13	40.8407	132.732	22	69.1150	380.133	31⅛	97.7821	760.867
4⅛	12.9591	13.3640	13⅛	41.2334	135.297	22⅛	69.5077	384.465	31¼	98.1748	766.990
4¼	13.3518	14.1863	13¼	41.6261	137.886	22¼	69.9004	388.821	31⅜	98.5675	773.139
4⅜	13.7445	15.0330	13⅜	42.0188	140.500	22⅜	70.2931	393.203	31½	98.9602	779.311
4½	14.1372	15.9043	13½	42.4115	143.139	22½	70.6858	397.608	31⅝	99.3529	785.509
4⅝	14.5299	16.8002	13⅝	42.8042	145.802	22⅝	71.0785	402.038	31¾	99.7456	791.731
4¾	14.9226	17.7206	13¾	43.1969	148.489	22¾	71.4712	406.493	31⅞	100.1383	797.977
4⅞	15.3153	18.6655	13⅞	43.5896	151.201	22⅞	71.8639	410.972			
5	15.7080	19.6350	14	43.9823	153.938	23	72.2566	415.476	32	100.5310	804.248
5⅛	16.1007	20.6290	14⅛	44.3750	156.699	23⅛	72.6493	420.004	32⅛	100.9237	810.543
5¼	16.4934	21.6476	14¼	44.7677	159.485	23¼	73.0420	424.557	32¼	101.3164	816.863
5⅜	16.8861	22.6906	14⅜	45.1604	162.295	23⅜	73.4347	429.134	32⅜	101.7091	823.208
5½	17.2788	23.7583	14½	45.5531	165.130	23½	73.8274	433.736	32½	102.1018	829.577
5⅝	17.6715	24.8505	14⅝	45.9458	167.989	23⅝	74.2201	438.363	32⅝	102.4945	835.971
5¾	18.0642	25.9672	14¾	46.3385	170.873	23¾	74.6128	443.014	32¾	102.8872	842.389
5⅞	18.4569	27.1085	14⅞	46.7312	173.782	23⅞	75.0055	447.689	32⅞	103.2799	848.831
6	18.8496	28.2743	15	47.1239	176.715	24	75.3982	452.389	33	103.6726	855.299
6⅛	19.2423	29.4647	15⅛	47.5166	179.672	24⅛	75.7909	457.114	33⅛	104.0653	861.791
6¼	19.6350	30.6796	15¼	47.9094	182.654	24¼	76.1836	461.863	33¼	104.4580	868.307
6⅜	20.0277	31.9191	15⅜	48.3020	185.661	24⅜	76.5763	466.637	33⅜	104.8507	874.848
6½	20.4204	33.1831	15½	48.6947	188.692	24½	76.9690	471.435	33½	105.2434	881.413
6⅝	20.8131	34.4716	15⅝	49.0874	191.748	24⅝	77.3617	476.258	33⅝	105.6361	888.003
6¾	21.2058	35.7847	15¾	49.4801	194.828	24¾	77.7544	481.106	33¾	106.0288	894.618
6⅞	21.5985	37.1223	15⅞	49.8728	197.933	24⅞	78.1471	485.977	33⅞	106.4215	901.257
7	21.9912	38.4845	16	50.2655	201.062	25	78.5398	490.874	34	106.8142	907.920
7⅛	22.3839	39.8712	16⅛	50.6582	204.216	25⅛	78.9325	495.795	34⅛	107.2069	914.609
7¼	22.7765	41.2825	16¼	51.0509	207.394	25¼	79.3252	500.740	34¼	107.5996	921.321
7⅜	23.1692	42.7183	16⅜	51.4436	210.597	25⅜	79.7179	505.711	34⅜	107.9923	928.058
7½	23.5619	44.1787	16½	51.8363	213.825	25½	80.1106	510.705	34½	108.3850	934.820
7⅝	23.9546	45.6636	16⅝	52.2290	217.077	25⅝	80.5033	515.724	34⅝	108.7777	941.607
7¾	24.3473	47.1730	16¾	52.6217	220.353	25¾	80.8960	520.768	34¾	109.1704	948.417
7⅞	24.7400	48.7069	16⅞	53.0144	223.654	25⅞	81.2887	525.836	34⅞	109.5631	955.253

TRIGONOMETRIC FORMULAS

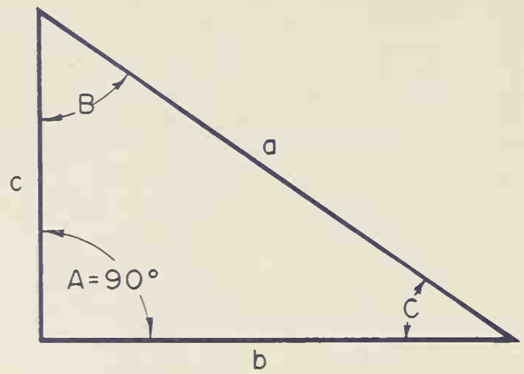


FORMULAS FOR FINDING FUNCTIONS OF ANGLES
$\frac{\text{Side opposite}}{\text{Hypotenuse}}$ = SINE
$\frac{\text{Side adjacent}}{\text{Hypotenuse}}$ = COSINE
$\frac{\text{Side opposite}}{\text{Side adjacent}}$ = TANGENT
$\frac{\text{Side adjacent}}{\text{Side opposite}}$ = COTANGENT
$\frac{\text{Hypotenuse}}{\text{Side adjacent}}$ = SECANT
$\frac{\text{Hypotenuse}}{\text{Side opposite}}$ = COSECANT

FORMULAS FOR FINDING THE LENGTH OF SIDES FOR RIGHT-ANGLE TRIANGLES WHEN AN ANGLE AND SIDE ARE KNOWN	
Length of side opposite	Hypotenuse × Sine Hypotenuse ÷ Cosecant Side adjacent × Tangent Side adjacent ÷ Cotangent
Length of side adjacent	Hypotenuse × Cosine Hypotenuse ÷ Secant Side opposite × Cotangent Side opposite ÷ Tangent
Length of Hypotenuse	Side opposite × Cosecant Side opposite ÷ Sine Side adjacent × Secant Side adjacent ÷ Cosine

Table 6

RIGHT-TRIANGLE FORMULAS

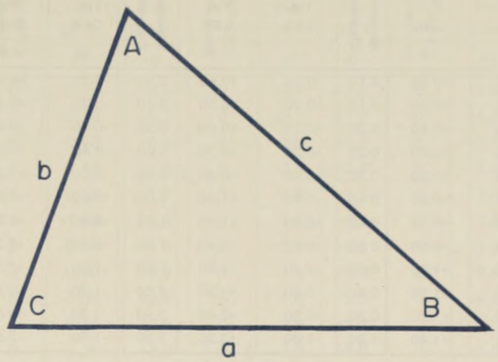


TO FIND ANGLES	FORMULAS	
C	$\frac{c}{a}$ = Sine C	90°—B
C	$\frac{b}{a}$ = Cosine C	90°—B
C	$\frac{c}{b}$ = Tan. C	90°—B
C	$\frac{b}{c}$ = Cotan. C	90°—B
C	$\frac{a}{b}$ = Secant C	90°—B
C	$\frac{a}{c}$ = Cosec. C	90°—B
B	$\frac{b}{a}$ = Sine B	90°—C
B	$\frac{c}{a}$ = Cosine B	90°—C
B	$\frac{b}{c}$ = Tan. B	90°—C
B	$\frac{c}{b}$ = Cotan. B	90°—C
B	$\frac{a}{c}$ = Secant B	90°—C
B	$\frac{a}{b}$ = Cosec. B	90°—C

TO FIND SIDES	FORMULAS	
a	$\sqrt{b^2 + c^2}$	
a	c × Cosec. C	$\frac{c}{\text{sine C}}$
a	c × Secant B	$\frac{c}{\text{Cosine B}}$
a	b × Cosec. B	$\frac{b}{\text{Sine B}}$
a	b × Secant C	$\frac{b}{\text{Cosine C}}$
b	$\sqrt{a^2 - c^2}$	
b	a × Sine B	$\frac{a}{\text{Cosecant B}}$
b	a × Cos. C	$\frac{a}{\text{Secant C}}$
b	c × Tan. B	$\frac{c}{\text{Cotangent B}}$
b	c × Cot. C	$\frac{c}{\text{Tangent C}}$
c	$\sqrt{a^2 - b^2}$	
c	a × Cos. B	$\frac{a}{\text{Secant B}}$
c	a × Sine C	$\frac{a}{\text{Cosecant C}}$
c	b × Cot. B	$\frac{b}{\text{Tangent B}}$
c	b × Tan C	$\frac{b}{\text{Cotangent C}}$

Table 7

OBLIQUE-ANGLED TRIANGLE FORMULAS



TO FIND	KNOWN	SOLUTION
C	A-B	180° − (A + B)
b	a-B-A	$\frac{a \times \text{Sin. B}}{\text{Sin. A}}$
c	a-A-C	$\frac{a \times \text{Sin. C}}{\text{Sin. A}}$
Tan. A	a-C-b	$\frac{a \times \text{Sin. C}}{b - (a \times \text{Cos. C})}$
B	A-C	180° − (A + C)
Sin. B	b-A-a	$\frac{b \times \text{Sin. A}}{a}$
A	B-C	180° − (B + C)
Cos. A	a-b-c	$\frac{b^2 + C^2 - a^2}{2bc}$
Sin. C	c-A-a	$\frac{c \times \text{Sin. A}}{a}$
Cot. B	a-C-b	$\frac{a \times \text{csc}C}{b} - \text{Cot. C}$
c	b-C-B	b × Sin. C × cscB

Table 8

RUNNING AND SLIDING FITS

VALUES IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class RC1 Precision Sliding			Class RC2 Sliding Fit			Class RC3 Precision Running			Class RC4 Close Running			Class RC5 Medium Running		
		Hole Tol. GR5	Minimum Clearance	Shaft Tol. GR4	Hole Tol. GR6	Minimum Clearance	Shaft Tol. GR5	Hole Tol. GR7	Minimum Clearance	Shaft Tol. GR6	Hole Tol. GR8	Minimum Clearance	Shaft Tol. GR7	Hole Tol. GR8	Minimum Clearance	Shaft Tol. GR7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+0.15	0.10	-0.12	+0.25	0.10	-0.15	+0.40	0.30	-0.25	+0.60	0.30	-0.40	+0.60	0.60	-0.40
.12	.24	+0.20	0.15	-0.15	+0.30	0.15	-0.20	+0.50	0.40	-0.30	+0.70	0.40	-0.50	+0.70	0.80	-0.50
.24	.40	+0.25	0.20	-0.15	+0.40	0.20	-0.25	+0.60	0.50	-0.40	+0.90	0.50	-0.60	+0.90	1.00	-0.60
.40	.71	+0.30	0.25	-0.20	+0.40	0.25	-0.30	+0.70	0.60	-0.40	+1.00	0.60	-0.70	+1.00	1.20	-0.70
.71	1.19	+0.40	0.30	-0.25	+0.50	0.30	-0.40	+0.80	0.80	-0.50	+1.20	0.80	-0.80	+1.20	1.60	-0.50
1.19	1.97	+0.40	0.40	-0.30	+0.60	0.40	-0.40	+1.00	1.00	-0.60	+1.60	1.00	-1.00	+1.60	2.00	-1.00
1.97	3.15	+0.50	0.40	-0.30	+0.70	0.40	-0.50	+1.20	1.20	-0.70	+1.80	1.20	-1.20	+1.80	2.50	-1.20
3.15	4.73	+0.60	0.50	-0.40	+0.90	0.50	-0.60	+1.40	1.40	-0.90	+2.20	1.40	-1.40	+2.20	3.00	-1.40
4.73	7.09	+0.70	0.60	-0.50	+1.00	0.60	-0.70	+1.60	1.60	-1.00	+2.50	1.60	-1.60	+2.50	3.50	-1.60
7.09	9.85	+0.80	0.60	-0.60	+1.20	0.60	-0.80	+1.80	2.00	-1.20	+2.80	2.00	-1.80	+2.80	4.50	-1.80
9.85	12.41	+0.90	0.80	-0.60	+1.20	0.80	-0.90	+2.00	2.50	-1.20	+3.00	2.50	-2.00	+3.00	5.00	-2.00
12.41	15.75	+1.00	1.00	-0.70	+1.40	1.00	-1.00	+2.20	3.00	-1.40	+3.50	3.00	-2.20	+3.50	6.00	-2.20

Nominal Size Range Inches		Class RC6 Medium Running			Class RC7 Free Running			Class RC8 Loose Running			Class RC9 Loose Running		
		Hole Tol. GR9	Minimum Clearance	Shaft Tol. GR8	Hole Tol. GR9	Minimum Clearance	Shaft Tol. GR8	Hole Tol. GR10	Minimum Clearance	Shaft Tol. GR9	Hole Tol. GR11	Minimum Clearance	Shaft Tol. GR10
Over	To	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+1.00	0.60	-0.60	+1.00	1.00	-0.60	+1.60	2.50	-1.00	+2.50	4.00	-1.60
.12	.24	+1.20	0.80	-0.70	+1.20	1.20	-0.70	+1.80	2.80	-1.20	+3.00	4.50	-1.80
.24	.40	+1.40	1.00	-0.90	+1.40	1.60	-0.90	+2.20	3.00	-1.40	+3.50	6.00	-2.20
.40	.71	+1.60	1.20	-1.00	+1.60	2.00	-1.00	+2.80	3.50	-1.60	+4.00	6.00	-2.80
.71	1.19	+2.00	1.60	-1.20	+2.00	2.50	-1.20	+3.50	4.50	-2.00	+5.00	7.00	-3.50
1.19	1.97	+2.50	2.00	-1.60	+2.50	3.00	-1.60	+4.00	5.00	-2.50	+6.00	8.00	-4.00
1.97	3.15	+3.00	2.50	-1.80	+3.00	4.00	-1.80	+4.50	6.00	-3.00	+7.00	9.00	-4.50
3.15	4.73	+3.50	3.00	-2.20	+3.50	5.00	-2.20	+5.00	7.00	-3.50	+9.00	10.00	-5.00
4.73	7.09	+4.00	3.50	-2.50	+4.00	6.00	-2.50	+6.00	8.00	-4.00	+10.00	12.00	-6.00
7.09	9.85	+4.50	4.00	-2.80	+4.50	7.00	-2.80	+7.00	10.00	-4.50	+12.00	15.00	-7.00
9.85	12.41	+5.00	5.00	-3.00	+5.00	8.00	-3.00	+8.00	12.00	-5.00	+12.00	18.00	-8.00
12.41	15.75	+6.00	6.00	-3.50	+6.00	10.00	-3.50	+9.00	14.00	-6.00	+14.00	22.00	-9.00

VALUES IN MILLIMETRES

Nominal Size Range Millimetres		Class RC1 Precision Sliding			Class RC2 Sliding Fit			Class RC3 Precision Running			Class RC4 Close Running			Class RC5 Medium Running		
		Hole Tol. H5	Minimum Clearance	Shaft Tol. g4	Hole Tol. H6	Minimum Clearance	Shaft Tol. g5	Hole Tol. H7	Minimum Clearance	Shaft Tol. f6	Hole Tol. H8	Minimum Clearance	Shaft Tol. f7	Hole Tol. H8	Minimum Clearance	Shaft Tol. e7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.004	0.003	-0.003	+0.006	0.003	-0.004	+0.010	0.008	-0.006	+0.015	0.008	-0.010	+0.015	0.015	-0.010
3	6	+0.005	0.004	-0.004	+0.008	0.004	-0.005	+0.013	0.010	-0.008	+0.018	0.010	-0.013	+0.018	0.020	-0.013
6	10	+0.006	0.005	-0.004	+0.010	0.005	-0.006	+0.015	0.013	-0.010	+0.023	0.013	-0.015	+0.023	0.025	-0.015
10	18	+0.008	0.006	-0.005	+0.010	0.006	-0.008	+0.018	0.015	-0.010	+0.025	0.015	-0.018	+0.025	0.030	-0.018
18	30	+0.010	0.008	-0.006	+0.013	0.008	-0.010	+0.020	0.020	-0.013	+0.030	0.020	-0.020	+0.030	0.040	-0.020
30	50	+0.010	0.010	-0.008	+0.015	0.010	-0.010	+0.030	0.030	-0.015	+0.040	0.030	-0.030	+0.040	0.050	-0.030
50	80	+0.013	0.010	-0.008	+0.018	0.010	-0.013	+0.030	0.030	-0.020	+0.050	0.030	-0.030	+0.050	0.060	-0.030
80	120	+0.015	0.013	-0.010	+0.023	0.013	-0.015	+0.040	0.040	-0.020	+0.060	0.040	-0.040	+0.060	0.080	-0.040
120	180	+0.018	0.015	-0.013	+0.025	0.015	-0.018	+0.040	0.040	-0.030	+0.060	0.040	-0.040	+0.060	0.090	-0.040
180	250	+0.020	0.015	-0.015	+0.030	0.015	-0.020	+0.050	0.050	-0.030	+0.070	0.050	-0.050	+0.070	0.110	-0.050
250	315	+0.023	0.020	-0.015	+0.030	0.020	-0.023	+0.050	0.060	-0.030	+0.080	0.060	-0.050	+0.080	0.130	-0.050
315	400	+0.025	0.025	-0.018	+0.036	0.025	-0.025	+0.060	0.080	-0.040	+0.090	0.080	-0.060	+0.090	0.150	-0.060

Nominal Size Range Millimetres		Class RC6 Medium Running			Class RC7 Free Running			Class RC8 Loose Running			Class RC9 Loose Running		
		Hole Tol. H9	Minimum Clearance	Shaft Tol. e8	Hole Tol. H9	Minimum Clearance	Shaft Tol. d8	Hole Tol. H10	Minimum Clearance	Shaft Tol. e9	Hole Tol. GR11	Minimum Clearance	Shaft Tol. gr10
Over	To	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.025	0.015	-0.015	+0.025	0.025	-0.015	+0.041	0.064	-0.025	+0.060	0.100	-0.040
3	6	+0.030	0.015	-0.018	+0.030	0.030	-0.018	+0.046	0.071	-0.030	+0.080	0.110	-0.050
6	10	+0.036	0.025	-0.023	+0.036	0.040	-0.023	+0.056	0.076	-0.036	+0.070	0.130	-0.060
10	18	+0.040	0.030	-0.025	+0.040	0.050	-0.025	+0.070	0.090	-0.040	+0.100	0.150	-0.070
18	30	+0.050	0.040	-0.030	+0.050	0.060	-0.030	+0.090	0.110	-0.050	+0.130	0.180	-0.090
30	50	+0.060	0.050	-0.040	+0.060	0.080	-0.040	+0.100	0.130	-0.060	+0.150	0.200	-0.100
50	80	+0.080	0.060	-0.050	+0.080	0.100	-0.050	+0.110	0.150	-0.080	+0.180	0.230	-0.120
80	120	+0.090	0.080	-0.060	+0.090	0.130	-0.060	+0.130	0.180	-0.090	+0.230	0.250	-0.130
120	180	+0.100	0.090	-0.060	+0.100	0.150	-0.060	+0.150	0.200	-0.100	+0.250	0.300	-0.150
180	250	+0.110	0.100	-0.070	+0.110	0.180	-0.070	+0.180	0.250	-0.110	+0.300	0.380	-0.180
250	315	+0.130	0.130	-0.080	+0.130	0.200	-0.080	+0.200	0.300	-0.130	+0.300	0.460	-0.200
315	400	+0.150	0.150	-0.090	+0.150	0.250	-0.090	+0.230	0.360	-0.150	+0.360	0.560	-0.230

Table 9

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson. Delmar Publishers Inc.

LOCATIONAL CLEARANCE FITS

VALUES IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class LC1			Class LC2			Class LC3			Class LC4			Class LC5			Class LC6		
		Hole Tol. GR6	Minimum Clearance	Shaft Tol. GR5	Hole Tol. GR8	Minimum Clearance	Shaft Tol. GR7	Hole Tol. GR10	Minimum Clearance	Shaft Tol. GR9	Hole Tol. GR7	Minimum Clearance	Shaft Tol. GR6	Hole Tol. GR9	Minimum Clearance	Shaft Tol. GR8	Hole Tol. GR9	Minimum Clearance	Shaft Tol. GR8
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+0.25	0	-0.15	+0.4	0	-0.25	+0.6	0	-0.4	+1.6	0	-1.0	+0.4	0.10	-0.25	+1.0	0.3	-0.6
.12	.24	+0.30	0	-0.20	+0.5	0	-0.30	+0.7	0	-0.5	+1.8	0	-1.2	+0.5	0.15	-0.30	+1.2	0.4	-0.7
.24	.40	+0.40	0	-0.25	+0.6	0	-0.40	+0.9	0	-0.6	+2.2	0	-1.4	+0.6	0.20	-0.40	+1.4	0.5	-0.9
.40	.71	+0.40	0	-0.30	+0.7	0	-0.40	+1.0	0	-0.7	+2.8	0	-1.6	+0.7	0.25	-0.40	+1.6	0.6	-1.0
.71	1.19	+0.50	0	-0.40	+0.8	0	-0.50	+1.2	0	-0.8	+3.5	0	-2.0	+0.8	0.30	-0.50	+2.0	0.8	-1.2
1.19	1.97	+0.60	0	-0.40	+1.0	0	-0.60	+1.6	0	-1.0	+4.0	0	-2.5	+1.0	0.40	-0.60	+2.5	1.0	-1.6
1.97	3.15	+0.70	0	-0.50	+1.2	0	-0.70	+1.8	0	-1.2	+4.5	0	-3.0	+1.2	0.40	-0.70	+3.0	1.2	-1.8
3.15	4.73	+0.90	0	-0.60	+1.4	0	-0.90	+2.7	0	-1.4	+5.0	0	-3.5	+1.4	0.50	-0.90	+3.5	1.4	-2.2
4.73	7.09	+1.00	0	-0.70	+1.6	0	-1.00	+2.5	0	-1.6	+6.0	0	-4.0	+1.6	0.60	-1.00	+4.0	1.6	-2.5
7.09	9.85	+1.20	0	-0.80	+1.8	0	-1.20	+2.8	0	-1.8	+7.0	0	-4.5	+1.8	0.60	-1.20	+4.5	2.0	-2.8
9.85	12.41	+1.20	0	-0.90	+2.0	0	-1.20	+3.0	0	-2.0	+8.0	0	-5.0	+2.0	0.70	-1.20	+5.0	2.2	-3.0
12.41	15.75	+1.40	0	-1.00	+2.2	0	-1.40	+3.5	0	-2.2	+9.0	0	-6.0	+2.2	0.70	-1.40	+6.0	2.5	-3.5

Nominal Size Range Inches		Class LC7			Class LC8			Class LC9			Class LC10			Class LC11		
		Hole Tol. GR10	Minimum Clearance	Shaft Tol. GR9	Hole Tol. GR10	Minimum Clearance	Shaft Tol. GR9	Hole Tol. GR11	Minimum Clearance	Shaft Tol. GR10	Hole Tol. GR12	Minimum Clearance	Shaft Tol. GR11	Hole Tol. GR13	Minimum Clearance	Shaft Tol. GR12
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+1.6	0.6	-1.0	+1.6	1.0	-1.0	+2.5	2.5	-1.6	+1.0	4.0	-2.5	+6.0	5.0	-4.0
.12	.24	+1.8	0.8	-1.2	+1.8	1.2	-1.2	+3.0	2.8	-1.8	+5.0	4.5	-3.0	+7.0	6.0	-5.0
.24	.40	+2.2	1.0	-1.4	+2.2	1.6	-1.4	+3.5	3.0	-2.2	+6.0	5.0	-3.5	+9.0	7.0	-6.0
.40	.71	+2.8	1.2	-1.6	+2.8	2.0	-1.6	+4.0	3.5	-2.8	+7.0	6.0	-4.0	+10.0	8.0	-7.0
.71	1.19	+3.5	1.6	-2.0	+3.5	2.5	-2.0	+5.0	4.5	-3.5	+8.0	7.0	-5.0	+12.0	10.0	-8.0
1.19	1.97	+4.0	2.0	-2.5	+4.0	3.6	-2.5	+6.0	5.0	-4.0	+10.0	8.0	-6.0	+16.0	12.0	-10.0
1.97	3.15	+4.5	2.5	-3.0	+4.5	4.0	-3.0	+7.0	6.0	-4.5	+12.0	10.0	-7.0	+18.0	14.0	-12.0
3.15	4.73	+5.0	3.0	-3.5	+5.0	5.0	-3.5	+9.0	7.0	-5.0	+14.0	11.0	-9.0	+22.0	16.0	-14.0
4.73	7.09	+6.0	3.5	-4.0	+6.0	6.0	-4.0	+10.0	8.0	-6.0	+16.0	12.0	-10.0	+25.0	18.0	-16.0
7.09	9.85	+7.0	4.0	-4.5	+7.0	7.0	-4.5	+12.0	10.0	-7.0	+18.0	16.0	-12.0	+28.0	22.0	-18.0
9.85	12.41	+8.0	4.5	-5.0	+8.0	7.0	-5.0	+12.0	12.0	-8.0	+20.0	20.0	-12.0	+30.0	28.0	-20.0
12.41	15.75	+9.0	5.0	-6.0	+9.0	8.0	-6.0	+14.0	14.0	-9.0	+22.0	22.0	-14.0	+35.0	30.0	-22.0

VALUES IN MILLIMETRES

Nominal Size Range Millimetres		Class LC1			Class LC2			Class LC3			Class LC4			Class LC5			Class LC6		
		Hole Tol. H6	Minimum Clearance	Shaft Tol. h5	Hole Tol. H7	Minimum Clearance	Shaft Tol. h6	Hole Tol. H8	Minimum Clearance	Shaft Tol. h7	Hole Tol. H10	Minimum Clearance	Shaft Tol. h9	Hole Tol. H7	Minimum Clearance	Shaft Tol. g6	Hole Tol. H9	Minimum Clearance	Shaft Tol. f8
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.006	0	-0.004	+0.010	0	-0.006	+0.015	0	-0.010	+0.041	0	-0.025	+0.010	0.002	-0.006	+0.025	0.008	-0.015
3	6	+0.008	0	-0.005	+0.013	0	-0.008	+0.018	0	-0.013	+0.046	0	-0.030	+0.013	0.004	-0.008	+0.030	0.010	-0.018
6	10	+0.010	0	-0.006	+0.015	0	-0.010	+0.023	0	-0.015	+0.056	0	-0.036	+0.015	0.005	-0.010	+0.036	0.013	-0.023
10	18	+0.010	0	-0.008	+0.018	0	-0.010	+0.025	0	-0.018	+0.070	0	-0.040	+0.018	0.006	-0.010	+0.041	0.015	-0.025
18	30	+0.013	0	-0.010	+0.020	0	-0.013	+0.030	0	-0.020	+0.090	0	-0.050	+0.020	0.008	-0.013	+0.050	0.020	-0.030
30	50	+0.015	0	-0.010	+0.025	0	-0.015	+0.041	0	-0.025	+0.100	0	-0.060	+0.025	0.010	-0.015	+0.060	0.030	-0.040
50	80	+0.018	0	-0.013	+0.030	0	-0.018	+0.046	0	-0.030	+0.110	0	-0.080	+0.030	0.010	-0.018	+0.080	0.030	-0.050
80	120	+0.023	0	-0.015	+0.036	0	-0.023	+0.056	0	-0.036	+0.130	0	-0.080	+0.036	0.013	-0.023	+0.090	0.040	-0.060
120	180	+0.025	0	-0.018	+0.041	0	-0.025	+0.064	0	-0.041	+0.150	0	-0.100	+0.041	0.015	-0.025	+0.100	0.040	-0.060
180	250	+0.030	0	-0.020	+0.046	0	-0.030	+0.071	0	-0.046	+0.180	0	-0.110	+0.046	0.015	-0.030	+0.110	0.050	-0.070
250	315	+0.020	0	-0.023	+0.051	0	-0.030	+0.076	0	-0.051	+0.200	0	-0.130	+0.051	0.018	-0.030	+0.130	0.060	-0.080
315	400	+0.036	0	-0.025	+0.056	0	-0.036	+0.089	0	-0.056	+0.230	0	-0.150	+0.056	0.018	-0.036	+0.150	0.060	-0.090

Nominal Size Range Millimetres		Class LC7			Class LC8			Class LC9			Class LC10			Class LC11		
		Hole Tol. H10	Minimum Clearance	Shaft Tol. e9	Hole Tol. H10	Minimum Clearance	Shaft Tol. d9	Hole Tol. H11	Minimum Clearance	Shaft Tol. c10	Hole Tol. GR12	Minimum Clearance	Shaft Tol. gr11	Hole Tol. GR13	Minimum Clearance	Shaft Tol. gr12
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.041	0.015	-0.025	+0.041	0.025	-0.025	+0.064	0.06	-0.041	+0.10	0.10	-0.06	+0.15	0.13	-0.10
3	6	+0.046	0.020	-0.030	+0.046	0.030	-0.030	+0.076	0.07	-0.046	+0.13	0.11	-0.08	+0.18	0.15	-0.13
6	10	+0.056	0.025	-0.036	+0.056	0.041	-0.036	+0.089	0.08	-0.056	+0.15	0.13	-0.09	+0.23	0.18	-0.15
10	18	+0.070	0.030	-0.040	+0.070	0.050	-0.040	+0.100	0.09	-0.070	+0.18	0.15	-0.10	+0.25	0.20	-0.18
18	30	+0.090	0.040	-0.050	+0.090	0.060	-0.050	+0.130	0.11	-0.090	+0.20	0.18	-0.13	+0.31	0.25	-0.20
30	50	+0.100	0.050	-0.060	+0.100	0.090	-0.060	+0.150	0.13	-0.100	+0.25	0.20	-0.15	+0.41	0.31	-0.25
50	80	+0.110	0.060	-0.080	+0.110	0.100	-0.080	+0.180	0.15	-0.110	+0.31	0.25	-0.18	+0.46	0.36	-0.31
80	120	+0.130	0.080	-0.090	+0.130	0.130	-0.090	+0.230	0.18	-0.130	+0.36	0.28	-0.23	+0.56	0.41	-0.36
120	180	+0.150	0.090	-0.100	+0.150	0.150	-0.100	+0.250	0.20	-0.150	+0.41	0.31	-0.25	+0.64	0.46	-0.41
180	250	+0.180	0.100	-0.110	+0.180	0.180	-0.110	+0.310	0.25	-0.180	+0.46	0.41	-0.31	+0.71	0.56	-0.46
250	315	+0.200	0.110	-0.130	+0.200	0.180	-0.130	+0.310	0.31	-0.200	+0.51	0.51	-0.31	+0.76	0.71	-0.51
315	400	+0.230	0.130	-0.150	+0.230	0.200	-0.150	+0.360	0.36	-0.230	+0.56	0.56	-0.36	+0.89	0.76	-0.56

Table 10

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson Delmar Publishers Inc.

LOCATIONAL TRANSITION FITS

VALUES IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class LT1			Class LT2			Class LT3			Class LT4			Class LT5			Class LT6		
		Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR8	Maximum Interference	Shaft Tol. GR7	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR8	Maximum Interference	Shaft Tol. GR7	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR8	Maximum Interference	Shaft Tol. GR7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+0.4	0.10	-0.25	+0.6	0.20	-0.4	+0.4	0.25	-0.25	+0.6	0.4	-0.4	+0.4	0.5	-0.25	+0.6	0.65	-0.4
.12	.24	+0.5	0.15	-0.30	+0.7	0.25	-0.5	+0.5	0.40	-0.30	+0.7	0.6	-0.5	+0.5	0.6	-0.30	+0.7	0.80	-0.5
.24	.40	+0.6	0.20	-0.40	+0.9	0.30	-0.6	+0.6	0.50	-0.40	+0.9	0.7	-0.6	+0.6	0.8	-0.40	+0.9	1.00	-0.6
.40	.71	+0.7	0.20	-0.40	+1.0	0.30	-0.7	+0.7	0.50	-0.40	+1.0	0.8	-0.7	+0.7	0.9	-0.40	+1.0	1.20	-0.7
.71	1.19	+0.8	0.25	-0.50	+1.2	0.40	-0.8	+0.8	0.60	-0.50	+1.2	0.9	-0.8	+0.8	1.1	-0.50	+1.2	1.40	-0.8
1.19	1.97	+1.0	0.30	-0.60	+1.6	0.50	-1.0	+1.0	0.70	-0.60	+1.6	1.1	-1.0	+1.0	1.3	-0.60	+1.6	1.70	-1.0
1.97	3.15	+1.2	0.30	-0.70	+1.8	0.60	-1.2	+1.2	0.80	-0.70	+1.8	1.3	-1.2	+1.2	1.5	-0.70	+1.8	2.00	-1.2
3.15	4.73	+1.4	0.40	-0.90	+2.2	0.70	-1.4	+1.4	1.00	-0.90	+2.2	1.5	-1.4	+1.4	1.9	-0.90	+2.2	2.40	-1.4
4.73	7.09	+1.6	0.50	-1.00	+2.5	0.80	-1.6	+1.6	1.10	-1.00	+2.5	1.7	-1.6	+1.6	2.2	-1.00	+2.5	2.80	-1.6
7.09	9.85	+1.8	0.60	-1.20	+2.8	0.90	-1.8	+1.8	1.40	-1.20	+2.8	2.0	-1.8	+1.8	2.6	-1.20	+2.8	3.20	-1.8
9.85	12.41	+2.0	0.60	-1.20	+3.0	1.00	-2.0	+2.0	1.40	-1.20	+3.0	2.2	-2.0	+2.0	2.6	-1.20	+3.0	3.40	-2.0
12.41	15.75	+2.2	0.70	-1.40	+3.5	1.00	-2.2	+2.2	1.60	-1.40	+3.5	2.4	-2.2	+2.2	3.0	-1.40	+3.5	3.80	-2.2

VALUES IN MILLIMETRES

Nominal Size Range Millimetres		Class LT1			Class LT2			Class LT3			Class LT4			Class LT5			Class LT6		
		Hole Tol. H7	Maximum Interference	Shaft Tol. js6	Hole Tol. H8	Maximum Interference	Shaft Tol. js7	Hole Tol. H7	Maximum Interference	Shaft Tol. k6	Hole Tol. H8	Maximum Interference	Shaft Tol. k7	Hole Tol. H7	Maximum Interference	Shaft Tol. n6	Hole Tol. H8	Maximum Interference	Shaft Tol. n7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.010	0.002	-0.006	+0.015	0.005	-0.010	+0.010	0.006	-0.006	+0.015	0.010	-0.010	+0.010	0.013	-0.006	+0.015	0.016	-0.010
3	6	+0.013	0.004	-0.008	+0.018	0.006	-0.013	+0.013	0.010	-0.008	+0.018	0.015	-0.013	+0.013	0.015	-0.008	+0.018	0.020	-0.013
6	10	+0.015	0.005	-0.010	+0.023	0.008	-0.015	+0.015	0.013	-0.010	+0.023	0.018	-0.015	+0.015	0.020	-0.010	+0.023	0.025	-0.015
10	18	+0.018	0.005	-0.010	+0.025	0.008	-0.018	+0.018	0.013	-0.010	+0.025	0.020	-0.018	+0.018	0.023	-0.010	+0.025	0.030	-0.018
18	30	+0.020	0.006	-0.013	+0.030	0.010	-0.020	+0.020	0.015	-0.013	+0.030	0.023	-0.020	+0.020	0.028	-0.013	+0.030	0.036	-0.020
30	50	+0.025	0.008	-0.015	+0.041	0.013	-0.025	+0.025	0.018	-0.015	+0.041	0.028	-0.025	+0.025	0.033	-0.015	+0.041	0.044	-0.025
50	80	+0.030	0.008	-0.018	+0.046	0.015	-0.030	+0.030	0.020	-0.018	+0.046	0.033	-0.030	+0.030	0.038	-0.018	+0.046	0.051	-0.030
80	120	+0.036	0.010	-0.023	+0.056	0.018	-0.036	+0.036	0.025	-0.023	+0.056	0.038	-0.036	+0.036	0.048	-0.023	+0.056	0.062	-0.036
120	180	+0.041	0.013	-0.025	+0.064	0.020	-0.041	+0.041	0.028	-0.025	+0.064	0.044	-0.041	+0.041	0.056	-0.025	+0.064	0.071	-0.041
180	250	+0.046	0.015	-0.030	+0.071	0.023	-0.046	+0.046	0.036	-0.030	+0.071	0.051	-0.046	+0.046	0.066	-0.030	+0.071	0.081	-0.046
250	315	+0.051	0.015	-0.030	+0.076	0.025	-0.051	+0.051	0.036	-0.030	+0.076	0.056	-0.051	+0.051	0.066	-0.030	+0.076	0.086	-0.051
315	400	+0.056	0.018	-0.036	+0.089	0.025	-0.056	+0.056	0.041	-0.036	+0.089	0.062	-0.056	+0.056	0.076	-0.036	+0.089	0.096	-0.056

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson. Delmar Publishers Inc.

Table 11

LOCATIONAL INTERFERENCE FITS

VALUES IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class LN1 Light Press Fit			Class LN2 Medium Press Fit			Class LN3 Heavy Press Fit			Class LN4			Class LN5			Class LN6		
		Hole Tol. GR6	Maximum Interference	Shaft Tol. GR5	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR8	Maximum Interference	Shaft Tol. GR7	Hole Tol. GR9	Maximum Interference	Shaft Tol. GR8	Hole Tol. GR10	Maximum Interference	Shaft Tol. GR9
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+0.25	0.40	-0.15	+0.4	0.65	-0.25	+0.4	0.75	-0.25	+0.6	1.2	-0.4	+1.0	1.8	-0.6	+1.6	3.0	-1.0
.12	.24	+0.30	0.50	-0.20	+0.5	0.80	-0.30	+0.5	0.90	-0.30	+0.7	1.5	-0.5	+1.2	2.3	-0.7	+1.8	3.6	-1.2
.24	.40	+0.40	0.65	-0.25	+0.6	1.00	-0.40	+0.6	1.20	-0.40	+0.9	1.8	-0.6	+1.4	2.8	-0.9	+2.2	4.4	-1.4
.40	.71	+0.40	0.70	-0.30	+0.7	1.10	-0.40	+0.7	1.40	-0.40	+1.0	2.2	-0.7	+1.6	3.4	-1.0	+2.8	5.6	-1.6
.71	1.19	+0.50	0.90	-0.40	+0.8	1.30	-0.50	+0.8	1.70	-0.50	+1.2	2.6	-0.8	+2.0	4.2	-1.2	+3.5	7.0	-2.0
1.19	1.97	+0.60	1.00	-0.40	+1.0	1.60	-0.60	+1.0	2.00	-0.60	+1.6	3.4	-1.0	+2.5	5.3	-1.6	+4.0	8.5	-2.5
1.97	3.15	+0.70	1.30	-0.50	+1.2	2.10	-0.70	+1.2	2.30	-0.70	+1.8	4.0	-1.2	+3.0	6.3	-1.8	+4.5	10.0	-3.0
3.15	4.73	+0.90	1.60	-0.60	+1.4	2.50	-0.90	+1.4	2.90	-0.90	+2.2	4.8	-1.4	+4.0	7.7	-2.2	+5.0	11.5	-3.5
4.73	7.09	+1.00	1.90	-0.70	+1.6	2.80	-1.00	+1.6	3.50	-1.00	+2.5	5.6	-1.6	+4.5	8.7	-2.5	+6.0	13.5	-4.0
7.09	9.85	+1.20	2.20	-0.80	+1.8	3.20	-1.20	+1.8	4.20	-1.20	+2.8	6.6	-1.8	+5.0	10.3	-2.8	+7.0	16.5	-4.5
9.85	12.41	+1.20	2.30	-0.90	+2.0	3.40	-1.20	+2.0	4.70	-1.20	+3.0	7.5	-2.0	+6.0	12.0	-3.0	+8.0	19.0	-5.0
12.41	15.75	+1.40	2.60	-1.00	+2.2	3.90	-1.40	+2.2	5.90	-1.40	+3.5	8.7	-2.2	+6.0	14.5	-3.5	+9.0	23.0	-6.0

VALUES IN MILLIMETRES

Nominal Size Range Millimetres		Class LN1 Light Press Fit			Class LN2 Medium Press Fit			Class LN3 Heavy Press Fit			Class LN4			Class LN5			Class LN6		
		Hole Tol. GR6	Maximum Interference	Shaft Tol. gr5	Hole Tol. H7	Maximum Interference	Shaft Tol. p6	Hole Tol. H7	Maximum Interference	Shaft Tol. t6	Hole Tol. GR8	Maximum Interference	Shaft Tol. gr7	Hole Tol. GR9	Maximum Interference	Shaft Tol. gr8	Hole Tol. GR10	Maximum Interference	Shaft Tol. gr9
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.006		-0.004	+0.010	0.016	-0.006	+0.010	0.019	-0.006	+0.015	0.030	-0.010	+0.025	0.046	-0.015	+0.041	0.076	-0.025
3	6	+0.008		-0.005	+0.013	0.020	-0.008	+0.013	0.023	-0.008	+0.018	0.038	-0.013	+0.030	0.059	-0.018	+0.046	0.091	-0.030
6	10	+0.010		-0.006	+0.015	0.025	-0.010	+0.015	0.030	-0.010	+0.023	0.046	-0.015	+0.036	0.071	-0.023	+0.056	0.112	-0.036
10	18	+0.010		-0.008	+0.018	0.028	-0.010	+0.018	0.036	-0.010	+0.025	0.056	-0.018	+0.041	0.086	-0.025	+0.071	0.142	-0.041
18	30	+0.013		-0.010	+0.020	0.033	-0.013	+0.020	0.044	-0.013	+0.030	0.066	-0.020	+0.051	0.107	-0.030	+0.089	0.178	-0.051
30	50	+0.015		-0.010	+0.025	0.041	-0.015	+0.025	0.051	-0.015	+0.041	0.086	-0.025	+0.064	0.135	-0.041	+0.102	0.216	-0.064
50	80	+0.018		-0.013	+0.030	0.054	-0.018	+0.030	0.059	-0.018	+0.046	0.102	-0.030	+0.076	0.160	-0.046	+0.114	0.254	-0.076
80	120	+0.023		-0.015	+0.036	0.064	-0.023	+0.036	0.074	-0.023	+0.056	0.122	-0.036	+0.102	0.196	-0.056	+0.127	0.292	-0.102
120	180	+0.025		-0.018	+0.041	0.071	-0.025	+0.041	0.089	-0.025	+0.064	0.142	-0.041	+0.114	0.221	-0.064	+0.152	0.343	-0.114
180	250	+0.030		-0.020	+0.046	0.081	-0.030	+0.046	0.107	-0.030	+0.071	0.168	-0.046	+0.127	0.262	-0.071	+0.178	0.419	-0.127
250	315	+0.030		-0.023	+0.051	0.086	-0.030	+0.051	0.119	-0.030	+0.076	0.191	-0.051	+0.152	0.305	-0.076	+0.203	0.483	-0.152
315	400	+0.036		-0.025	+0.056	0.099	-0.036	+0.056	0.150	-0.036	+0.089	0.221	-0.056	+0.152	0.368	-0.089	+0.229	0.584	-0.152

From Drafting for Trades and Industry—Mechanical and Electronic Nelson Delmar Publishers Inc

Table 12

VALUES IN THOUSANDTHS OF AN INCH

Nominal Size Range Inches		Class FN1 Light Drive Fit			Class FN2 Medium Drive Fit			Class FN3 Heavy Drive Fit			Class FN4 Shrink Fit			Class FN5 Heavy Shrink Fit		
		Hole Tol. GR6	Maximum Interference	Shaft Tol. GR5	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR7	Maximum Interference	Shaft Tol. GR6	Hole Tol. GR8	Maximum Interference	Shaft Tol. GR7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	.12	+0.25	0.50	-0.15	+0.40	0.85	-0.25				+0.40	0.95	-0.25	+0.60	1.30	-0.40
.12	.24	+0.30	0.60	-0.20	+0.50	1.00	-0.30				+0.50	1.20	-0.30	+0.70	1.70	-0.50
.24	.40	+0.40	0.75	-0.25	+0.60	1.40	-0.40				+0.60	1.60	-0.40	+0.90	2.00	-0.60
.40	.56	+0.40	0.80	-0.30	+0.70	1.60	-0.40				+0.70	1.80	-0.40	+1.00	2.30	-0.70
.56	.71	+0.40	0.90	-0.30	+0.70	1.60	-0.40				+0.70	1.80	-0.40	+1.00	2.50	-0.70
.71	.95	+0.50	1.10	-0.40	+0.80	1.90	-0.50				+0.80	2.10	-0.50	+1.20	3.00	-0.80
.95	1.19	+0.50	1.20	-0.40	+0.80	1.90	-0.50	+0.80	2.10	-0.50	+0.80	2.30	-0.50	+1.20	3.30	-0.80
1.19	1.58	+0.60	1.30	-0.40	+1.00	2.40	-0.60	+1.00	2.60	-0.60	+1.00	3.10	-0.60	+1.60	4.00	-1.00
1.58	1.97	+0.60	1.40	-0.40	+1.00	2.40	-0.60	+1.00	2.80	-0.60	+1.00	3.40	-0.60	+1.60	5.00	-1.00
1.97	2.56	+0.70	1.80	-0.50	+1.20	2.70	-0.70	+1.20	3.20	-0.70	+1.20	4.20	-0.70	+1.80	6.20	-1.20
2.56	3.15	+0.70	1.90	-0.50	+1.20	2.90	-0.70	+1.20	3.70	-0.70	+1.20	4.70	-0.70	+1.80	7.20	-1.20
3.15	3.94	+0.90	2.40	-0.60	+1.40	3.70	-0.90	+1.40	4.40	-0.70	+1.40	5.90	-0.90	+2.20	8.40	-1.40

VALUES IN MILLIMETRES

Nominal Size Range Millimetres		Class FN1 Light Drive Fit			Class FN2 Medium Drive Fit			Class FN3 Heavy Drive Fit			Class FN4 Shrink Fit			Class FN5 Heavy Shrink Fit		
		Hole Tol. GR6	Maximum Interference	Shaft Tol. gr5	Hole Tol. H7	Maximum Interference	Shaft Tol. s6	Hole Tol. H7	Maximum Interference	Shaft Tol. t6	Hole Tol. GR8	Maximum Interference	Shaft Tol. gr7	Hole Tol. H8	Maximum Interference	Shaft Tol. t7
Over	To	-0		+0	-0		+0	-0		+0	-0		+0	-0		+0
0	3	+0.006	0.013	-0.004	+0.010	0.216	-0.006				+0.010	0.024	-0.006	+0.015	0.033	-0.010
3	6	+0.007	0.015	-0.005	+0.013	0.025	-0.007				+0.013	0.030	-0.007	+0.018	0.043	-0.013
6	10	+0.010	0.019	-0.006	+0.015	0.036	-0.010				+0.015	0.041	-0.010	+0.023	0.051	-0.015
10	14	+0.010	0.020	-0.008	+0.018	0.041	-0.010				+0.018	0.046	-0.010	+0.025	0.058	-0.018
14	18	+0.010	0.023	-0.008	+0.018	0.041	-0.010				+0.018	0.046	-0.010	+0.025	0.064	-0.018
18	24	+0.013	0.028	-0.010	+0.020	0.048	-0.013				+0.020	0.053	-0.013	+0.030	0.076	-0.020
24	30	+0.013	0.030	-0.010	+0.020	0.048	-0.013	+0.020	0.053	-0.013	+0.020	0.058	-0.013	+0.030	0.084	-0.020
30	40	+0.015	0.033	-0.010	+0.025	0.061	-0.015	+0.025	0.066	-0.015	+0.025	0.079	-0.015	+0.041	0.102	-0.025
40	50	+0.015	0.036	-0.010	+0.025	0.061	-0.015	+0.025	0.071	-0.015	+0.025	0.086	-0.015	+0.041	0.127	-0.025
50	65	+0.018	0.046	-0.013	+0.030	0.069	-0.018	+0.030	0.082	-0.018	+0.030	0.107	-0.018	+0.046	0.157	-0.030
65	80	+0.018	0.048	-0.013	+0.030	0.074	-0.018	+0.030	0.094	-0.018	+0.030	0.119	-0.018	+0.046	0.183	-0.030
80	100	+0.023	0.061	-0.015	+0.035	0.094	-0.023	+0.035	0.112	-0.023	+0.036	0.150	-0.023	+0.056	0.213	-0.036

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson. Delmar Publishers Inc.

Table 13

UNIFIED STANDARD SCREW THREAD SERIES

Sizes		Basic Major Diameter	THREADS PER INCH											Sizes
			Series with graded pitches			Series with constant pitches								
Primary	Secondary		Coarse UNC	Fine UNF	Extra fine UNEF	4UN	6UN	8UN	12UN	16UN	20UN	28UN	32UN	
0		0.0600	–	80	–	–	–	–	–	–	–	–	–	0
	1	0.0730	64	72	–	–	–	–	–	–	–	–	–	1
2		0.0860	56	64	–	–	–	–	–	–	–	–	–	2
	3	0.0990	48	56	–	–	–	–	–	–	–	–	–	3
4		0.1120	40	48	–	–	–	–	–	–	–	–	–	4
5		0.1250	40	44	–	–	–	–	–	–	–	–	–	5
6		0.1380	32	40	–	–	–	–	–	–	–	–	UNC	6
8		0.1640	32	36	–	–	–	–	–	–	–	–	UNC	8
10		0.1900	24	32	–	–	–	–	–	–	–	–	UNF	10
	12	0.2160	24	28	32	–	–	–	–	–	–	UNF	UNEF	12
1/4		0.2500	20	28	32	–	–	–	–	–	UNC	UNF	UNEF	1/4
5/16		0.3125	18	24	32	–	–	–	–	–	20	28	UNEF	5/16
3/8		0.3750	16	24	32	–	–	–	–	UNC	20	28	UNEF	3/8
7/16		0.4375	14	20	28	–	–	–	–	16	UNF	UNEF	32	7/16
1/2		0.5000	13	20	28	–	–	–	–	16	UNF	UNEF	32	1/2
9/16		0.5625	12	18	24	–	–	–	UNC	16	20	28	32	9/16
5/8		0.6250	11	18	24	–	–	–	12	16	20	28	32	5/8
	11/16	0.6875	–	–	24	–	–	–	12	16	20	28	32	11/16
3/4		0.7500	10	16	20	–	–	–	12	UNF	UNEF	28	32	3/4
	13/16	0.8125	–	–	20	–	–	–	12	16	UNEF	28	32	13/16
7/8		0.8750	9	14	20	–	–	–	12	16	UNEF	28	32	7/8
	15/16	0.9375	–	–	20	–	–	–	12	16	UNEF	28	32	15/16
1		1.0000	8	12	20	–	–	UNC	UNF	16	UNEF	28	32	1
	1 1/16	1.0625	–	–	18	–	–	8	12	16	20	28	–	1 1/16
1 1/8		1.1250	7	12	18	–	–	8	UNF	16	20	28	–	1 1/8
	1 3/16	1.1875	–	–	18	–	–	8	12	16	20	28	–	1 3/16
1 1/4		1.2500	7	12	18	–	–	8	UNF	16	20	28	–	1 1/4
	1 5/16	1.3125	–	–	18	–	–	8	12	16	20	28	–	1 5/16
1 3/8		1.3750	6	12	18	–	UNC	8	UNF	16	20	28	–	1 3/8
	1 7/16	1.4375	–	–	18	–	6	8	12	16	20	28	–	1 7/16
1 1/2		1.5000	6	12	18	–	UNC	8	UNF	16	20	28	–	1 1/2
	1 9/16	1.5625	–	–	18	–	6	8	12	16	20	–	–	1 9/16
1 5/8		1.6250	–	–	18	–	6	8	12	16	20	–	–	1 5/8
	1 11/16	1.6875	–	–	18	–	6	8	12	16	20	–	–	1 11/16
1 3/4		1.7500	5	–	–	–	6	8	12	16	20	–	–	1 3/4
	1 13/16	1.8125	–	–	–	–	6	8	12	16	20	–	–	1 13/16
1 7/8		1.8750	–	–	–	–	6	8	12	16	20	–	–	1 7/8
	1 15/16	1.9375	–	–	–	–	6	8	12	16	20	–	–	1 15/16
2		2.0000	4 1/2	–	–	–	6	8	12	16	20	–	–	2
	2 1/8	2.1250	–	–	–	–	6	8	12	16	20	–	–	2 1/8
2 1/4		2.2500	4 1/2	–	–	–	6	8	12	16	20	–	–	2 1/4
	2 3/8	2.3750	–	–	–	–	6	8	12	16	20	–	–	2 3/8
2 1/2		2.5000	4	–	–	UNC	6	8	12	16	20	–	–	2 1/2
	2 5/8	2.6250	–	–	–	4	6	8	12	16	20	–	–	2 5/8
2 3/4		2.7500	4	–	–	UNC	6	8	12	16	20	–	–	2 3/4
	2 7/8	2.8750	–	–	–	4	6	8	12	16	20	–	–	2 7/8
3		3.0000	4	–	–	UNC	6	8	12	16	20	–	–	3
	3 1/8	3.1250	–	–	–	4	6	8	12	16	–	–	–	3 1/8
3 1/4		3.2500	4	–	–	UNC	6	8	12	16	–	–	–	3 1/4
	3 3/8	3.3750	–	–	–	4	6	8	12	16	–	–	–	3 3/8
3 1/2		3.5000	4	–	–	UNC	6	8	12	16	–	–	–	3 1/2
	3 5/8	3.6250	–	–	–	4	6	8	12	16	–	–	–	3 5/8
3 3/4		3.7500	4	–	–	UNC	6	8	12	16	–	–	–	3 3/4
	3 7/8	3.8750	–	–	–	4	6	8	12	16	–	–	–	3 7/8
4		4.0000	4	–	–	UNC	6	8	12	16	–	–	–	4
	4 1/8	4.1250	–	–	–	4	6	8	12	16	–	–	–	4 1/8
4 1/4		4.2500	–	–	–	4	6	8	12	16	–	–	–	4 1/4
	4 3/8	4.3750	–	–	–	4	6	8	12	16	–	–	–	4 3/8
4 1/2		4.5000	–	–	–	4	6	8	12	16	–	–	–	4 1/2
	4 5/8	4.6250	–	–	–	4	6	8	12	16	–	–	–	4 5/8
4 3/4		4.7500	–	–	–	4	6	8	12	16	–	–	–	4 3/4
	4 7/8	4.8750	–	–	–	4	6	8	12	16	–	–	–	4 7/8
5		5.0000	–	–	–	4	6	8	12	16	–	–	–	5
	5 1/8	5.1250	–	–	–	4	6	8	12	16	–	–	–	5 1/8
5 1/4		5.2500	–	–	–	4	6	8	12	16	–	–	–	5 1/4
	5 3/8	5.3750	–	–	–	4	6	8	12	16	–	–	–	5 3/8
5 1/2		5.5000	–	–	–	4	6	8	12	16	–	–	–	5 1/2
	5 5/8	5.6250	–	–	–	4	6	8	12	16	–	–	–	5 5/8
5 3/4		5.7500	–	–	–	4	6	8	12	16	–	–	–	5 3/4
	5 7/8	5.8750	–	–	–	4	6	8	12	16	–	–	–	5 7/8
6		6.0000	–	–	–	4	6	8	12	16	–	–	–	6

Table 14

DRILL AND TAP SIZES

DECIMAL EQUIVALENTS AND TAP DRILL SIZES
OF WIRE GAGE LETTER AND FRACTIONAL SIZE DRILLS
(TAP DRILL SIZES BASED ON 75% MAXIMUM THREAD)

FRACTIONAL SIZE DRILLS INCHES	WIRE GAGE DRILLS	DECIMAL EQUIVALENT INCHES	TAP SIZES	
			SIZE OF THREAD	THREADS PER INCH
	80	.0135		
	79	.0145		
1/64	....	.0156		
	78	.0160		
	77	.0180		
	76	.0200		
	75	.0210		
	74	.0225		
	73	.0240		
	72	.0250		
	71	.0260		
	70	.0280		
	69	.0292		
	68	.0310		
1/32	....	.0312		
	67	.0320		
	66	.0330		
	65	.0350		
	64	.0360		
	63	.0370		
	62	.0380		
	61	.0390		
	60	.0400		
	59	.0410		
	58	.0420		
	57	.0430		
	56	.0465		
3/64	....	.0469	0	80
	55	.0520		
	54	.0550		
	53	.0595	1	64
1/16	....	.0625		72
	52	.0635		
	51	.0670		
	50	.0700	2	56
	49	.0730		64
	48	.0760		
5/64	....	.0781		
	47	.0785	3	48
	46	.0810		
	45	.0820	3	56
	44	.0860		
	43	.0890	4	40
	42	.0935	4	48
3/32	....	.0937		
	41	.0960		
	40	.0980		
	39	.0995		
	38	.1015	5	40
	37	.1040	5	44
	36	.1065	6	32
7/64	....	.1094		
	35	.1100		
	34	.1110		
	33	.1130	6	40
	32	.1160		
	31	.1200		
1/8	....	.1250		
	30	.1285		
	29	.1360	8	32
	28	.1405		36

FRACTIONAL SIZE DRILLS INCHES	WIRE GAGE DRILLS	DECIMAL EQUIVALENT INCHES	TAP SIZES	
			SIZE OF THREAD	THREADS PER INCH
9/64	....	.1406		
	27	.1440		
	26	.1470		
	25	.1495	10	24
	24	.1520		
	23	.1540		
5/32	....	.1562		
	22	.1570		
	21	.1590	10	32
	20	.1610		
	19	.1660		
	18	.1695		
11/64	....	.1719		
	17	.1730		
	16	.1770	12	24
	15	.1800		
	14	.1820	12	28
	13	.1850		
3/16	....	.1875		
	12	.1890		
	11	.1910		
	10	.1935		
	9	.1960		
	8	.1990		
	7	.2010	1/4	20
13/64	....	.2031		
	6	.2040		
	5	.2055		
	4	.2090		
	3	.2130	1/4	28
7/32	....	.2187		
	2	.2210		
	1	.2280		
	A	.2340		
15/64	....	.2344		
	B	.2380		
	C	.2420		
	D	.2460		
1/4	E	.2500		
	F	.2570	5/16	18
	G	.2610		
17/64	....	.2656		
	H	.2660		
	I	.2720	5/16	24
	J	.2770		
	K	.2810		
9/32	....	.2812		
	L	.2900		
	M	.2950		
19/64	....	.2969		
	N	.3020		
5/16	....	.3125	3/8	16
	O	.3160		
	P	.3230		
21/64	....	.3281		
	Q	.3320	3/8	24
	R	.3390		
11/32	....	.3437		
	S	.3480		
	T	.3580		

FRACTIONAL SIZE DRILLS INCHES	WIRE GAGE DRILLS	DECIMAL EQUIVALENT INCHES	TAP SIZES	
			SIZE OF THREAD	THREADS PER INCH
23/64	....	.3594		
	U	.3680	7/16	14
3/8	....	.3750		
	V	.3770		
	W	.3860		
25/64	....	.3906	7/16	20
	X	.3970		
	Y	.4040		
13/32	....	.4062		
	Z	.4130		
27/64	....	.4219	1/2	13
7/16	....	.4375		
29/64	....	.4531	1/2	20
15/32	....	.4687		
31/64	....	.4844	9/16	12
1/2	....	.5000		
33/64	....	.5156	9/16	18
17/32	....	.5312	5/8	11
35/64	....	.5469		
9/16	....	.5625		
37/64	....	.5781	5/8	18
19/32	....	.5937		
39/64	....	.6094		
5/8	....	.6250		
41/64	....	.6406		
21/32	....	.6562	3/4	10
43/64	....	.6719		
11/16	....	.6875	3/4	16
45/64	....	.7031		
23/32	....	.7187		
47/64	....	.7344		
3/4	....	.7500		
49/64	....	.7656	7/8	9
25/32	....	.7812		
51/64	....	.7969		
13/16	....	.8125	7/8	14
53/64	....	.8281		
27/32	....	.8437		
55/64	....	.8594		
7/8	....	.8750	1	8
57/64	....	.8906		
29/32	....	.9062		
59/64	....	.9219		
15/16	....	.9375	1	12
61/64	....	.9531		
31/32	....	.9687		
63/64	....	.9844	1 1/8	7
1	....	1.0000		

Table 15

DRILLED HOLE TOLERANCE (UNDER NORMAL SHOP CONDITIONS)

STANDARD DRILL SIZE				TOLERANCE IN DECIMALS	
DRILL SIZE				PLUS	MINUS
Number	Fraction	Decimal	Metric (MM)		
80		0.0135	0.3412	0.0023	.0005
79		0.0145	0.3788	0.0024	
–	1/64	0.0156	0.3969	0.0025	
78		0.0160	0.4064	0.0025	
77		0.0180	0.4572	0.0026	
76		0.0200	0.5080	0.0027	
75		0.0210	0.5334	0.0027	
74		0.0225	0.5631	0.0028	
73		0.0240	0.6096	0.0028	
72		0.0250	0.6350	0.0029	
71		0.0260	0.6604	0.0029	
70		0.0280	0.7112	0.0030	
69		0.0292	0.7483	0.0030	
68		0.0310	0.7874	0.0031	
–	1/32	0.0312	0.7937	0.0031	
67		0.0320	0.8128	0.0031	
66		0.0330	0.8382	0.0032	
65		0.0350	0.8890	0.0032	
64		0.0360	0.9144	0.0033	
63		0.0370	0.9398	0.0033	
62		0.0380	0.9652	0.0033	.001
61		0.0390	0.9906	0.0033	
60		0.0400	1.0160	0.0034	
59		0.0410	1.0414	0.0034	
58		0.0420	1.0668	0.0034	
57		0.0430	1.0922	0.0035	
56		0.0465	1.1684	0.0035	
–	3/64	0.0469	1.1906	0.0036	
55		0.0520	1.3208	0.0037	
54		0.0550	1.3970	0.0038	
53		0.0595	1.5122	0.0039	
–	1/16	0.0625	1.5875	0.0039	
52		0.0635	1.6002	0.0039	
51		0.0670	1.7018	0.0040	
50		0.0700	1.7780	0.0041	
49		0.0730	1.8542	0.0041	
48		0.0760	1.9304	0.0042	
–	5/64	0.0781	1.9844	0.0042	
47		0.0785	2.0001	0.0042	
46		0.0810	2.0574	0.0043	
45		0.0820	2.0828	0.0043	
44		0.0860	2.1844	0.0044	
43		0.0890	2.2606	0.0044	
42		0.0935	2.3622	0.0045	
–	3/32	0.0937	2.3812	0.0045	
41		0.0960	2.4384	0.0045	
40		0.0980	2.4892	0.0046	
39		0.0995	2.5377	0.0046	
38		0.1015	2.5908	0.0046	
37		0.1040	2.6416	0.0047	
36		0.1065	2.6924	0.0047	
–	7/64	0.1094	2.7781	0.0047	

Table 16

DRILLED HOLE TOLERANCE (UNDER NORMAL SHOP CONDITIONS)

STANDARD DRILL SIZE				TOLERANCE IN DECIMALS	
DRILL SIZE				PLUS	MINUS
No./Letter	Fraction	Decimal	Metric (MM)		
35		0.1100	2.7490	0.0047	↑
34		0.1110	2.8194	0.0048	
33		0.1130	2.8702	0.0048	
32		0.1160	2.9464	0.0048	
31		0.1200	3.0480	0.0049	
–	1/8	0.1250	3.1750	0.0050	
30		0.1285	3.2766	0.0050	
29		0.1360	3.4544	0.0051	
28		0.1405	3.5560	0.0052	
–	9/64	0.1406	3.5719	0.0052	
27		0.1440	3.6576	0.0052	
26		0.1470	3.7338	0.0052	
25		0.1495	3.7886	0.0053	
24		0.1520	3.8608	0.0053	
23		0.1540	3.9116	0.0053	
–	5/32	0.1562	3.9687	0.0053	
22		0.1570	3.9878	0.0053	
21		0.1590	4.0386	0.0054	
20		0.1610	4.0894	0.0054	
19		0.1660	4.2164	0.0055	
18		0.1695	4.3180	0.0055	
–	11/64	0.1719	4.3656	0.0055	
17		0.1730	4.3942	0.0055	
16		0.1770	4.4958	0.0056	.001
15		0.1800	4.5720	0.0056	
14		0.1820	4.6228	0.0057	
13		0.1850	4.6990	0.0057	
–	3/16	0.1875	4.7625	0.0057	
12		0.1890	4.8006	0.0057	
11		0.1910	4.8514	0.0057	
10		0.1935	4.9276	0.0058	
9		0.1960	4.9784	0.0058	
8		0.1990	5.0800	0.0058	
7		0.2010	5.1054	0.0058	
–	13/64	0.2031	5.1594	0.0058	
6		0.2040	5.1816	0.0058	
5		0.2055	5.2070	0.0059	
4		0.2090	5.3086	0.0059	
3		0.2130	5.4102	0.0059	
–	7/32	0.2187	5.5562	0.0060	
2		0.2210	5.6134	0.0060	
1		0.2280	5.7912	0.0061	
A		0.2340	5.9436	0.0061	
–	15/64	0.2344	5.9531	0.0061	
B		0.2380	6.0452	0.0061	
C		0.2420	6.1468	0.0062	
D		0.2460	6.2484	0.0062	
E	1/4	0.2500	6.3500	0.0063	↓
F		0.2570	6.5278	0.0063	↑
G		0.2610	6.6294	0.0063	
–	17/64	0.2656	6.7469	0.0064	
H		0.2660	6.7564	0.0064	
I		0.2720	6.9088	0.0064	.002
J		0.2770	7.0358	0.0065	
K		0.2810	7.1374	0.0065	
–	9/32	0.2812	7.1437	0.0065	
L		0.2900	7.3660	0.0066	
M		0.2950	7.4930	0.0066	
–	19/64	0.2969	7.5406	0.0066	↓

Table 16
(Cont'd)

DRILLED HOLE TOLERANCE (UNDER NORMAL SHOP CONDITIONS)

STANDARD DRILL SIZE				TOLERANCE IN DECIMALS	
DRILL SIZE				PLUS	MINUS
Letter	Fraction	Decimal	Metric (MM)		
N		0.3020	7.6708	0.0067	
—	5/16	0.3125	7.9375	0.0067	
O		0.3160	8.0264	0.0068	
P		0.3230	8.2042	0.0068	
—	21/64	0.3281	8.3344	0.0068	
Q		0.3320	8.4328	0.0069	
R		0.3390	8.6106	0.0069	
—	11/32	0.3437	8.7312	0.0070	
S		0.3480	8.8392	0.0070	
T		0.3580	9.0932	0.0071	
—	23/64	0.3594	9.1281	0.0071	
U		0.3680	9.3472	0.0071	
—	3/8	0.3750	9.5250	0.0072	
V		0.3770	9.5758	0.0072	
W		0.3860	9.8044	0.0072	
—	25/64	0.3906	9.9219	0.0073	
X		0.3970	10.0838	0.0073	
Y		0.4040	10.2616	0.0073	
—	13/32	0.4062	10.3187	0.0074	
Z		0.4130	10.4902	0.0074	.002
	27/64	0.4219	10.7156	0.0075	
	7/16	0.4375	10.1125	0.0075	
	29/64	0.4531	11.5094	0.0076	
	15/32	0.4687	11.9062	0.0077	
	31/64	0.4844	12.3031	0.0078	
	1/2	0.5000	12.7000	0.0079	
	33/64	0.5156	13.0968	0.0080	
	17/32	0.5312	13.4937	0.0081	
	35/64	0.5469	13.8906	0.0081	
	9/16	0.5625	14.2875	0.0082	
	37/64	0.5781	14.6844	0.0083	
	19/32	0.5927	15.0812	0.0084	
	39/64	0.6094	15.4781	0.0084	
	5/8	0.6250	15.8750	0.0085	
	41/64	0.6406	16.2719	0.0086	
	21/32	0.6562	16.6687	0.0086	
	43/64	0.6719	17.0656	0.0087	
	11/16	0.6875	17.4625	0.0088	
	45/64	0.7031	17.8594	0.0088	
	23/32	0.7187	18.2562	0.0089	
	47/64	0.7344	18.6532	0.0090	
	3/4	0.7500	19.0500	0.0090	
	49/64	0.7656	19.4469	0.0091	
	25/32	0.7812	19.8433	0.0092	
	51/64	0.7969	20.2402	0.0092	
	13/16	0.8125	20.6375	0.0093	
	53/64	0.8281	21.0344	0.0093	
	27/32	0.8437	21.4312	0.0094	
	55/64	0.8594	21.8281	0.0095	
	7/8	0.8750	22.2250	0.0095	.003
	57/64	0.8906	22.6219	0.0096	
	29/32	0.9062	23.0187	0.0096	
	59/64	0.9219	23.4156	0.0097	
	15/16	0.9375	23.8125	0.0097	
	61/64	0.9531	24.2094	0.0098	
	31/32	0.9687	24.6062	0.0098	
	63/64	0.9844	25.0031	0.0099	
	1	1.0000	25.4000	0.0100	

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Table 16 (Cont'd)

INCH – METRIC THREAD COMPARISON

INCH SERIES			METRIC			
Size	Dia.(In.)	TPI	Size	Dia. (In.)	Pitch (MM)	TPI (Approx)
			M1.4	.055	.3 .2	85 127
#0	.060	80				
			M1.6	.063	.35 .2	74 127
#1	.073	64 72				
			M2	.079	.4 .25	64 101
#2	.086	56 64				
			M2.5	.098	.45 .35	56 74
#3	.099	48 56				
#4	.112	40 48				
			M3	.118	.5 .35	51 74
#5	.125	40 44				
#6	.138	32 40				
			M4	.157	.7 .5	36 51
#8	.164	32 36				
#10	.190	24 32				
			M5	.196	.8 .5	32 51
			M6	.236	1.0 .75	25 34
¼	.250	20 28				
5/16	.312	18 24				
			M8	.315	1.25 1.0	20 25
3/8	.375	16 24				
			M10	.393	1.5 1.25	17 20
7/16	.437	14 20				
			M12	.472	1.75 1.25	14.5 20
½	.500	13 20				
			M14	.551	2 1.5	12.5 17
5/8	.625	11 18				
			M16	.630	2 1.5	12.5 17
			M18	.709	2.5 1.5	10 17
¾	.750	10 16				
			M20	.787	2.5 1.5	10 17
			M22	.866	2.5 1.5	10 17
7/8	.875	9 14				
			M24	.945	3 2	8.5 12.5
1"	1.000	8 12				
			M27	1.063	3 2	8.5 12.5

Table 17

I.S.O. BASIC METRIC THREAD INFORMATION

	INTERNAL THREADS			EXTERNAL THREADS		
Basic Major DIA & Pitch	Tap Drill DIA	Minor DIA MAX	Minor DIA MIN	Major DIA MAX	Major DIA MIN	Clearance Hole
M1.6 × 0.35	1.25	1.321	1.221	1.576	1.491	1.9
M2 × 0.4	1.60	1.679	1.567	1.976	1.881	2.4
M2.5 × 0.45	2.05	2.138	2.013	2.476	2.013	2.9
M3 × 0.5	2.50	2.599	2.459	2.976	2.870	3.4
M3.5 × 0.6	2.90	3.010	2.850	3.476	3.351	4.0
M4 × 0.7	3.30	3.422	3.242	3.976	3.836	4.5
M5 × 0.8	4.20	4.334	4.134	4.976	4.826	5.5
M6 × 1	5.00	5.153	4.917	5.974	5.794	6.6
M8 × 1.25	6.80	6.912	6.647	7.972	7.760	9.0
M10 × 1.5	8.50	8.676	8.376	9.968	9.732	11.0
M12 × 1.75	10.20	10.441	10.106	11.966	11.701	13.5
M14 × 2	12.00	12.210	11.835	13.962	13.682	15.5
M16 × 2	14.00	14.210	13.835	15.962	15.682	17.5
M20 × 2.5	17.50	17.744	17.294	19.958	19.623	22.0
M24 × 3	21.00	21.252	20.752	23.952	23.577	26.0
M30 × 3.5	26.50	26.771	26.211	29.947	29.522	33.0
M36 × 4	32.00	32.270	31.670	35.940	35.465	39.0
M42 × 4.5	37.50	37.799	37.129	41.937	41.437	45.0
M48 × 5	43.00	43.297	42.587	47.929	47.399	52.0
M56 × 5.5	50.50	50.796	50.046	55.925	55.365	62.0
M64 × 6	58.00	58.305	57.505	63.920	63.320	70.0
M72 × 6	66.00	66.305	65.505	71.920	71.320	78.0
M80 × 6	74.00	74.305	73.505	79.920	79.320	86.0
M90 × 6	84.00	84.305	83.505	89.920	89.320	96.0
M100 × 6	94.00	94.305	93.505	99.920	99.320	107.0

Table 18

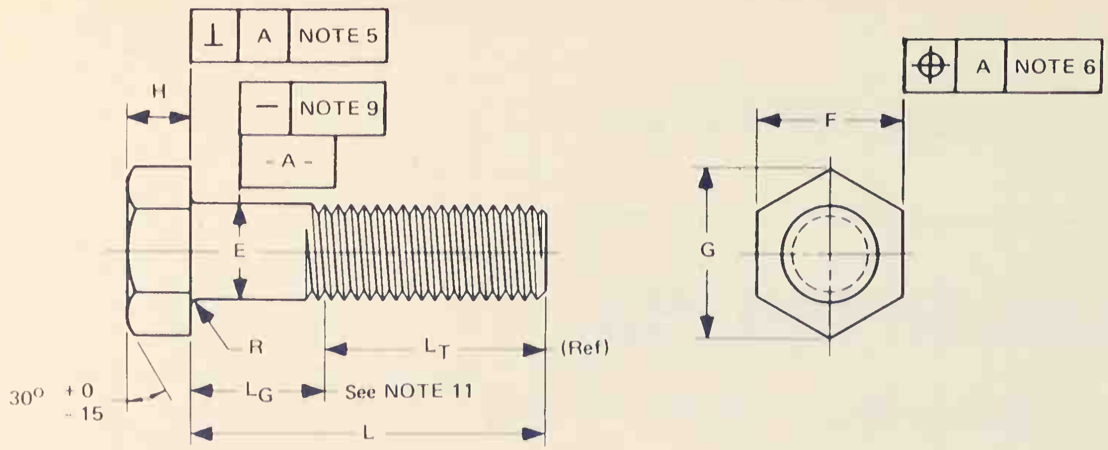

TABLE 19 DIMENSIONS OF HEX BOLTS

Nominal Size or Basic Product Dia (17)		E Body Dia (7)	F Width Across Flats (4)			G Width Across Corners		H Height			R Radius of Fillet		L_T Thread Length For Bolt Lengths (11) 6 in. and shorter	L_T Thread Length For Bolt Lengths (11) over 6 in.
		Max	Basic	Max	Min	Max	Min	Basic	Max	Min	Max	Min	Basic	Basic
1/4	0.2500	0.260	7/16	0.438	0.425	0.505	0.484	11/64	0.188	0.150	0.03	0.01	0.750	1.000
5/16	0.3125	0.324	1/2	0.500	0.484	0.577	0.552	7/32	0.235	0.195	0.03	0.01	0.875	1.125
3/8	0.3750	0.388	9/16	0.562	0.544	0.650	0.620	1/4	0.268	0.226	0.03	0.01	1.000	1.250
7/16	0.4375	0.452	5/8	0.625	0.603	0.722	0.687	19/64	0.316	0.272	0.03	0.01	1.125	1.375
1/2	0.5000	0.515	3/4	0.750	0.725	0.866	0.826	11/32	0.364	0.302	0.03	0.01	1.250	1.500
5/8	0.6250	0.642	15/16	0.928	0.906	1.083	1.033	27/64	0.444	0.378	0.06	0.02	1.500	1.750
3/4	0.7500	0.768	1 1/8	1.125	1.088	1.299	1.240	1/2	0.524	0.455	0.06	0.02	1.750	2.000
7/8	0.8750	0.895	1 5/16	1.312	1.269	1.516	1.447	37/64	0.604	0.531	0.06	0.02	2.000	2.250
1	1.0000	1.022	1 1/2	1.500	1.450	1.732	1.653	43/64	0.700	0.591	0.09	0.03	2.250	2.500
1 1/8	1.1250	1.149	1 11/16	1.688	1.631	1.949	1.859	3/4	0.780	0.658	0.09	0.03	2.500	2.750
1 1/4	1.2500	1.277	1 7/8	1.875	1.812	2.165	2.066	27/32	0.876	0.749	0.09	0.03	2.750	3.000
1 3/8	1.3750	1.404	2 1/16	2.062	1.994	2.382	2.273	29/32	0.940	0.810	0.09	0.03	3.000	3.250
1 1/2	1.5000	1.531	2 1/4	2.250	2.175	2.598	2.480	1	1.036	0.902	0.09	0.03	3.250	3.500
1 3/4	1.7500	1.785	2 5/8	2.625	2.538	3.031	2.893	1 5/32	1.196	1.054	0.12	0.04	3.750	4.000
2	2.0000	2.039	3	3.000	2.900	3.464	3.306	1 11/32	1.388	1.175	0.12	0.04	4.250	4.500
2 1/4	2.2500	2.305	3 3/8	3.375	3.262	3.897	3.719	1 1/2	1.548	1.327	0.19	0.06	4.750	5.000
2 1/2	2.5000	2.559	3 3/4	3.750	3.625	4.330	4.133	1 21/32	1.708	1.479	0.19	0.06	5.250	5.500
2 3/4	2.7500	2.827	4 1/8	4.125	3.988	4.763	4.546	1 13/16	1.869	1.632	0.19	0.06	5.750	6.000
3	3.0000	3.081	4 1/2	4.500	4.350	5.196	4.959	2	2.060	1.815	0.19	0.06	6.250	6.500
3 1/4	3.2500	3.335	4 7/8	4.875	4.712	5.629	5.372	2 3/16	2.251	1.936	0.19	0.06	6.750	7.000
3 1/2	3.5000	3.589	5 1/4	5.250	5.075	6.062	5.786	2 5/16	2.380	2.057	0.19	0.06	7.250	7.500
3 3/4	3.7500	3.858	5 5/8	5.625	5.437	6.495	6.198	2 1/2	2.572	2.241	0.19	0.06	7.750	8.000
4	4.0000	4.111	6	6.000	5.800	6.928	6.612	2 11/16	2.764	2.424	0.19	0.06	8.250	8.500

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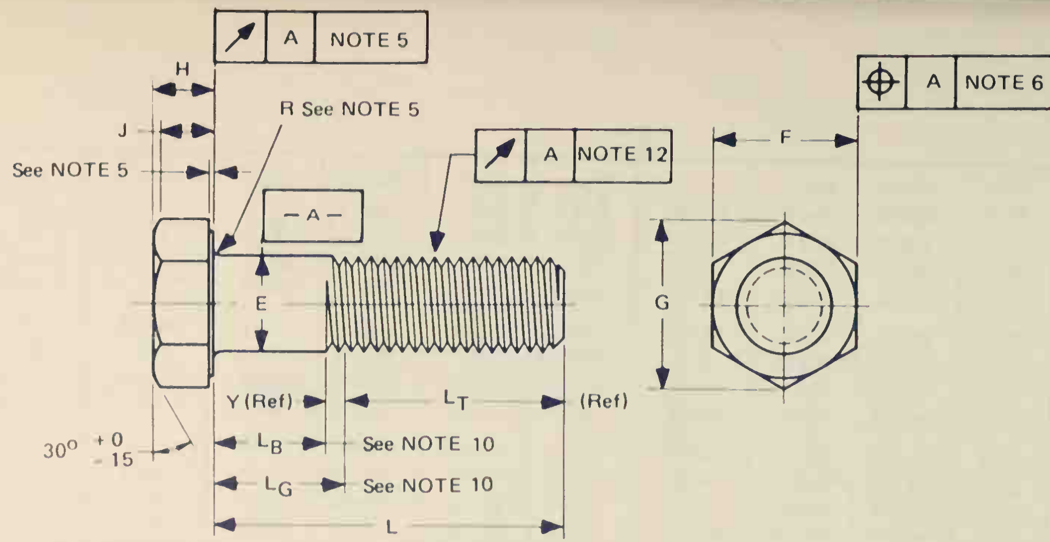


TABLE 20 DIMENSIONS OF HEX CAP SCREWS (FINISHED HEX BOLTS)

Nominal Size or Basic Product Dia (18)		E Body Dia (8)		F Width Across Flats			G Width Across Corners (4)		H Height			J Wrenching Height (4)	L_T Thread Length For Screw Lengths (10): 6 in. and Shorter	L_T Thread Length For Screw Lengths (10): Over 6 in.	Y Transition Thread Length (10)	Runout of Bearing Surface FIM (5)
		Max	Min	Basic	Max	Min	Max	Min	Basic	Max	Min	Min	Basic	Basic	Max	Max
1/4	0.2500	0.2500	0.2450	7/16	0.438	0.428	0.505	0.488	5/32	0.163	0.150	0.106	0.750	1.000	0.250	0.010
5/16	0.3125	0.3125	0.3065	1/2	0.500	0.489	0.577	0.557	13/64	0.211	0.195	0.140	0.875	1.125	0.278	0.011
3/8	0.3750	0.3750	0.3690	9/16	0.562	0.551	0.650	0.628	15/64	0.243	0.226	0.160	1.000	1.250	0.312	0.012
7/16	0.4375	0.4375	0.4305	5/8	0.625	0.612	0.722	0.698	9/32	0.291	0.272	0.195	1.125	1.375	0.357	0.013
1/2	0.5000	0.5000	0.4930	3/4	0.750	0.736	0.866	0.840	5/16	0.323	0.302	0.215	1.250	1.500	0.385	0.014
9/16	0.5625	0.5625	0.5545	13/16	0.812	0.798	0.938	0.910	23/64	0.371	0.348	0.250	1.375	1.625	0.417	0.015
5/8	0.6250	0.6250	0.6170	15/16	0.938	0.922	1.083	1.051	25/64	0.403	0.378	0.269	1.500	1.750	0.455	0.017
3/4	0.7500	0.7500	0.7410	1 1/8	1.125	1.100	1.299	1.254	15/32	0.483	0.455	0.324	1.750	2.000	0.500	0.020
7/8	0.8750	0.8750	0.8660	1 5/16	1.312	1.285	1.516	1.465	35/64	0.563	0.531	0.378	2.000	2.250	0.556	0.023
1	1.0000	1.0000	0.9900	1 1/2	1.500	1.469	1.732	1.675	39/64	0.627	0.591	0.416	2.250	2.500	0.625	0.026
1 1/8	1.1250	1.1250	1.1140	1 11/16	1.688	1.631	1.949	1.859	11/16	0.718	0.658	0.461	2.500	2.750	0.714	0.029
1 1/4	1.2500	1.2500	1.2390	1 7/8	1.875	1.812	2.165	2.066	25/32	0.813	0.749	0.530	2.750	3.000	0.714	0.033
1 3/8	1.3750	1.3750	1.3630	2 1/16	2.062	1.994	2.382	2.273	27/32	0.878	0.810	0.569	3.000	3.250	0.833	0.036
1 1/2	1.5000	1.5000	1.4880	2 1/4	2.230	2.175	2.598	2.480	1 5/16	0.974	0.902	0.640	3.250	3.500	0.833	0.039
1 3/4	1.7500	1.7500	1.7380	2 5/8	2.625	2.538	3.031	2.893	1 3/32	1.134	1.054	0.748	3.750	4.000	1.000	0.046
2	2.0000	2.0000	1.9880	3	3.000	2.900	3.464	3.306	1 7/32	1.263	1.175	0.825	4.250	4.500	1.111	0.052
2 1/4	2.2500	2.2500	2.2380	3 3/8	3.375	3.262	3.897	3.719	1 3/8	1.423	1.327	0.933	4.750	5.000	1.111	0.059
2 1/2	2.5000	2.5000	2.4880	3 3/4	3.750	3.625	4.330	4.133	1 17/32	1.583	1.479	1.042	5.250	5.500	1.250	0.065
2 3/4	2.7500	2.7500	2.7380	4 1/8	4.125	3.988	4.763	4.546	1 11/16	1.744	1.632	1.151	5.750	6.000	1.250	0.072
3	3.0000	3.0000	2.9880	4 1/2	4.500	4.350	5.196	4.959	1 7/8	1.935	1.815	1.290	6.250	6.500	1.250	0.079

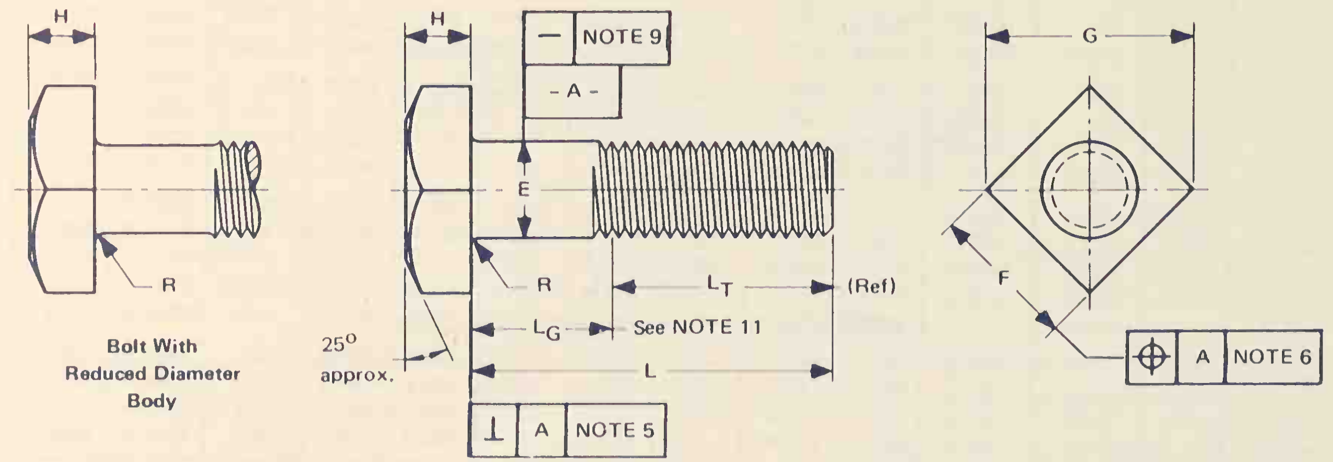
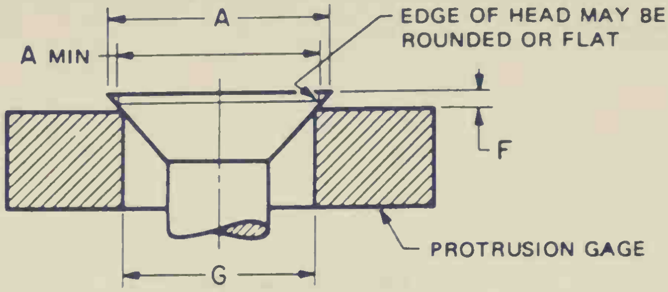


TABLE 21 DIMENSIONS OF SQUARE BOLTS

Nominal Size or Basic Product Dia (17)		E Body Dia (7), (14)	F Width Across Flats (4)			G Width Across Corners		H Height			R Radius of Fillet		L_T Thread Length For Bolt Lengths (11)	
													6 in. and shorter	over 6 in.
		Max	Basic	Max	Min	Max	Min	Basic	Max	Min	Max	Min	Basic	Basic
1/4	0.2500	0.260	3/8	0.375	0.362	0.530	0.498	11/64	0.188	0.156	0.03	0.01	0.750	1.000
5/16	0.3125	0.324	1/2	0.500	0.484	0.707	0.665	13/64	0.220	0.186	0.03	0.01	0.875	1.125
3/8	0.3750	0.388	9/16	0.562	0.544	0.795	0.747	1/4	0.268	0.232	0.03	0.01	1.000	1.250
7/16	0.4375	0.452	5/8	0.625	0.603	0.884	0.828	19/64	0.316	0.278	0.03	0.01	1.125	1.375
1/2	0.5000	0.515	3/4	0.750	0.725	1.061	0.995	21/64	0.348	0.308	0.03	0.01	1.250	1.500
5/8	0.6250	0.642	15/16	0.938	0.906	1.326	1.244	27/64	0.444	0.400	0.06	0.02	1.500	1.750
3/4	0.7500	0.768	1 1/8	1.125	1.088	1.591	1.494	1/2	0.524	0.476	0.06	0.02	1.750	2.000
7/8	0.8750	0.895	1 5/16	1.312	1.269	1.856	1.742	19/32	0.620	0.568	0.06	0.02	2.000	2.250
1	1.0000	1.022	1 1/2	1.500	1.450	2.121	1.991	21/32	0.684	0.628	0.09	0.03	2.250	2.500
1 1/8	1.1250	1.149	1 11/16	1.688	1.631	2.386	2.239	3/4	0.780	0.720	0.09	0.03	2.500	2.750
1 1/4	1.2500	1.277	1 7/8	1.875	1.812	2.652	2.489	27/32	0.876	0.812	0.09	0.03	2.750	3.000
1 3/8	1.3750	1.404	2 1/16	2.062	1.994	2.917	2.738	29/32	0.940	0.872	0.09	0.03	3.000	3.250
1 1/2	1.5000	1.531	2 1/4	2.250	2.175	3.182	2.986	1	1.036	0.964	0.09	0.03	3.250	3.500

SLOTTED
FLAT

Type of Head



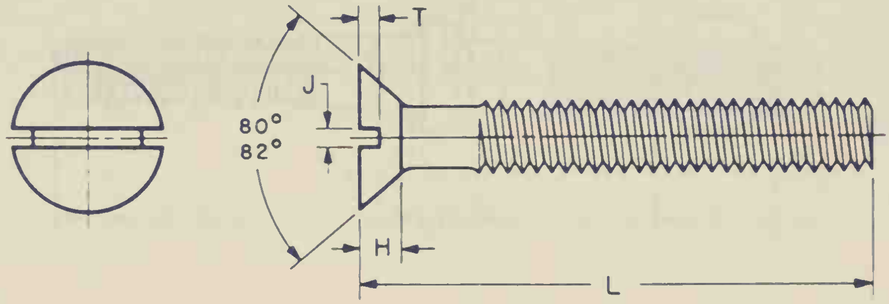


TABLE 22 DIMENSIONS OF SLOTTED FLAT COUNTERSUNK HEAD MACHINE SCREWS

Nominal Size[1] or Basic Screw Diameter		L[2]	A		H[3]	J		T		F[4]		G[4]
		These Lengths or Shorter are Undercut.	Head Diameter		Head Height	Slot Width		Slot Depth		Protrusion Above Gaging Diameter		Gaging Diameter
			Max, Edge Sharp	Min, Edge Rounded or Flat	Ref	Max	Min	Max	Min	Max	Min	
0000	0.0210	—	0.043	0.037	0.011	0.008	0.004	0.007	0.003	*	*	*
000	0.0340	—	0.064	0.058	0.016	0.011	0.007	0.009	0.005	*	*	*
00	0.0470	—	0.093	0.085	0.028	0.017	0.010	0.014	0.009	*	*	*
0	0.0600	1/8	0.119	0.099	0.035	0.023	0.016	0.015	0.010	0.026	0.016	0.078
1	0.0730	1/8	0.146	0.123	0.043	0.026	0.019	0.019	0.012	0.028	0.016	0.101
2	0.0860	1/8	0.172	0.147	0.051	0.031	0.023	0.023	0.015	0.029	0.017	0.124
3	0.0990	1/8	0.199	0.171	0.059	0.035	0.027	0.027	0.017	0.031	0.018	0.148
4	0.1120	3/16	0.225	0.195	0.067	0.039	0.031	0.030	0.020	0.032	0.019	0.172
5	0.1250	3/16	0.252	0.220	0.075	0.043	0.035	0.034	0.022	0.034	0.020	0.196
6	0.1380	3/16	0.279	0.244	0.083	0.048	0.039	0.038	0.024	0.036	0.021	0.220
8	0.1640	1/4	0.332	0.292	0.100	0.054	0.045	0.045	0.029	0.039	0.023	0.267
10	0.1900	5/16	0.385	0.340	0.116	0.060	0.050	0.053	0.034	0.042	0.025	0.313
12	0.2160	3/8	0.438	0.389	0.132	0.067	0.056	0.060	0.039	0.045	0.027	0.362
1/4	0.2500	7/16	0.507	0.452	0.153	0.075	0.064	0.070	0.046	0.050	0.029	0.424
5/16	0.3125	1/2	0.635	0.568	0.191	0.084	0.072	0.088	0.058	0.057	0.034	0.539
3/8	0.3750	9/16	0.762	0.685	0.230	0.094	0.081	0.106	0.070	0.065	0.039	0.653
7/16	0.4375	5/8	0.812	0.723	0.223	0.094	0.081	0.103	0.066	0.073	0.044	0.690
1/2	0.5000	3/4	0.875	0.775	0.223	0.106	0.091	0.103	0.065	0.081	0.049	0.739
9/16	0.5625	—	1.000	0.889	0.260	0.118	0.102	0.120	0.077	0.089	0.053	0.851
5/8	0.6250	—	1.125	1.002	0.298	0.133	0.116	0.137	0.088	0.097	0.058	0.962
3/4	0.7500	—	1.375	1.230	0.372	0.149	0.131	0.171	0.111	0.112	0.067	1.186

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

2 Screws of these lengths and shorter shall have undercut heads as shown in Table 5.

3 Tabulated values determined from formula for maximum H, Appendix V.

4 No tolerance for gaging diameter is given. If the gaging diameter of the gage used differs from tabulated value, the protrusion will be affected accordingly and the proper protrusion values must be recalculated using the formulas shown in Appendix I.

*Not practical to gage.

Type of Head

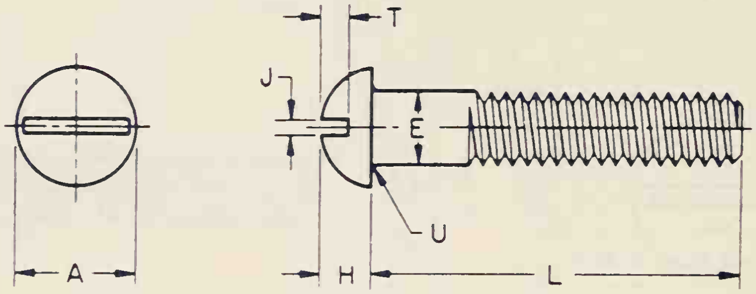


TABLE 23 DIMENSIONS OF SLOTTED ROUND HEAD CAP SCREWS

Nominal Size[1] or Basic Screw Diameter		E Body Diameter		A Head Diameter		H Head Height		J Slot Width		T Slot Depth		U Fillet Radius	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1/4	0.2500	0.2500	0.2450	0.437	0.418	0.191	0.175	0.075	0.064	0.117	0.097	0.031	0.016
5/16	0.3125	0.3125	0.3070	0.562	0.540	0.245	0.226	0.084	0.072	0.151	0.126	0.031	0.016
3/8	0.3750	0.3750	0.3690	0.625	0.603	0.273	0.252	0.094	0.081	0.168	0.138	0.031	0.016
7/16	0.4375	0.4375	0.4310	0.750	0.725	0.328	0.302	0.094	0.081	0.202	0.167	0.047	0.016
1/2	0.5000	0.5000	0.4930	0.812	0.786	0.354	0.327	0.106	0.091	0.218	0.178	0.047	0.016
9/16	0.5625	0.5625	0.5550	0.937	0.909	0.409	0.378	0.118	0.102	0.252	0.207	0.047	0.016
5/8	0.6250	0.6250	0.6170	1.000	0.970	0.437	0.405	0.133	0.116	0.270	0.220	0.062	0.031
3/4	0.7500	0.7500	0.7420	1.250	1.215	0.546	0.507	0.149	0.131	0.338	0.278	0.062	0.031

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

From The American Society of Mechanical Engineers - ANSI B18.6.2 - 1972

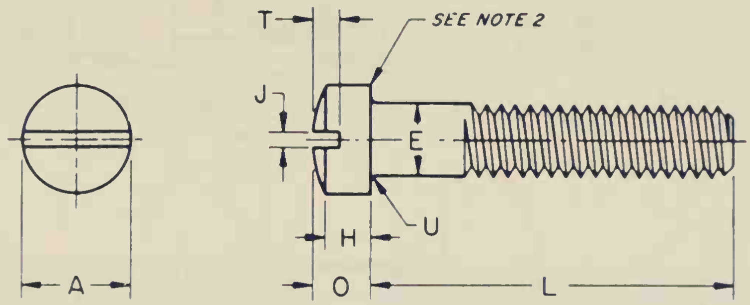


TABLE 24 DIMENSIONS OF SLOTTED FILLISTER HEAD CAP SCREWS

Nominal Size[1] or Basic Screw Diameter		E		A		H		O		J		T		U	
		Body Diameter		Head Diameter		Head Side Height		Total Head Height		Slot Width		Slot Depth		Fillet Radius	
		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
1/4	0.2500	0.2500	0.2450	0.375	0.363	0.172	0.157	0.216	0.194	0.075	0.064	0.097	0.077	0.031	0.016
5/16	0.3125	0.3125	0.3070	0.437	0.424	0.203	0.186	0.253	0.230	0.084	0.072	0.115	0.090	0.031	0.016
3/8	0.3750	0.3750	0.3690	0.562	0.547	0.250	0.229	0.314	0.284	0.094	0.081	0.142	0.112	0.031	0.016
7/16	0.4375	0.4375	0.4310	0.625	0.608	0.297	0.274	0.368	0.336	0.094	0.081	0.168	0.133	0.047	0.016
1/2	0.5000	0.5000	0.4930	0.750	0.731	0.328	0.301	0.413	0.376	0.106	0.091	0.193	0.153	0.047	0.016
9/16	0.5625	0.5625	0.5550	0.812	0.792	0.375	0.346	0.467	0.427	0.118	0.102	0.213	0.168	0.047	0.016
5/8	0.6250	0.6250	0.6170	0.875	0.853	0.422	0.391	0.521	0.478	0.133	0.116	0.239	0.189	0.062	0.031
3/4	0.7500	0.7500	0.7420	1.000	0.976	0.500	0.466	0.612	0.566	0.149	0.131	0.283	0.223	0.062	0.031
7/8	0.8750	0.8750	0.8660	1.125	1.098	0.594	0.556	0.720	0.668	0.167	0.147	0.334	0.264	0.062	0.031
1	1.0000	1.0000	0.9900	1.312	1.282	0.656	0.612	0.803	0.743	0.188	0.166	0.371	0.291	0.062	0.031

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

2 A slight rounding of the edges at periphery of head shall be permissible provided the diameter of the bearing circle is equal to no less than 90 per cent of the specified minimum head diameter.

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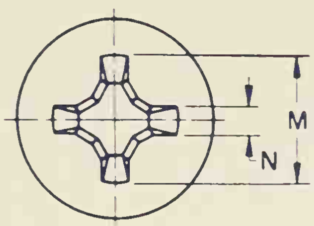
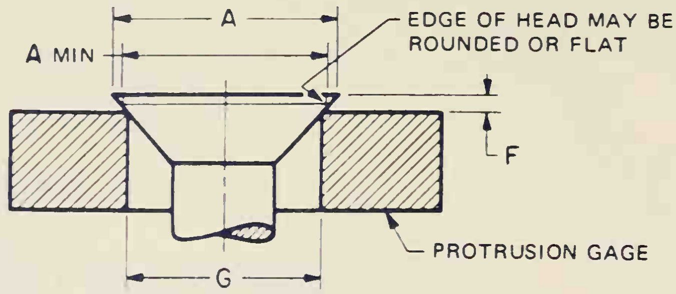


This type of recess has a large center opening, tapered wings, and blunt bottom, with all edges relieved or rounded



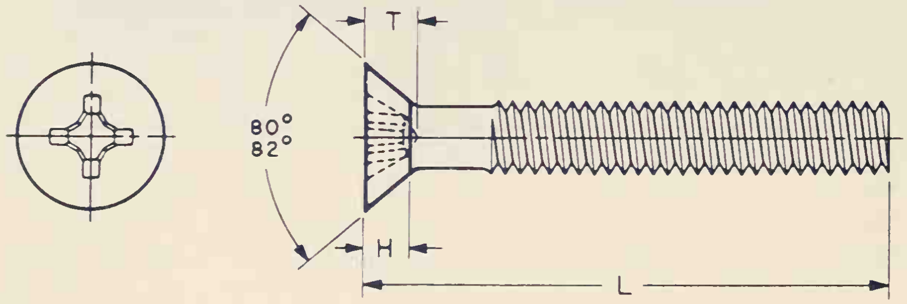


TABLE 25 DIMENSIONS OF TYPE I CROSS RECESSED FLAT COUNTERSUNK HEAD MACHINE SCREWS

Nominal Size[1] or Basic Screw Diameter		L[2]	A		H[3]	M		T		N	Driver Size	Recess Penetration Gaging Depth		F[4]		G[4]
		These Lengths or Shorter are Undercut	Head Diameter		Head Height	Recess Diameter		Recess Depth		Recess Width				Protrusion Above Gaging Diameter		Gaging Diameter
			Max, Edge Sharp	Min, Edge Rounded or Flat	Ref	Max	Min	Max	Min	Min		Max	Min	Max	Min	
0	0.0600	1/8	0.119	0.099	0.035	0.069	0.056	0.043	0.027	0.014	0	0.036	0.020	0.026	0.016	0.078
1	0.0730	1/8	0.146	0.123	0.043	0.077	0.064	0.051	0.035	0.015	0	0.044	0.028	0.028	0.016	0.101
2	0.0860	1/8	0.172	0.147	0.051	0.102	0.089	0.063	0.047	0.017	1	0.056	0.040	0.029	0.017	0.124
3	0.0990	1/8	0.199	0.171	0.059	0.107	0.094	0.068	0.052	0.018	1	0.061	0.045	0.031	0.018	0.148
4	0.1120	3/16	0.225	0.195	0.067	0.128	0.115	0.089	0.073	0.018	1	0.082	0.066	0.032	0.019	0.172
5	0.1250	3/16	0.252	0.220	0.075	0.154	0.141	0.086	0.063	0.027	2	0.075	0.052	0.034	0.020	0.196
6	0.1380	3/16	0.279	0.244	0.083	0.174	0.161	0.106	0.083	0.029	2	0.095	0.072	0.036	0.021	0.220
8	0.1640	1/4	0.332	0.292	0.100	0.189	0.176	0.121	0.098	0.030	2	0.110	0.087	0.039	0.023	0.267
10	0.1900	5/16	0.385	0.340	0.116	0.204	0.191	0.136	0.113	0.032	2	0.125	0.102	0.042	0.025	0.313
12	0.2160	3/8	0.438	0.389	0.132	0.268	0.255	0.156	0.133	0.035	3	0.139	0.116	0.045	0.027	0.362
1/4	0.2500	7/16	0.507	0.452	0.153	0.283	0.270	0.171	0.148	0.036	3	0.154	0.131	0.050	0.029	0.424
5/16	0.3125	1/2	0.635	0.568	0.191	0.365	0.352	0.216	0.194	0.061	4	0.196	0.174	0.057	0.034	0.539
3/8	0.3750	9/16	0.762	0.685	0.230	0.393	0.380	0.245	0.223	0.065	4	0.225	0.203	0.065	0.039	0.653
7/16	0.4375	5/8	0.812	0.723	0.223	0.409	0.396	0.261	0.239	0.068	4	0.241	0.219	0.073	0.044	0.690
1/2	0.5000	3/4	0.875	0.775	0.223	0.424	0.411	0.276	0.254	0.069	4	0.256	0.234	0.081	0.049	0.739
9/16	0.5625	—	1.000	0.889	0.260	0.454	0.431	0.300	0.278	0.073	4	0.280	0.258	0.089	0.053	0.851
5/8	0.6250	—	1.125	1.002	0.298	0.576	0.553	0.342	0.316	0.079	5	0.309	0.283	0.097	0.058	0.962
3/4	0.7500	—	1.375	1.230	0.372	0.640	0.617	0.406	0.380	0.087	5	0.373	0.347	0.112	0.067	1.186

[1]Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.
[2]Screws of these lengths and shorter shall have undercut heads.
[3]Tabulated values determined from formula for maximum H, Appendix V, ANSI B18.6.3-1972.
[4]No tolerance for gaging diameter is given. If the gaging diameter of the gage used differs from tabulated value, the protrusion will be affected accordingly and the proper protrusion values must be recalculated using the formulas shown in Appendix I, ANSI B18.6.3-1972.

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SLOTTED

OVAL

Type of Head

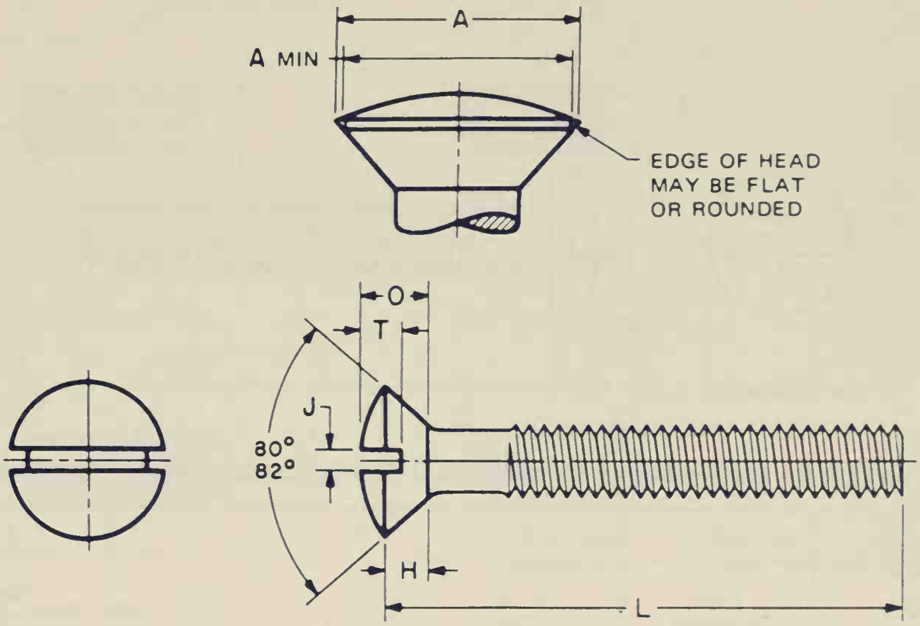

TABLE 26 DIMENSIONS OF SLOTTED OVAL COUNTERSUNK HEAD MACHINE SCREWS

Nominal Size[1] or Basic Screw Diameter		L[2]	A		H[3]	O		J		T	
		These Lengths or Shorter are Undercut	Head Diameter		Head Side Height	Total Head Height		Slot Width		Slot Depth	
			Max, Edge Sharp	Min, Edge Rounded or Flat	Ref	Max	Min	Max	Min	Max	Min
00	0.0470	—	0.093	0.085	0.028	0.042	0.034	0.017	0.010	0.023	0.016
0	0.0600	1/8	0.119	0.099	0.035	0.056	0.041	0.023	0.016	0.030	0.025
1	0.0730	1/8	0.146	0.123	0.043	0.068	0.052	0.026	0.019	0.038	0.031
2	0.0860	1/8	0.172	0.147	0.051	0.080	0.063	0.031	0.023	0.045	0.037
3	0.0990	1/8	0.199	0.171	0.059	0.092	0.073	0.035	0.027	0.052	0.043
4	0.1120	3/16	0.225	0.195	0.067	0.104	0.084	0.039	0.031	0.059	0.049
5	0.1250	3/16	0.252	0.220	0.075	0.116	0.095	0.043	0.035	0.067	0.055
6	0.1380	3/16	0.279	0.244	0.083	0.128	0.105	0.048	0.039	0.074	0.060
8	0.1640	1/4	0.332	0.292	0.100	0.152	0.126	0.054	0.045	0.088	0.072
10	0.1900	5/16	0.385	0.340	0.116	0.176	0.148	0.060	0.050	0.103	0.084
12	0.2160	3/8	0.438	0.389	0.132	0.200	0.169	0.067	0.056	0.117	0.096
1/4	0.2500	7/16	0.507	0.452	0.153	0.232	0.197	0.075	0.064	0.136	0.112
5/16	0.3125	1/2	0.635	0.568	0.191	0.290	0.249	0.084	0.072	0.171	0.141
3/8	0.3750	9/16	0.762	0.685	0.230	0.347	0.300	0.094	0.081	0.206	0.170
7/16	0.4375	5/8	0.812	0.723	0.223	0.345	0.295	0.094	0.081	0.210	0.174
1/2	0.5000	3/4	0.875	0.775	0.223	0.354	0.299	0.106	0.091	0.216	0.176
9/16	0.5625	—	1.000	0.889	0.260	0.410	0.350	0.118	0.102	0.250	0.207
5/8	0.6250	—	1.125	1.002	0.298	0.467	0.399	0.133	0.116	0.285	0.235
3/4	0.7500	—	1.375	1.230	0.372	0.578	0.497	0.149	0.131	0.353	0.293

[1]Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.
[2]Screws of these lengths and shorter shall have undercut heads.
[3]Tabulated values determined from formula for maximum H, Appendix V, ANSI B18.6.3-1972.

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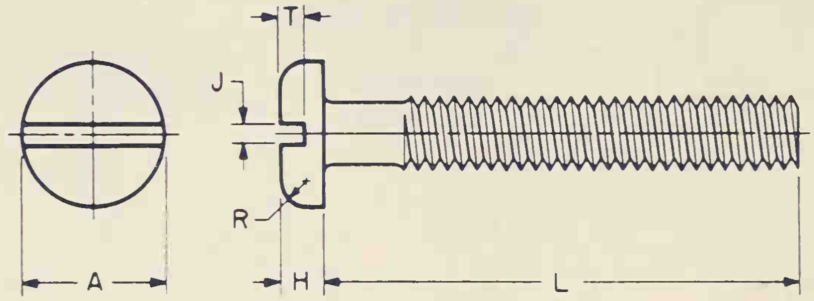

TABLE 27 DIMENSIONS OF SLOTTED PAN HEAD MACHINE SCREWS

Nominal Size[1] or Basic Screw Diameter	A		H		R	J		T	
	Head Diameter		Head Height		Head Radius	Slot Width		Slot Depth	
	Max	Min	Max	Min	Max	Max	Min	Max	Min
0000 0.0210	0.042	0.036	0.016	0.010	0.007	0.008	0.004	0.008	0.004
000 0.0340	0.066	0.060	0.023	0.017	0.010	0.012	0.008	0.012	0.008
00 0.0470	0.090	0.082	0.032	0.025	0.015	0.017	0.010	0.016	0.010
0 0.0600	0.116	0.104	0.039	0.031	0.020	0.023	0.016	0.022	0.014
1 0.0730	0.142	0.130	0.046	0.038	0.025	0.026	0.019	0.027	0.018
2 0.0860	0.167	0.155	0.053	0.045	0.035	0.031	0.023	0.031	0.022
3 0.0990	0.193	0.180	0.060	0.051	0.037	0.035	0.027	0.036	0.026
4 0.1120	0.219	0.205	0.068	0.058	0.042	0.039	0.031	0.040	0.030
5 0.1250	0.245	0.231	0.075	0.065	0.044	0.043	0.035	0.045	0.034
6 0.1380	0.270	0.256	0.082	0.072	0.046	0.048	0.039	0.050	0.037
8 0.1640	0.322	0.306	0.096	0.085	0.052	0.054	0.045	0.058	0.045
10 0.1900	0.373	0.357	0.110	0.099	0.061	0.060	0.050	0.068	0.053
12 0.2160	0.425	0.407	0.125	0.112	0.078	0.067	0.056	0.077	0.061
1/4 0.2500	0.492	0.473	0.144	0.130	0.087	0.075	0.064	0.087	0.070
5/16 0.3125	0.615	0.594	0.178	0.162	0.099	0.084	0.072	0.106	0.085
3/8 0.3750	0.740	0.716	0.212	0.195	0.143	0.094	0.081	0.124	0.100
7/16 0.4375	0.863	0.837	0.247	0.228	0.153	0.094	0.081	0.142	0.116
1/2 0.5000	0.987	0.958	0.281	0.260	0.175	0.106	0.091	0.161	0.131
9/16 0.5625	1.041	1.000	0.315	0.293	0.197	0.118	0.102	0.179	0.146
5/8 0.6250	1.172	1.125	0.350	0.325	0.219	0.133	0.116	0.197	0.162
3/4 0.7500	1.435	1.375	0.419	0.390	0.263	0.149	0.131	0.234	0.192

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

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AMERICAN NATIONAL STANDARD – SLOTTED HEAD CAP SCREWS, SQUARE HEAD SET SCREWS, AND SLOTTED HEADLESS SET SCREWS — ANSI B18.6.2–1972

Type of Head

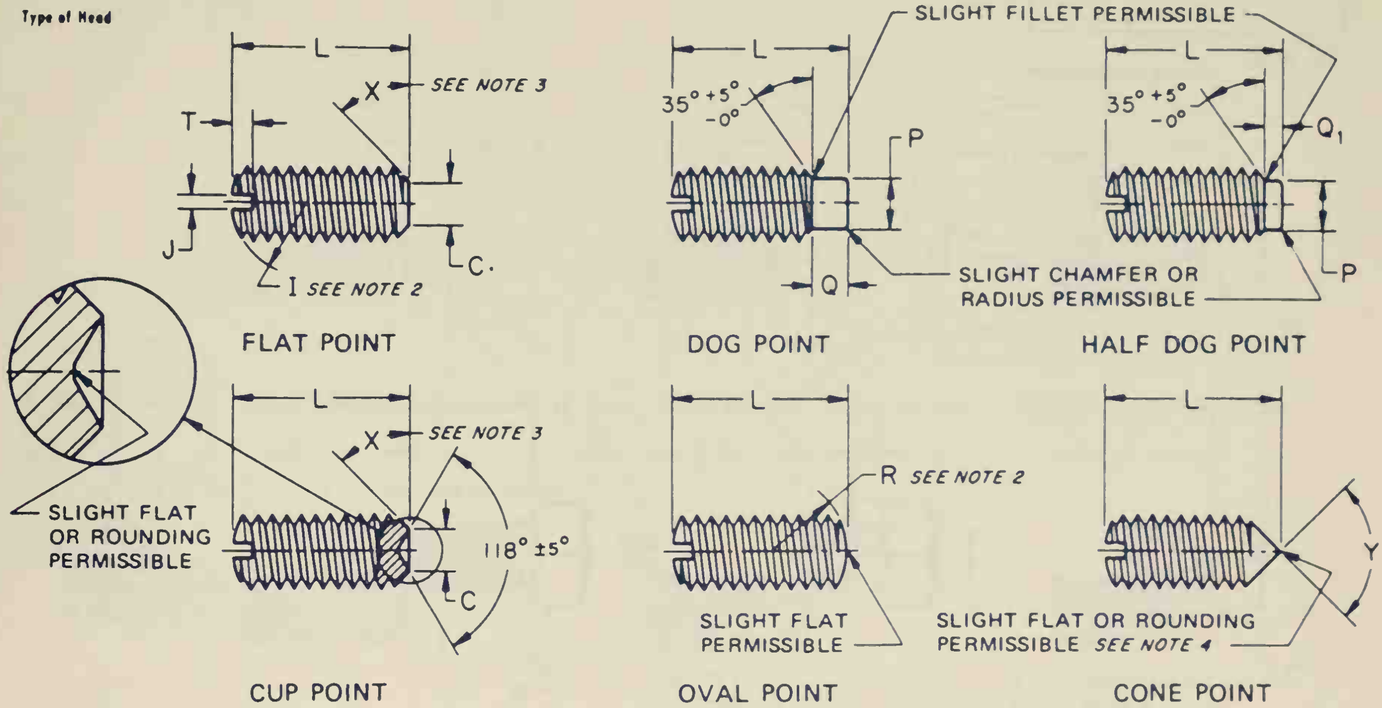


TABLE 28 DIMENSIONS OF SLOTTED HEADLESS SET SCREWS

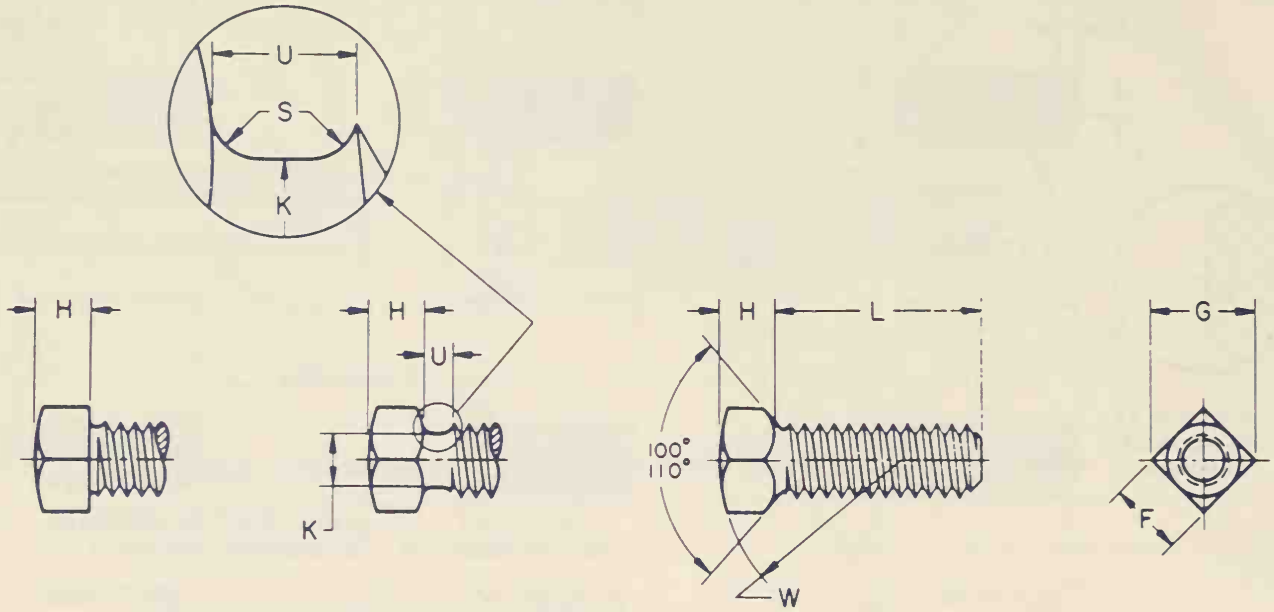
Nominal Size[1] or Basic Screw Diameter		I[2] Crown Radius	J Slot Width		T Slot Depth		C Cup and Flat Point Diameters		P Dog Point Diameters		Q Point Length Dog		Q1 Point Length Half Dog		R[2] Oval Point Radius	Y Cone Point Angle 90° ±2° For These Nominal Lengths or Longer; 118° ±2° For Shorter Screws
		Basic	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Basic	
0	0.0600	0.060	0.014	0.010	0.020	0.016	0.033	0.027	0.040	0.037	0.032	0.028	0.017	0.013	0.045	5/64
1	0.0730	0.073	0.016	0.012	0.020	0.016	0.040	0.033	0.049	0.045	0.040	0.036	0.021	0.017	0.055	3/32
2	0.0860	0.086	0.018	0.014	0.025	0.019	0.047	0.039	0.057	0.053	0.046	0.042	0.024	0.020	0.064	7/64
3	0.0990	0.099	0.020	0.016	0.028	0.022	0.054	0.045	0.066	0.062	0.052	0.048	0.027	0.023	0.074	1/8
4	0.1120	0.112	0.024	0.018	0.031	0.025	0.061	0.051	0.075	0.070	0.058	0.054	0.030	0.026	0.084	5/32
5	0.1250	0.125	0.026	0.020	0.036	0.026	0.067	0.057	0.083	0.078	0.063	0.057	0.033	0.027	0.094	3/16
6	0.1380	0.138	0.028	0.022	0.040	0.030	0.074	0.064	0.092	0.087	0.073	0.067	0.038	0.032	0.104	3/16
8	0.1640	0.164	0.032	0.026	0.046	0.036	0.087	0.076	0.109	0.103	0.083	0.077	0.043	0.037	0.123	1/4
10	0.1900	0.190	0.035	0.029	0.053	0.043	0.102	0.088	0.127	0.120	0.095	0.085	0.050	0.040	0.142	1/4
12	0.2160	0.216	0.042	0.035	0.061	0.051	0.115	0.101	0.144	0.137	0.115	0.105	0.060	0.050	0.162	5/16
1/4	0.2500	0.250	0.049	0.041	0.068	0.058	0.132	0.118	0.156	0.149	0.130	0.120	0.068	0.058	0.188	5/16
5/16	0.3125	0.312	0.055	0.047	0.083	0.073	0.172	0.156	0.203	0.195	0.161	0.151	0.083	0.073	0.234	3/8
3/8	0.3750	0.375	0.068	0.060	0.099	0.089	0.212	0.194	0.250	0.241	0.193	0.183	0.099	0.089	0.281	7/16
7/16	0.4375	0.438	0.076	0.068	0.114	0.104	0.252	0.232	0.297	0.287	0.224	0.214	0.114	0.104	0.328	1/2
1/2	0.5000	0.500	0.086	0.076	0.130	0.120	0.291	0.270	0.344	0.334	0.255	0.245	0.130	0.120	0.375	9/16
9/16	0.5625	0.562	0.096	0.086	0.146	0.136	0.332	0.309	0.391	0.379	0.287	0.275	0.146	0.134	0.422	5/8
5/8	0.6250	0.625	0.107	0.097	0.161	0.151	0.371	0.347	0.469	0.456	0.321	0.305	0.164	0.148	0.469	3/4
3/4	0.7500	0.750	0.134	0.124	0.193	0.183	0.450	0.425	0.562	0.549	0.383	0.367	0.196	0.180	0.562	7/8

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

2 Tolerance on radius for nominal sizes up to and including 5 (0.125 in.) shall be plus 0.015 in. and minus 0.000, and for larger sizes, plus 0.031 in. and minus 0.000. Slotted ends on screws may be flat at option of manufacturer.

3 Point angle X shall be 45° plus 5°, minus 0°, for screws of nominal lengths equal to or longer than those listed in Column Y, and 30° minimum for screws of shorter nominal lengths.

4 The extent of rounding or flat at apex of cone point shall not exceed an amount equivalent to 10 per cent of the basic screw diameter.



OPTIONAL HEAD CONSTRUCTIONS

TABLE 29 DIMENSIONS OF SQUARE HEAD SET SCREWS

Nominal Size[1] or Basic Screw Diameter	F		G		H		K		S	U	W
	Width Across Flats		Width Across Corners		Head Height		Neck Relief Diameter		Neck Relief Fillet Radius	Neck Relief Width	Head Radius
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Min
10 0.1900	0.188	0.180	0.265	0.247	0.148	0.134	0.145	0.140	0.027	0.083	0.48
1/4 0.2500	0.250	0.241	0.354	0.331	0.196	0.178	0.185	0.170	0.032	0.100	0.62
5/16 0.3125	0.312	0.302	0.442	0.415	0.245	0.224	0.240	0.225	0.036	0.111	0.78
3/8 0.3750	0.375	0.362	0.530	0.497	0.293	0.270	0.294	0.279	0.041	0.125	0.94
7/16 0.4375	0.438	0.423	0.619	0.581	0.341	0.315	0.345	0.330	0.046	0.143	1.09
1/2 0.5000	0.500	0.484	0.707	0.665	0.389	0.361	0.400	0.385	0.050	0.154	1.25
9/16 0.5625	0.562	0.545	0.795	0.748	0.437	0.407	0.454	0.439	0.054	0.167	1.41
5/8 0.6250	0.625	0.606	0.884	0.833	0.485	0.452	0.507	0.492	0.059	0.182	1.56
3/4 0.7500	0.750	0.729	1.060	1.001	0.582	0.544	0.620	0.605	0.065	0.200	1.88
7/8 0.8750	0.875	0.852	1.237	1.170	0.678	0.635	0.731	0.716	0.072	0.222	2.19
1 1.0000	1.000	0.974	1.414	1.337	0.774	0.726	0.838	0.823	0.081	0.250	2.50
1 1/8 1.1250	1.125	1.096	1.591	1.505	0.870	0.817	0.939	0.914	0.092	0.283	2.81
1 1/4 1.2500	1.250	1.219	1.768	1.674	0.966	0.908	1.064	1.039	0.092	0.283	3.12
1 3/8 1.3750	1.375	1.342	1.945	1.843	1.063	1.000	1.159	1.134	0.109	0.333	3.44
1 1/2 1.5000	1.500	1.464	2.121	2.010	1.159	1.091	1.284	1.259	0.109	0.333	3.75

[1] Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.

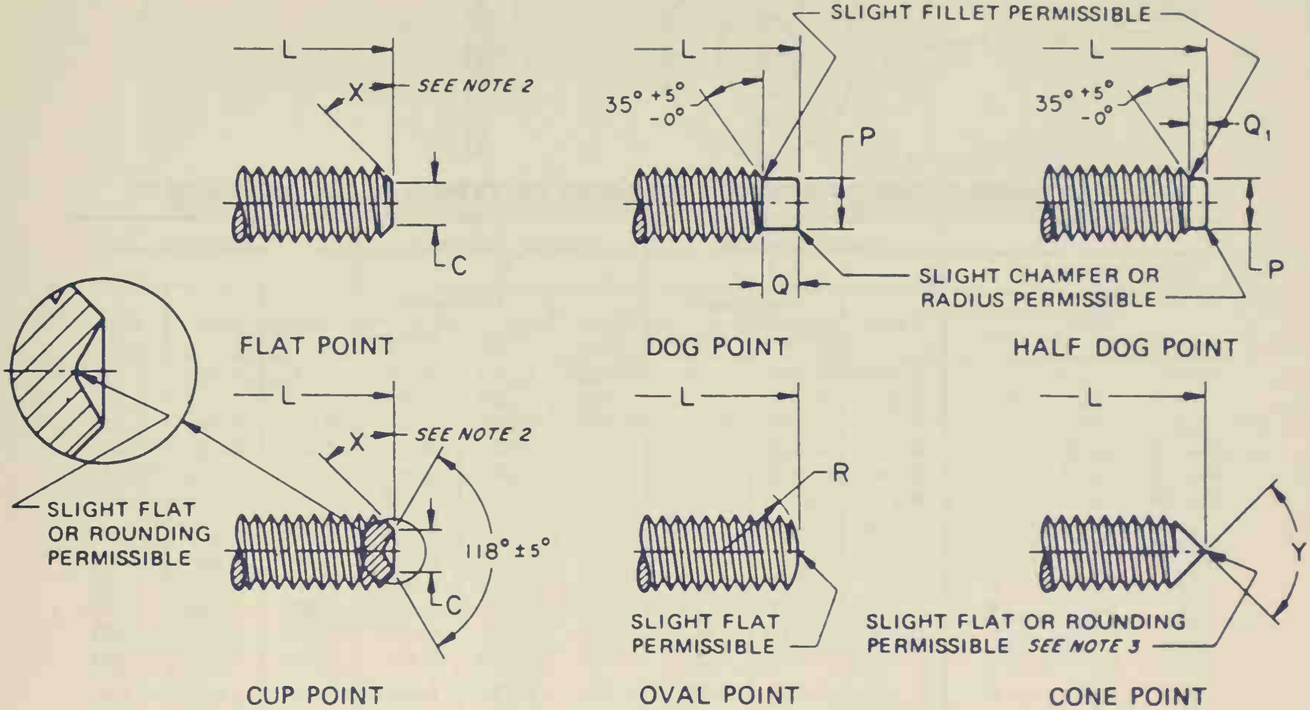


TABLE 29 DIMENSIONS OF SQUARE HEAD SET SCREWS (CONTINUED)

Nominal Size[1] or Basic Screw Diameter	C		P		Q		Q_1		R	Y
	Cup and Flat Point Diameters		Dog and Half Dog Point Diameters		Point Length				Oval Point Radius	Cone Point Angle 90° ±2° For These Nominal Lengths or Longer; 118° ±2° For Shorter Screws
					Dog		Half Dog			
	Max	Min	Max	Min	Max	Min	Max	Min	+0.031 −0.000	
10 0.1900	0.102	0.088	0.127	0.120	0.095	0.085	0.050	0.040	0.142	1/4
1/4 0.2500	0.132	0.118	0.156	0.149	0.130	0.120	0.068	0.058	0.188	5/16
5/16 0.3125	0.172	0.156	0.203	0.195	0.161	0.151	0.083	0.073	0.234	3/8
3/8 0.3750	0.212	0.194	0.250	0.241	0.193	0.183	0.099	0.089	0.281	7/16
7/16 0.4375	0.252	0.232	0.297	0.287	0.224	0.214	0.114	0.104	0.328	1/2
1/2 0.5000	0.291	0.270	0.344	0.334	0.255	0.245	0.130	0.120	0.375	9/16
9/16 0.5625	0.332	0.309	0.391	0.379	0.287	0.275	0.146	0.134	0.422	5/8
5/8 0.6250	0.371	0.347	0.469	0.456	0.321	0.305	0.164	0.148	0.469	3/4
3/4 0.7500	0.450	0.425	0.562	0.549	0.383	0.367	0.196	0.180	0.562	7/8
7/8 0.8750	0.530	0.502	0.656	0.642	0.446	0.430	0.227	0.211	0.656	1
1 1.0000	0.609	0.579	0.750	0.734	0.510	0.490	0.260	0.240	0.750	1 1/8
1 1/8 1.1250	0.689	0.655	0.844	0.826	0.572	0.552	0.291	0.271	0.844	1 1/4
1 1/4 1.2500	0.767	0.733	0.938	0.920	0.635	0.615	0.323	0.303	0.938	1 1/2
1 3/8 1.3750	0.848	0.808	1.031	1.011	0.698	0.678	0.354	0.334	1.031	1 5/8
1 1/2 1.5000	0.926	0.886	1.125	1.105	0.760	0.740	0.385	0.365	1.125	1 3/4

1 Where specifying nominal size in decimals, zeros preceding decimal and in the fourth decimal place shall be omitted.
2 Point angle X shall be 45° plus 5°, minus 0°, for screws of nominal lengths equal to or longer than those listed in Column Y, and 30° minimum for screws of shorter nominal lengths.
3 The extent of rounding or flat at apex of cone point shall not exceed an amount equivalent to 10 per cent of the basic screw diameter.

From The American Society of Mechanical Engineers · ANSI B18.6.2 – 1972

AMERICAN STANDARD

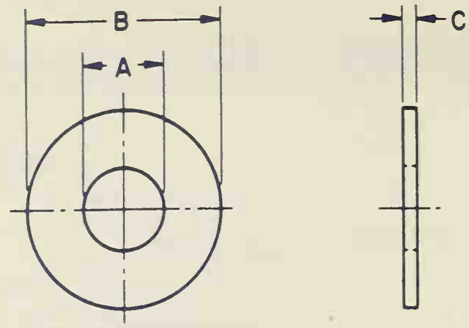


TABLE 30 DIMENSIONS OF PREFERRED SIZES OF TYPE A PLAIN WASHERS **

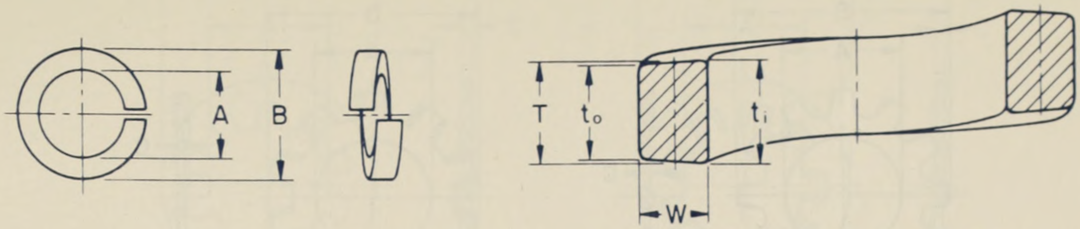
Nominal Washer Size***			Inside Diameter A			Outside Diameter B			Thickness C		
			Basic	Tolerance		Basic	Tolerance		Basic	Max	Min
				Plus	Minus		Plus	Minus			
–	–		0.078	0.000	0.005	0.188	0.000	0.005	0.020	0.025	0.016
–	–		0.094	0.000	0.005	0.250	0.000	0.005	0.020	0.025	0.016
–	–		0.125	0.008	0.005	0.312	0.008	0.005	0.032	0.040	0.025
No. 6	0.138		0.156	0.008	0.005	0.375	0.015	0.005	0.049	0.065	0.036
No. 8	0.164		0.188	0.008	0.005	0.438	0.015	0.005	0.049	0.065	0.036
No. 10	0.190		0.219	0.008	0.005	0.500	0.015	0.005	0.049	0.065	0.036
3/16	0.188		0.250	0.015	0.005	0.562	0.015	0.005	0.049	0.065	0.036
No. 12	0.216		0.250	0.015	0.005	0.562	0.015	0.005	0.065	0.080	0.051
1/4	0.250	N	0.281	0.015	0.005	0.625	0.015	0.005	0.065	0.080	0.051
1/4	0.250	W	0.312	0.015	0.005	0.734*	0.015	0.007	0.065	0.080	0.051
5/16	0.312	N	0.344	0.015	0.005	0.688	0.015	0.007	0.065	0.080	0.051
5/16	0.312	W	0.375	0.015	0.005	0.875	0.030	0.007	0.083	0.104	0.064
3/8	0.375	N	0.406	0.015	0.005	0.812	0.015	0.007	0.065	0.080	0.051
3/8	0.375	W	0.438	0.015	0.005	1.000	0.030	0.007	0.083	0.104	0.064
7/16	0.438	N	0.469	0.015	0.005	0.922	0.015	0.007	0.065	0.080	0.051
7/16	0.438	W	0.500	0.015	0.005	1.250	0.030	0.007	0.083	0.104	0.064
1/2	0.500	N	0.531	0.015	0.005	1.062	0.030	0.007	0.095	0.121	0.074
1/2	0.500	W	0.562	0.015	0.005	1.375	0.030	0.007	0.109	0.132	0.086
9/16	0.562	N	0.594	0.015	0.005	1.156*	0.030	0.007	0.095	0.121	0.074
9/16	0.562	W	0.625	0.015	0.005	1.469*	0.030	0.007	0.109	0.132	0.086
5/8	0.625	N	0.656	0.030	0.007	1.312	0.030	0.007	0.095	0.121	0.074
5/8	0.625	W	0.688	0.030	0.007	1.750	0.030	0.007	0.134	0.160	0.108
3/4	0.750	N	0.812	0.030	0.007	1.469	0.030	0.007	0.134	0.160	0.108
3/4	0.750	W	0.812	0.030	0.007	2.000	0.030	0.007	0.148	0.177	0.122
7/8	0.875	N	0.938	0.030	0.007	1.750	0.030	0.007	0.134	0.160	0.108
7/8	0.875	W	0.938	0.030	0.007	2.250	0.030	0.007	0.165	0.192	0.136
1	1.000	N	1.062	0.030	0.007	2.000	0.030	0.007	0.134	0.160	0.108
1	1.000	W	1.062	0.030	0.007	2.500	0.030	0.007	0.165	0.192	0.136
1 1/8	1.125	N	1.250	0.030	0.007	2.250	0.030	0.007	0.134	0.160	0.108
1 1/8	1.125	W	1.250	0.030	0.007	2.750	0.030	0.007	0.165	0.192	0.136
1 1/4	1.250	N	1.375	0.030	0.007	2.500	0.030	0.007	0.165	0.192	0.136
1 1/4	1.250	W	1.375	0.030	0.007	3.000	0.030	0.007	0.165	0.192	0.136
1 3/8	1.375	N	1.500	0.030	0.007	2.750	0.030	0.007	0.165	0.192	0.136
1 3/8	1.375	W	1.500	0.045	0.010	3.250	0.045	0.010	0.180	0.213	0.153
1 1/2	1.500	N	1.625	0.030	0.007	3.000	0.030	0.007	0.165	0.192	0.136
1 1/2	1.500	W	1.625	0.045	0.010	3.500	0.045	0.010	0.180	0.213	0.153
1 5/8	1.625		1.750	0.045	0.010	3.750	0.045	0.010	0.180	0.213	0.153
1 3/4	1.750		1.875	0.045	0.010	4.000	0.045	0.010	0.180	0.213	0.153
1 7/8	1.875		2.000	0.045	0.010	4.250	0.045	0.010	0.180	0.213	0.153
2	2.000		2.125	0.045	0.010	4.500	0.045	0.010	0.180	0.213	0.153
2 1/4	2.250		2.375	0.045	0.010	4.750	0.045	0.010	0.220	0.248	0.193
2 1/2	2.500		2.625	0.045	0.010	5.000	0.045	0.010	0.238	0.280	0.210
2 3/4	2.750		2.875	0.065	0.010	5.250	0.065	0.010	0.259	0.310	0.228
3	3.000		3.125	0.065	0.010	5.500	0.065	0.010	0.284	0.327	0.249

*The 0.734 in., 1.156 in., and 1.469 in. outside diameters avoid washers which could be used in coin operated devices.

**Preferred sizes are for the most part from series previously designated "Standard Plate" and "SAE." Where common sizes existed in the two series, the SAE size is designated "N" (narrow) and the Standard Plate "W" (wide). These sizes as well as all other sizes of Type A Plain Washers are to be ordered by ID, OD, and thickness dimensions.

***Nominal washer sizes are intended for use with comparable nominal screw or bolt sizes.

From The American Society of Mechanical Engineers - ANSI B18.22.1 - 1965 (R1975)



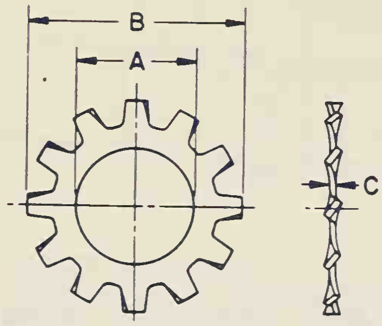
ENLARGED SECTION

TABLE 31 DIMENSIONS OF REGULAR HELICAL SPRING LOCK WASHERS[1]

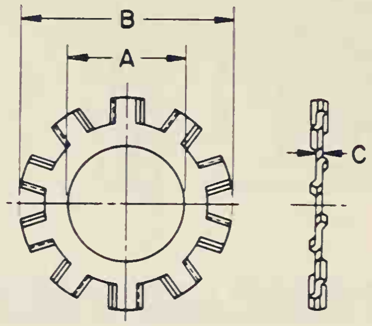
Nominal Washer Size		A Inside Diameter		B Outside Diameter	T Mean Section Thickness $\left(\frac{t_i + t_o}{2}\right)$	W Section Width
		Max	Min	Max[2]	Min	Min
No. 4	0.112	0.120	0.114	0.173	0.022	0.022
No. 5	0.125	0.133	0.127	0.202	0.030	0.030
No. 6	0.138	0.148	0.141	0.216	0.030	0.030
No. 8	0.164	0.174	0.167	0.267	0.047	0.042
No. 10	0.190	0.200	0.193	0.294	0.047	0.042
1/4	0.250	0.262	0.254	0.365	0.078	0.047
5/16	0.312	0.326	0.317	0.460	0.093	0.062
3/8	0.375	0.390	0.380	0.553	0.125	0.076
7/16	0.438	0.455	0.443	0.647	0.140	0.090
1/2	0.500	0.518	0.506	0.737	0.172	0.103
5/8	0.625	0.650	0.635	0.923	0.203	0.125
3/4	0.750	0.775	0.760	1.111	0.218	0.154
7/8	0.875	0.905	0.887	1.296	0.234	0.182
1	1.000	1.042	1.017	1.483	0.250	0.208
1 1/8	1.125	1.172	1.144	1.669	0.313	0.236
1 1/4	1.250	1.302	1.271	1.799	0.313	0.236
1 3/8	1.375	1.432	1.398	2.041	0.375	0.292
1 1/2	1.500	1.561	1.525	2.170	0.375	0.292
1 3/4	1.750	1.811	1.775	2.602	0.469	0.383
2	2.000	2.061	2.025	2.852	0.469	0.383
2 1/4	2.250	2.311	2.275	3.352	0.508	0.508
2 1/2	2.500	2.561	2.525	3.602	0.508	0.508
2 3/4	2.750	2.811	2.775	4.102	0.633	0.633
3	3.000	3.061	3.025	4.352	0.633	0.633

[1] For use with 1960 Series Socket Head Cap Screws specified in American National Standard, ANSI B18.3.
[2] The maximum outside diameters specified allow for the commercial tolerances on cold drawn wire.

From The American Society of Mechanical Engineers—ANSI B18.21.1–1972



TYPE A

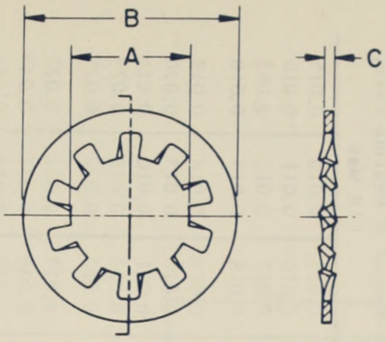


TYPE B

TABLE 32 DIMENSIONS OF EXTERNAL TOOTH LOCK WASHERS

Nominal Washer Size		*A* Inside Diameter		*B* Outside Diameter		*C* Thickness	
		Max	Min	Max	Min	Max	Min
No. 3	0.099	0.109	0.102	0.235	0.220	0.015	0.012
No. 4	0.112	0.123	0.115	0.260	0.245	0.019	0.015
No. 5	0.125	0.136	0.129	0.285	0.270	0.019	0.014
No. 6	0.138	0.150	0.141	0.320	0.305	0.022	0.016
No. 8	0.164	0.176	0.168	0.381	0.365	0.023	0.018
No. 10	0.190	0.204	0.195	0.410	0.395	0.025	0.020
No. 12	0.216	0.231	0.221	0.475	0.460	0.028	0.023
1/4	0.250	0.267	0.256	0.510	0.494	0.028	0.023
5/16	0.312	0.332	0.320	0.610	0.588	0.034	0.028
3/8	0.375	0.398	0.384	0.694	0.670	0.040	0.032
7/16	0.438	0.464	0.448	0.760	0.740	0.040	0.032
1/2	0.500	0.530	0.513	0.900	0.880	0.045	0.037
9/16	0.562	0.596	0.576	0.985	0.960	0.045	0.037
5/8	0.625	0.663	0.641	1.070	1.045	0.050	0.042
11/16	0.688	0.728	0.704	1.155	1.130	0.050	0.042
3/4	0.750	0.795	0.768	1.260	1.220	0.055	0.047
13/16	0.812	0.861	0.833	1.315	1.290	0.055	0.047
7/8	0.875	0.927	0.897	1.410	1.380	0.060	0.052
1	1.000	1.060	1.025	1.620	1.590	0.067	0.059

From The American Society of Mechanical Engineers–ANSI B18.21.1–1972



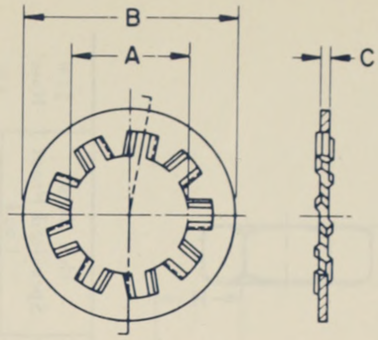


TABLE 33 DIMENSIONS OF INTERNAL TOOTH LOCK WASHERS

Nominal Washer Size		A		B		C	
		Inside Diameter		Outside Diameter		Thickness	
		Max	Min	Max	Min	Max	Min
No. 2	0.086	0.095	0.089	0.200	0.175	0.015	0.010
No. 3	0.099	0.109	0.102	0.232	0.215	0.019	0.012
No. 4	0.112	0.123	0.115	0.270	0.255	0.019	0.015
No. 5	0.125	0.136	0.129	0.280	0.245	0.021	0.017
No. 6	0.138	0.150	0.141	0.295	0.275	0.021	0.017
No. 8	0.164	0.176	0.168	0.340	0.325	0.023	0.018
No. 10	0.190	0.204	0.195	0.381	0.365	0.025	0.020
No. 12	0.216	0.231	0.221	0.410	0.394	0.025	0.020
1/4	0.250	0.267	0.256	0.478	0.460	0.028	0.023
5/16	0.312	0.332	0.320	0.610	0.594	0.034	0.028
3/8	0.375	0.398	0.384	0.692	0.670	0.040	0.032
7/16	0.438	0.464	0.448	0.789	0.740	0.040	0.032
1/2	0.500	0.530	0.512	0.900	0.867	0.045	0.037
9/16	0.562	0.596	0.576	0.985	0.957	0.045	0.037
5/8	0.625	0.663	0.640	1.071	1.045	0.050	0.042
11/16	0.688	0.728	0.704	1.166	1.130	0.050	0.042
3/4	0.750	0.795	0.769	1.245	1.220	0.055	0.047
13/16	0.812	0.861	0.832	1.315	1.290	0.055	0.047
7/8	0.875	0.927	0.894	1.410	1.364	0.060	0.052
1	1.000	1.060	1.019	1.637	1.590	0.067	0.059
1 1/8	1.125	1.192	1.144	1.830	1.799	0.067	0.059
1 1/4	1.250	1.325	1.275	1.975	1.921	0.067	0.059

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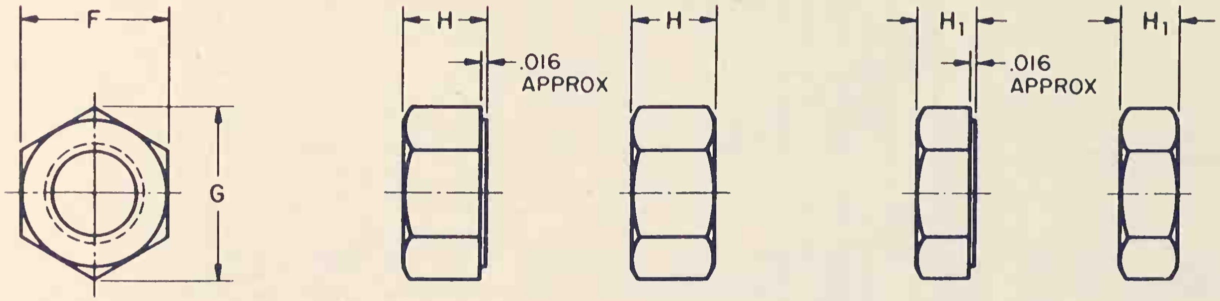


TABLE 34 DIMENSIONS OF HEX NUTS AND HEX JAM NUTS

Nominal Size or Basic Major Dia of Thread		F: Width Across Flats			G: Width Across Corners		H: Thickness Hex Nuts			H_1: Thickness Hex Jam Nuts			Hex Nuts Specified Proof Load: Up to 150,000 psi	Hex Nuts Specified Proof Load: 150,000 psi and Greater	Jam Nuts: All Strength Levels
		Basic	Max	Min	Max	Min	Basic	Max	Min	Basic	Max	Min	Runout of Bearing Face, FIR Max		
1/4	0.2500	7/16	0.438	0.428	0.505	0.488	7/32	0.226	0.212	5/32	0.163	0.150	0.015	0.010	0.015
5/16	0.3125	1/2	0.500	0.489	0.577	0.557	17/64	0.273	0.258	3/16	0.195	0.180	0.016	0.011	0.016
3/8	0.3750	9/16	0.562	0.551	0.650	0.628	21/64	0.337	0.320	7/32	0.227	0.210	0.017	0.012	0.017
7/16	0.4375	11/16	0.688	0.675	0.794	0.768	3/8	0.385	0.365	1/4	0.260	0.240	0.018	0.013	0.018
1/2	0.5000	3/4	0.750	0.736	0.866	0.840	7/16	0.448	0.427	5/16	0.323	0.302	0.019	0.014	0.019
9/16	0.5625	7/8	0.875	0.861	1.010	0.982	31/64	0.496	0.473	5/16	0.324	0.301	0.020	0.015	0.020
5/8	0.6250	15/16	0.938	0.922	1.083	1.051	35/64	0.559	0.535	3/8	0.387	0.363	0.021	0.016	0.021
3/4	0.7500	1 1/8	1.125	1.088	1.299	1.240	41/64	0.665	0.617	27/64	0.446	0.398	0.023	0.018	0.023
7/8	0.8750	1 5/16	1.312	1.269	1.516	1.447	3/4	0.776	0.724	31/64	0.510	0.458	0.025	0.020	0.025
1	1.0000	1 1/2	1.500	1.450	1.732	1.653	55/64	0.887	0.831	35/64	0.575	0.519	0.027	0.022	0.027
1 1/8	1.1250	1 11/16	1.688	1.631	1.949	1.859	31/32	0.999	0.939	39/64	0.639	0.579	0.030	0.025	0.030
1 1/4	1.2500	1 7/8	1.875	1.812	2.165	2.066	1 1/16	1.094	1.030	23/32	0.751	0.687	0.033	0.028	0.033
1 3/8	1.3750	2 1/16	2.062	1.994	2.382	2.273	1 11/64	1.206	1.138	25/32	0.815	0.747	0.036	0.031	0.036
1 1/2	1.5000	2 1/4	2.250	2.175	2.598	2.480	1 9/32	1.317	1.245	27/32	0.880	0.808	0.039	0.034	0.039
See Notes	9	3			4								2		

From The American Society of Mechanical Engineers–ANSI B18.2.2–1972

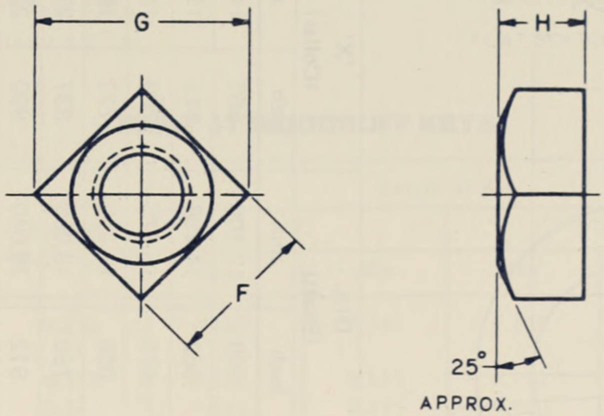
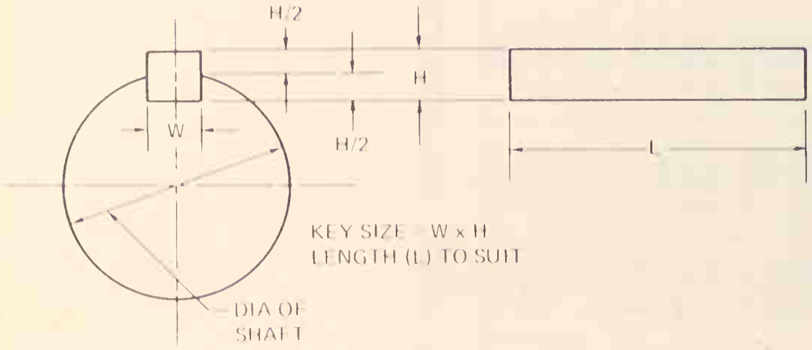


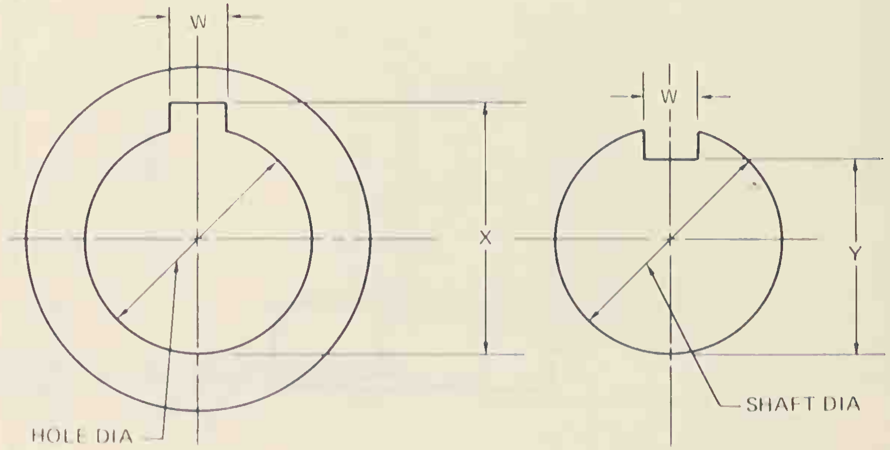
TABLE 35 DIMENSIONS OF SQUARE NUTS

Nominal Size or Basic Major Dia of Thread		F Width Across Flats			G Width Across Corners		H Thickness		
		Basic	Max	Min	Max	Min	Basic	Max	Min
1/4	0.2500	7/16	0.438	0.425	0.619	0.584	7/32	0.235	0.203
5/16	0.3125	9/16	0.562	0.547	0.795	0.751	17/64	0.283	0.249
3/8	0.3750	5/8	0.625	0.606	0.884	0.832	21/64	0.346	0.310
7/16	0.4375	3/4	0.750	0.728	1.061	1.000	3/8	0.394	0.356
1/2	0.5000	13/16	0.812	0.788	1.149	1.082	7/16	0.458	0.418
5/8	0.6250	1	1.000	0.969	1.414	1.330	35/64	0.569	0.525
3/4	0.7500	1 1/8	1.125	1.088	1.591	1.494	21/32	0.680	0.632
7/8	0.8750	1 5/16	1.312	1.269	1.856	1.742	49/64	0.792	0.740
1	1.0000	1 1/2	1.500	1.450	2.121	1.991	7/8	0.903	0.847
1 1/8	1.1250	1 11/16	1.688	1.631	2.386	2.239	1	1.030	0.970
1 1/4	1.2500	1 7/8	1.875	1.812	2.652	2.489	1 3/32	1.126	1.062
1 3/8	1.3750	2 1/16	2.062	1.994	2.917	2.738	1 13/64	1.237	1.169
1 1/2	1.5000	2 1/4	2.250	2.175	3.182	2.986	1 5/16	1.348	1.276
See Notes	8	3							

From The American Society of Mechanical Engineers—ANSI B18.2.2–1972

TABLE 36 KEY & KEYWAY SIZES



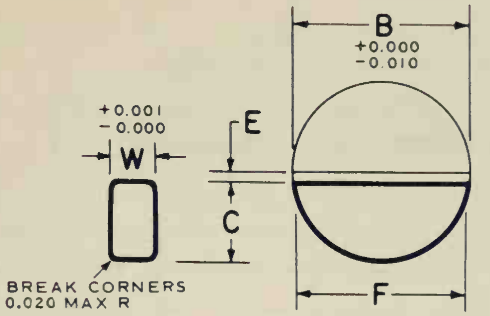


Shaft Nom. Size – DIA. – From	Shaft Nom. Size – DIA. – To & Incl.	Square (W = H)	Type	Square Key From	Square Key To & Incl.	Tolerance
5/16 (8)	7/16 (11)	3/32 (2.38)	Bar Stock	– –	3/4 (19.05)	+.000 - .002 (+.0000 - .0254)
7/16 (11)	9/16 (14)	1/8 (3.175)	Bar Stock	3/4 (19.05)	1 1/2 (38.1)	+.000 - .003 (+.0000 - .0762)
9/16 (14)	7/8 (22)	3/16 (4.76)	Bar Stock	1 1/2 (38.1)	2 1/2 (63.5)	+.000 - .004 (+.0000 - .1016)
7/8 (22)	1 1/4 (32)	1/4 (6.35)	Bar Stock	2 1/2 (63.5)	3 1/2 (88.9)	+.000 - .006 (+.0000 - .1524)
1 1/4 (32)	1 3/8 (35)	5/16 (7.94)	Keystock	– –	1 1/4 (31.75)	+.001 - .000 (+.0254 - .0000)
1 3/8 (35)	1 3/4 (44)	3/8 (9.53)	Keystock	1 1/4 (31.75)	3 (76.2)	+.002 - .000 (+.0508 - .0000)
1 3/4 (44)	2 1/4 (57)	1/2 (12.7)	Keystock	3 (76.2)	3 1/2 (88.9)	+.003 - .000 (+.0762 - .0000)
2 1/4 (57)	2 3/4 (70)	5/8 (15.88)				
2 3/4 (70)	3 1/4 (82)	3/4 (19.05)				
3 1/4 (82)	3 3/4 (95)	7/8 (22.23)				

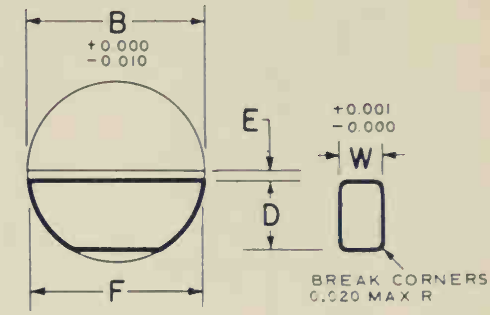
(Figures in parenthesis = mm)

Nom. Size (Inch)	– DIA. – (Shaft) Inch	– DIA. – (Shaft) mm	'X' (Collar) Inch	'X' (Collar) mm	'Y' (Shaft) Inch	'Y' (Shaft) mm
1/2	.500	12.700	.560	14.224	.430	10.922
9/16	.562	14.290	.623	15.824	.493	12.522
5/8	.625	15.875	.709	18.008	.517	13.132
11/16	.688	17.470	.773	18.618	.581	14.757
3/4	.750	19.050	.837	21.259	.644	16.357
13/16	.812	20.640	.900	22.860	.708	17.983
7/8	.875	22.225	.964	24.485	.771	19.583
15/16	.938	23.820	1.051	26.695	.791	20.091
1	1.000	25.400	1.114	28.295	.859	21.818
1 1/16	1.062	26.985	1.178	29.921	.923	23.444
1 1/8	1.125	28.575	1.241	31.521	.986	25.044
1 3/16	1.188	30.165	1.304	33.121	1.049	26.644
1 1/4	1.250	31.750	1.367	34.722	1.112	28.244
1 5/16	1.312	33.340	1.455	36.957	1.137	28.879
1 3/8	1.375	34.923	1.518	38.557	1.201	30.505

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson. Delmar Publishers Inc.



FULL RADIUS TYPE



FLAT BOTTOM TYPE

TABLE 37 WOODRUFF KEYS

Key No.	Nominal Key Size W × B	Actual Length F +0.000-0.010	Height of Key				Distance Below Center E
			C		D		
			Max	Min	Max	Min	
202	1/16 × 1/4	0.248	0.109	0.104	0.109	0.104	1/64
202.5	1/16 × 5/16	0.311	0.140	0.135	0.140	0.135	1/64
302.5	3/32 × 5/16	0.311	0.140	0.135	0.140	0.135	1/64
203	1/16 × 3/8	0.374	0.172	0.167	0.172	0.167	1/64
303	3/32 × 3/8	0.374	0.172	0.167	0.172	0.167	1/64
403	1/8 × 3/8	0.374	0.172	0.167	0.172	0.167	1/64
204	1/16 × 1/2	0.491	0.203	0.198	0.194	0.188	3/64
304	3/32 × 1/2	0.491	0.203	0.198	0.194	0.188	3/64
404	1/8 × 1/2	0.491	0.203	0.198	0.194	0.188	3/64
305	3/32 × 5/8	0.612	0.250	0.245	0.240	0.234	1/16
405	1/8 × 5/8	0.612	0.250	0.245	0.240	0.234	1/16
505	5/32 × 5/8	0.612	0.250	0.245	0.240	0.234	1/16
605	3/16 × 5/8	0.612	0.250	0.245	0.240	0.234	1/16
406	1/8 × 3/4	0.740	0.313	0.308	0.303	0.297	1/16
506	5/32 × 3/4	0.740	0.313	0.308	0.303	0.297	1/16
606	3/16 × 3/4	0.740	0.313	0.308	0.303	0.297	1/16
806	1/4 × 3/4	0.740	0.313	0.308	0.303	0.297	1/16
507	5/32 × 7/8	0.866	0.375	0.370	0.365	0.359	1/16
607	3/16 × 7/8	0.866	0.375	0.370	0.365	0.359	1/16
707	7/32 × 7/8	0.866	0.375	0.370	0.365	0.359	1/16
807	1/4 × 7/8	0.866	0.375	0.370	0.365	0.359	1/16
608	3/16 × 1	0.992	0.438	0.433	0.428	0.422	1/16
708	7/32 × 1	0.992	0.438	0.433	0.428	0.422	1/16
808	1/4 × 1	0.992	0.438	0.433	0.428	0.422	1/16
1008	5/16 × 1	0.992	0.438	0.433	0.428	0.422	1/16
1208	3/8 × 1	0.992	0.438	0.433	0.428	0.422	1/16
609	3/16 × 1 1/8	1.114	0.484	0.479	0.475	0.469	5/64
709	7/32 × 1 1/8	1.114	0.484	0.479	0.475	0.469	5/64
809	1/4 × 1 1/8	1.114	0.484	0.479	0.475	0.469	5/64
1009	5/16 × 1 1/8	1.114	0.484	0.479	0.475	0.469	5/64

TABLE 37 WOODRUFF KEYS (Concluded)

Key No.	Nominal Key Size W × B	Actual Length F +0.000-0.010	Height of Key				Distance Below Center E
			C		D		
			Max	Min	Max	Min	
610	3/16 × 1 1/4	1.240	0.547	0.542	0.537	0.531	5/64
710	7/32 × 1 1/4	1.240	0.547	0.542	0.537	0.531	5/64
810	1/4 × 1 1/4	1.240	0.547	0.542	0.537	0.531	5/64
1010	5/16 × 1 1/4	1.240	0.547	0.542	0.537	0.531	5/64
1210	3/8 × 1 1/4	1.240	0.547	0.542	0.537	0.531	5/64
811	1/4 × 1 3/8	1.362	0.594	0.589	0.584	0.578	3/32
1011	5/16 × 1 3/8	1.362	0.594	0.589	0.584	0.578	3/32
1211	3/8 × 1 3/8	1.362	0.594	0.589	0.584	0.578	3/32
812	1/4 × 1 1/2	1.484	0.641	0.636	0.631	0.625	7/64
1012	5/16 × 1 1/2	1.484	0.641	0.636	0.631	0.625	7/64
1212	3/8 × 1 1/2	1.484	0.641	0.636	0.631	0.625	7/64

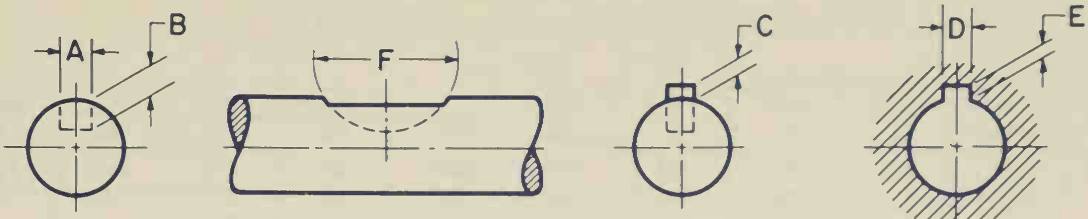
All dimensions given are in inches.

The key numbers indicate nominal key dimensions. The last two digits give the nominal diameter B in eighths of an inch and the digits preceding the last two give the nominal width W in thirty-seconds of an inch.

Example:

No. 204 indicates a key 2/32 × 4/8 or 1/16 × 1/2.
No. 808 indicates a key 8/32 × 8/8 or 1/4 × 1.
No. 1212 indicates a key 12/32 × 12/8 or 3/8 × 1 1/2.

From The American Society of Mechanical Engineers—ANSI B17.2—1967



Key Number	Nominal Size Key	Keyseat – Shaft					Key Above Shaft	Keyseat – Hub	
		Width A*		Depth B	Diameter F		Height C	Width D	Depth E
		Min	Max	+0.005 -0.000	Min	Max	+0.005 -0.005	+0.002 -0.000	+0.005 -0.000
202	1/16 × 1/4	0.0615	0.0630	0.0728	0.250	0.268	0.0312	0.0635	0.0372
202.5	1/16 × 5/16	0.0615	0.0630	0.1038	0.312	0.330	0.0312	0.0635	0.0372
302.5	3/32 × 5/16	0.0928	0.0943	0.0882	0.312	0.330	0.0469	0.0948	0.0529
203	1/16 × 3/8	0.0615	0.0630	0.1358	0.375	0.393	0.0312	0.0635	0.0372
303	3/32 × 3/8	0.0928	0.0943	0.1202	0.375	0.393	0.0469	0.0948	0.0529
403	1/8 × 3/8	0.1240	0.1255	0.1045	0.375	0.393	0.0625	0.1260	0.0685
204	1/16 × 1/2	0.0615	0.0630	0.1668	0.500	0.518	0.0312	0.0635	0.0372
304	3/32 × 1/2	0.0928	0.0943	0.1511	0.500	0.518	0.0469	0.0948	0.0529
404	1/8 × 1/2	0.1240	0.1255	0.1355	0.500	0.518	0.0625	0.1260	0.0685
305	3/32 × 5/8	0.0928	0.0943	0.1981	0.625	0.643	0.0469	0.0948	0.0529
405	1/8 × 5/8	0.1240	0.1255	0.1825	0.625	0.643	0.0625	0.1260	0.0685
505	5/32 × 5/8	0.1553	0.1568	0.1669	0.625	0.643	0.0781	0.1573	0.0841
605	3/16 × 5/8	0.1863	0.1880	0.1513	0.625	0.643	0.0937	0.1885	0.0997
406	1/8 × 3/4	0.1240	0.1255	0.2455	0.750	0.768	0.0625	0.1260	0.0685
506	5/32 × 3/4	0.1553	0.1568	0.2299	0.750	0.768	0.0781	0.1573	0.0841
606	3/16 × 3/4	0.1863	0.1880	0.2143	0.750	0.768	0.0937	0.1885	0.0997
806	1/4 × 3/4	0.2487	0.2505	0.1830	0.750	0.768	0.1250	0.2510	0.1310
507	5/32 × 7/8	0.1553	0.1568	0.2919	0.875	0.895	0.0781	0.1573	0.0841
607	3/16 × 7/8	0.1863	0.1880	0.2763	0.875	0.895	0.0937	0.1885	0.0997
707	7/32 × 7/8	0.2175	0.2193	0.2607	0.875	0.895	0.1093	0.2198	0.1153
807	1/4 × 7/8	0.2487	0.2505	0.2450	0.875	0.895	0.1250	0.2510	0.1310
608	3/16 × 1	0.1863	0.1880	0.3393	1.000	1.020	0.0937	0.1885	0.0997
708	7/32 × 1	0.2175	0.2193	0.3237	1.000	1.020	0.1093	0.2198	0.1153
808	1/4 × 1	0.2487	0.2505	0.3080	1.000	1.020	0.1250	0.2510	0.1310
1008	5/16 × 1	0.3111	0.3130	0.2768	1.000	1.020	0.1562	0.3135	0.1622
1208	3/8 × 1	0.3735	0.3755	0.2455	1.000	1.020	0.1875	0.3760	0.1935
609	3/16 × 1 1/8	0.1863	0.1880	0.3853	1.125	1.145	0.0937	0.1885	0.0997
709	7/32 × 1 1/8	0.2175	0.2193	0.3697	1.125	1.145	0.1093	0.2198	0.1153
809	1/4 × 1 1/8	0.2487	0.2505	0.3540	1.125	1.145	0.1250	0.2510	0.1310
1009	5/16 × 1 1/8	0.3111	0.3130	0.3228	1.125	1.145	0.1562	0.3135	0.1622

From The American Society of Mechanical Engineers–ANSI B17.2–1967

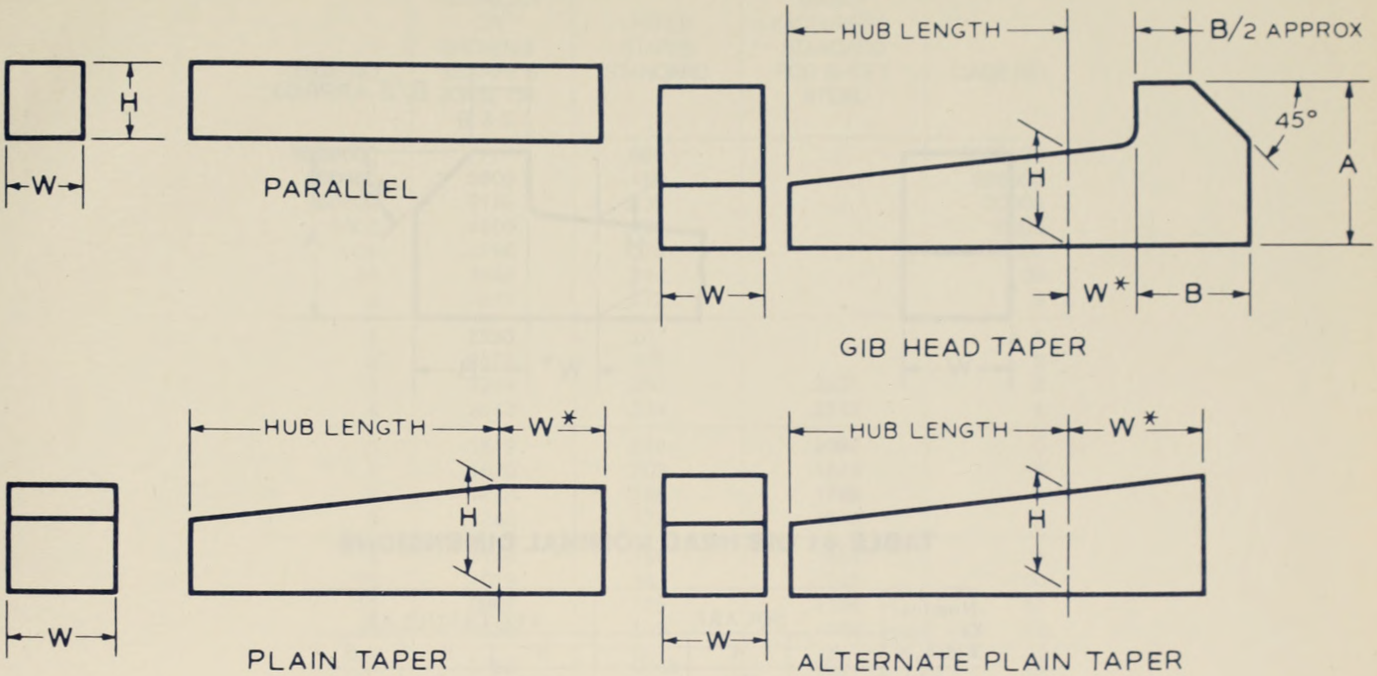
Table 38

WOODRUFF KEY SIZES FOR DIFFERENT SHAFT DIAMETERS

Shaft Diameter	5/16 to 3/8	7/16 to 1/2	9/16 to 3/4	13/16 to 15/16	1 to 1 3/16	1 1/4 to 1 7/16	1 1/2 to 1 3/4	1 13/16 to 2 1/8	2 3/16 to 2 1/2
Key Numbers	204	304 305	404 405 406	505 506 507	606 607 608 609	807 808 809	810 811 812	1011 1012	1211 1212

Table 39

4. KEY DIMENSIONS AND TOLERANCES



Plain and Gib Head Taper Keys Have a 1/8" Taper in 12"

KEY			NOMINAL KEY SIZE Width, *W*		TOLERANCE	
			Over	To (Incl)	Width, *W*	Height, *H*
Parallel	Square	Bar Stock	–	3/4	+0.000 –0.002	+0.000 –0.002
			3/4	1-1/2	+0.000 –0.003	+0.000 –0.003
			1-1/2	2-1/2	+0.000 –0.004	+0.000 –0.004
			2-1/2	3-1/2	+0.000 –0.006	+0.000 –0.006
		Keystock	–	1-1/4	+0.001 –0.000	+0.001 –0.000
			1-1/4	3	+0.002 –0.000	+0.002 –0.000
			3	3-1/2	+0.003 –0.000	+0.003 –0.000
	Rectangular	Bar Stock	–	3/4	+0.000 –0.003	+0.000 –0.003
			3/4	1-1/2	+0.000 –0.004	+0.000 –0.004
			1-1/2	3	+0.000 –0.005	+0.000 –0.005
			3	4	+0.000 –0.006	+0.000 –0.006
			4	6	+0.000 –0.008	+0.000 –0.008
			6	7	+0.000 –0.013	+0.000 –0.013
		Keystock	–	1-1/4	+0.001 –0.000	+0.005 –0.005
			1-1/4	3	+0.002 –0.000	+0.005 –0.005
			3	7	+0.003 –0.000	+0.005 –0.005
Taper	Plain or Gib Head Square or Rectangular		–	1-1/4	+0.001 –0.000	+0.005 –0.000
			1-1/4	3	+0.002 –0.000	+0.005 –0.000
			3	7	+0.003 –0.000	+0.005 –0.000

From The American Society of Mechanical Engineers—ANSI B17.1—1967

*For locating position of dimension H. Tolerance does not apply.
See Table 41 for dimensions on gib heads.
All dimensions given in inches.

TABLE 40 KEY DIMENSIONS AND TOLERANCES

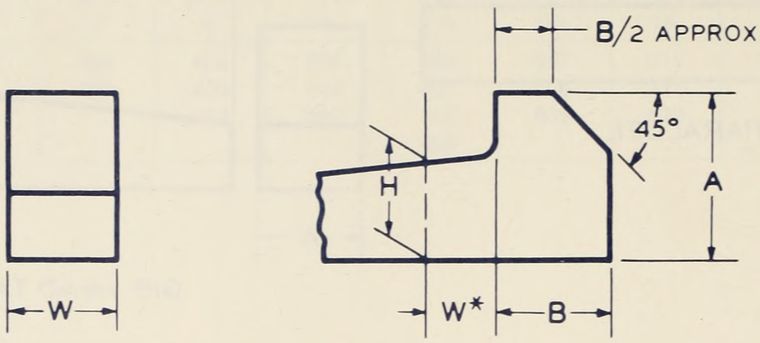


TABLE 41 GIB HEAD NOMINAL DIMENSIONS

Nominal Key Size Width, *W*	SQUARE			RECTANGULAR		
	H	*A*	*B*	*H*	*A*	*B*
1/8	1/8	1/4	1/4	3/32	3/16	1/8
3/16	3/16	5/16	5/16	1/8	1/4	1/4
1/4	1/4	7/16	3/8	3/16	5/16	5/16
5/16	5/16	1/2	7/16	1/4	7/16	3/8
3/8	3/8	5/8	1/2	1/4	7/16	3/8
1/2	1/2	7/8	5/8	3/8	5/8	1/2
5/8	5/8	1	3/4	7/16	3/4	9/16
3/4	3/4	1-1/4	7/8	1/2	7/8	5/8
7/8	7/8	1-3/8	1	5/8	1	3/4
1	1	1-5/8	1-1/8	3/4	1-1/4	7/8
1-1/4	1-1/4	2	1-7/16	7/8	1-3/8	1
1-1/2	1-1/2	2-3/8	1-3/4	1	1-5/8	1-1/8
1-3/4	1-3/4	2-3/4	2	1-1/2	2-3/8	1-3/4
2	2	3-1/2	2-1/4	1-1/2	2-3/8	1-3/4
2-1/2	2-1/2	4	3	1-3/4	2-3/4	2
3	3	5	3-1/2	2	3-1/2	2-1/4
3-1/2	3-1/2	6	4	2-1/2	4	3

*For locating position of dimension *H*.

For larger sizes the following relationships are suggested as guides for establishing *A* and *B*.

$A = 1.8H \qquad B = 1.2H$

All dimensions given in inches.

From The American Society of Mechanical Engineers–ANSI B17.1–1967

SHEET METAL AND WIRE GAGE DESIGNATION

GAGE NO.	AMERICAN OR BROWN & SHARPE'S A.W.G. OR B. & S.	UNITED STATES STANDARD	MANU-FACTURERS' STANDARD FOR SHEET STEEL	GAGE NO.
0000000	....	.500	....	0000000
000000	.5800	.469	....	000000
00000	.5165	.438	....	00000
0000	.4600	.406	....	0000
000	.4096	.375	....	000
00	.3648	.344	....	00
0	.3249	.312	....	0
1	.2893	.281	....	1
2	.2576	.266	....	2
3	.2294	.250	.2391	3
4	.2043	.234	.2242	4
5	.1819	.219	.2092	5
6	.1620	.203	.1943	6
7	.1443	.188	.1793	7
8	.1285	.172	.1644	8
9	.1144	.156	.1495	9
10	.1019	.141	.1345	10
11	.0907	.125	.1196	11
12	.0808	.109	.1046	12
13	.0720	.0938	.0897	13
14	.0642	.0781	.0747	14
15	.0571	.0703	.0673	15
16	.0508	.0625	.0598	16
17	.0453	.0562	.0538	17
18	.0403	.0500	.0478	18
19	.0359	.0438	.0418	19
20	.0320	.0375	.0359	20
21	.0285	.0344	.0329	21
22	.0253	.0312	.0299	22
23	.0226	.0281	.0269	23
24	.0201	.0250	.0239	24
25	.0179	.0219	.0209	25
26	.0159	.0188	.0179	26
27	.0142	.0172	.0164	27
28	.0126	.0156	.0149	28
29	.0113	.0141	.0135	29
30	.0100	.0125	.0120	30
31	.0089	.0109	.0105	31
32	.0080	.0102	.0097	32
33	.0071	.00938	.0090	33
34	.0063	.00859	.0082	34
35	.0056	.00781	.0075	35
36	.0050	.00703	.0067	36

Table 42

BEND ALLOWANCE FOR 90° BENDS (INCH)																
Radii / Thickness	.031	.063	.094	.125	.156	.188	.219	.250	.281	.313	.344	.375	.438	.500	.531	.625
.013	.058	.108	.157	.205	.254	.304	.353	.402	.450	.501	.549	.598	.697	.794	.843	.991
.016	.060	.110	.159	.208	.256	.307	.355	.404	.453	.503	.552	.600	.699	.796	.845	.993
.020	.062	.113	.161	.210	.259	.309	.358	.406	.455	.505	.554	.603	.702	.799	.848	.995
.022	.064	.114	.163	.212	.260	.311	.359	.408	.457	.507	.556	.604	.703	.801	.849	.997
.025	.066	.116	.165	.214	.263	.313	.362	410	.459	.509	.558	.607	.705	.803	.851	999
.028	.068	.119	.167	.216	.265	.315	.364	.412	.461	.511	.560	.609	.708	.805	.854	1.001
.032	.071	.121	.170	.218	.267	.317	.366	.415	.463	.514	562	.611	.710	.807	.856	1.004
.038	.075	.126	.174	.223	.272	.322	.371	.419	.468	.518	.567	.616	.715	.812	.861	1 008
.040	.077	.127	.176	.224	.273	.323	.372	.421	.469	.520	.568	.617	.716	.813	.862	1.010
.050		.134	.183	.232	.280	.331	.379	428	477	.527	.576	.624	.723	.821	.869	1.017
.064		.144	.192	.241	.290	.340	.389	.437	.486	.536	.585	.634	.732	.830	.878	1.026
.072			.198	.247	.296	.346	.394	.443	.492	.542	.591	.639	.738	.836	.885	1.032
.078			.202	.251	.300	.350	.399	.447	.496	.546	.595	.644	.743	840	.889	1 036
.081			.204	.253	.302	.352	.401	449	.498	.548	.598	.646	745	.842	.891	1.038
.091			.212	.260	.309	.359	.408	456	.505	.555	604	.653	.752	849	.898	1.045
.094			.214	262	.311	.361	.410	459	.507	.558	606	.655	754	851	.900	1.048
.102				.268	.317	.367	.416	464	.513	.563	.612	661	.760	857	.906	1.053
.109				.273	.321	.372	.420	469	.518	.568	617	.665	.764	862	910	1.058
.125				.284	.333	.383	432	.480	.529	.579	.628	.677	.776	.873	.922	1.069
.156					.355	.405	.453	.502	.551	.601	650	698	.797	.895	.943	1.091
.188						.427	.476	.525	.573	.624	.672	.721	.820	.917	.966	1.114
.203								.535	.584	634	.683	.731	830	.928	.976	1.124
.218								.546	.594	645	693	.742	841	.938	.987	1.135
.234								.557	.606	.656	705	753	852	950	998	1 146
.250								568	.617	.667	.716	.764	.863	.961	1.009	1 157

EXAMPLE: MATERIAL THICKNESS = 1/8", INSIDE RADII = 1/4" R WHERE THESE CROSS = .284" BEND ALLOWANCE (B.A.) PLUS TOTAL OF STRAIGHT LENGTHS = DEVELOPED LENGTH

BEND ALLOWANCE FOR 90° BENDS (MILLIMETRE)																
Radii / Thickness	0.80	1.58	2.38	3.18	3.96	4.76	5.56	6.35	7.15	7.94	8.74	9.52	11.12	12.70	13.50	15.85
.330	1.46	2.74	3.98	5.22	6.45	7.73	8.96	10.20	11.44	12.71	13.95	15.19	17.70	20.18	21.42	25.16
.406	1.52	2.80	4.04	5.27	6.51	7.78	9.02	10.26	11.50	12.77	14.01	15.24	17.76	20.23	21.47	25.22
.508	1.59	2.87	4.11	5.34	6.58	7.86	9.09	10.33	11.57	12.84	14.08	15.32	17.83	20.30	21.54	25.29
.559	1.63	2.91	4.14	5.38	6.62	7.89	9.13	10.37	11.60	12.88	14.12	15.35	17.86	20.34	21.57	25.32
.635	1.68	2.96	4.20	5.43	6.67	7.95	9.18	10.42	11.66	12.93	14.17	15.40	17.92	20.39	21.63	25.38
.711	1.74	3.02	4.25	5.49	6.72	8.00	9.24	10.47	11.71	12.99	14.22	15.46	17.98	20.44	21.68	25.43
.813	1.81	3.08	4.32	5.56	6.79	8.07	9.30	10.54	11.78	13.05	14.29	15.53	18.04	20.52	21.75	25.50
.965	1.91	3.19	4.42	5.66	6.90	8.18	9.41	10.65	11.89	13.16	14.40	15.64	18.15	20.62	21.86	25.61
1.016	1.95	2.23	4.46	5.70	6.94	8.21	9.45	10.69	11.92	13.20	14.44	15.67	18.19	20.66	21.90	25.64
1.270		3.40	4.64	5.88	7.11	8.39	9.63	10.86	12.10	13.38	14.61	15.85	18.36	20.84	22.07	25.82
1.625		3.65	4.89	6.13	7.36	8.64	9.88	11.11	12.35	13.63	14.86	16.10	18.61	21.08	22.32	26.07
1.829			5.03	6.27	7.51	8.78	10.02	11.26	12.49	13.77	15.01	16.24	18.76	21.23	22.47	26.22
1.981			5.14	6.38	7.61	8.89	10.13	11.36	12.60	13.88	15.11	16.35	18.86	21.34	22.57	26.32
2.058			5.19	6.43	7.67	8.94	10.18	11.42	12.65	13.93	15.17	16.40	18.92	21.39	22.63	26.38
2.311			5.37	6.60	7.85	9.12	10.36	11.60	12.83	14.11	15.35	16.58	19.09	21.57	22.80	26.55
2.388			5.43	6.66	7.90	9.18	10.41	11.65	12.89	14.16	15.40	16.64	19.15	21.62	22.86	26.61
2.591				6.81	8.04	9.31	10.55	11.79	13.03	14.30	15.54	16.78	19.29	21.76	23.00	26.75
2.769				6.93	8.17	9.44	10.68	11.92	13.15	14.43	15.67	16.90	19.42	21.89	23.13	26.88
3.175				7.22	8.45	9.73	10.96	12.20	13.44	14.71	15.95	17.19	19.70	22.17	23.41	27.16
3.962					9.00	10.28	11.52	12.75	13.99	15.27	16.74	17.74	20.25	22.72	23.96	27.71
4.775					9.58	10.85	12.09	13.32	14.56	15.84	17.07	18.31	20.82	23.30	24 53	28.28
5.156						11.12	12.36	13.59	14.83	16.11	17.34	18.58	21.09	23.57	24.80	28.55
5.537								13.85	15.10	16.37	17.61	18.85	21.36	23.83	25.07	28.82
5.944								14.15	15.38	16.66	17.89	19.13	21.64	24.12	25.35	29.10
6.350								14.43	15.67	16.94	18.18	19.42	21.93	24.40	25.64	29.39

EXAMPLE: MATERIAL THICKNESS = 3.18 MM, INSIDE RADII = 6.35 MM R. WHERE THESE CROSS = 12.20 MM BEND ALLOWANCE (B/A) PLUS TOTAL OF STRAIGHT LENGTHS = DEVELOPED LENGTH.

From Drafting for Trades and Industry—Basic Skills. Nelson. Delmar Publishers Inc.

Table 43

BEND ALLOWANCE FOR EACH 1° OF BEND (INCH)																
Radii / Thickness	.031	.063	.094	.125	.156	.188	.219	.250	.281	.313	.344	.375	.438	.500	.531	.625
.013	.00064	.00120	.00174	.00228	.00282	.00338	.00392	.00446	00500	.00556	00610	00664	00774	00883	00937	01101
.016	00067	.00122	00176	.00231	.00285	.00342	00395	00449	00503	00559	00613	00667	00777	00885	00939	01103
.020	.00069	00125	.00179	00233	00287	00343	00397	00452	00506	00561	00616	00670	00780	00888	00942	01106
.022	.00071	.00127	.00181	00235	00289	00345	00399	.00453	.00508	00563	00617	00672	00782	00890	00944	01108
.025	.00074	.00129	.00184	.00238	.00292	.00348	.00402	.00456	.00510	.00566	.00610	00674	00784	00892	00946	01110
.028	.00076	.00132	.00186	.00240	.00294	.00350	.00404	.00458	.00512	.00568	.00622	00676	.00786	00894	00948	01112
.032	.00079	.00134	.00189	.00243	.00297	.00353	.00407	.00461	.00515	.00571	.00625	00679	00789	00897	00951	01115
.038	.00084	.00140	.00194	.00248	.00302	.00358	.00412	.00466	.00520	.00576	.00630	00684	00794	00902	0094[illegible]	01120
.040	.00085	.00141	.00195	.00249	.00303	.00359	.00413	.00468	.00522	00577	.00632	00686	00796	00904	00958	01122
.050		.00149	.00203	.00258	.00312	.00368	.00422	.00476	.00530	.00586	.00640	00694	.00804	00912	00966	01130
.064		.00160	.00214	.00268	.00322	.00378	.00432	.00486	.00540	.00596	00650	00704	00814	00922	00976	01140
072			.00220	.00274	.00328	.00384	.00438	.00492	.00546	.00602	00656	00710	00820	00929	00983	01147
.078			.00225	.00279	.00333	.00389	.00443	.00497	.00551	.00607	.00661	.00715	00825	00933	00987	01152
.081			.00227	.00281	.00335	.00391	.00445	.00499	.00554	.00609	.00664	00718	00828	00936	00990	01154
.091			.00235	.00289	.00343	.00399	.00453	.00507	.00561	00617	00671	00725	00835	00944	00998	01162
.094			.00237	.00291	.00346	.00401	.00456	.00510	00564	.00620	00674	00728	00838	00946	00999	01164
.102				.00298	.00352	.00408	.00462	.00516	.00570	00626	00680	00734	00844	00952	01006	01170
.109				00303	.00357	.00413	.00467	.00521	.00575	.00631	.00685	00739	00849	00958	01012	01176
.125				.00316	.00370	.00426	.00480	.00534	00588	.00644	.00698	00752	00862	00970	01024	01188
156					.00394	.00450	.00504	.00558	.00612	.00668	00722	00776	00886	00994	01048	01212
.188						.00475	.00529	.00583	.00637	00693	.00747	00802	00911	01019	01073	01237
.203								.00595	.00649	.00704	.00759	00813	.00923	01031	01085	01249
.218								.00606	.00660	.00716	00770	00824	00934	.01042	01097	01261
.234								.00619	00673	.00729	.00783	00837	00947	01055	01109	01273
.250								.00631	.00685	.00741	.00795	.00849	.00959	.01068	01122	01286

EXAMPLE MATERIAL THICKNESS = 1/8", INSIDE RADII = 1/4" R. WHERE THESE CROSS = .00534" IF THE INSIDE OF YOUR BEND IS 20° THE BEND ALLOWANCE (B/A) = .1068 (.00534 X 20°) BEND ALLOWANCE (B/A) PLUS TOTAL OF STRAIGHT LENGTHS = DEVELOPED LENGTH

BEND ALLOWANCE FOR EACH 1° OF BEND (MILLIMETRE)																
Radii / Thickness	0.80	1.58	2.38	3.18	3.96	4.76	5.56	6.35	7.15	7.94	8.74	9.52	11.12	12.70	13.50	15.85
330	.0161	.0305	.0442	.0580	.0717	.0859	.0996	.1134	.1271	.1413	1550	1668	1967	2242	2379	2796
.406	.0169	.0311	.0448	.0586	.0723	.0865	.1002	1140	1277	1419	.1556	1694	1973	2248	2385	2802
508	.0177	.0319	.0456	.0594	.0731	.0873	.1010	.1148	.1285	1427	.1564	1702	1981	2256	2393	2810
.559	.0181	.0323	.0460	.0598	.0735	.0877	.1014	.1152	.1289	1431	1568	1706	1985	2260	2397	2814
635	.0187	.0329	.0466	.0604	.0741	.0883	.1020	.1158	.1295	.1437	1574	1712	1991	2266	2403	2820
.711	.0193	.0335	.0472	.0610	.0747	.0889	1026	1164	1301	1443	1580	1718	1997	2272	2409	2826
813	.0201	.0343	.0480	.0617	.0755	0897	.1034	.1174	.1309	1451	1588	1726	2005	2280	2417	2834
965	.0213	.0355	.0492	.0629	.0767	.0909	1046	.1183	.1321	1463	1600	1737	2017	2291	2429	2845
1.016	.0217	.0358	.0496	.0633	.0771	.0913	.1050	.1187	1325	1467	1604	1741	2021	2295	2433	2849
1 270		.0378	.0516	.0653	.0790	0932	1070	1207	1345	1486	1624	1761	2040	2315	2453	2869
1 625		.0406	0543	.0681	.0818	.0960	1097	1235	1372	1514	1652	1789	2066	2343	2480	2897
1 829			.0559	.0697	0834	.0976	.1113	1251	.1388	1530	1667	1805	2084	2359	2496	2913
1.981			.0571	.0709	.0846	0988	1125	1263	1400	1542	1679	1817	2096	2371	2508	2925
2.058			.0577	.0715	.0852	0994	.1131	1269	1406	1548	1685	1823	2102	2377	2514	2931
2.311			.0597	.0734	0872	.1014	1151	1288	1426	1568	1705	1842	2122	2396	2534	2950
2.388			.0603	.0740	0878	1020	1157	1294	1432	1574	1711	1848	2128	2402	2540	2956
2.591				.0756	.0894	.1035	.1173	1310	1448	1589	1727	1864	2143	2418	2556	2972
2.769				.0770	.0907	1049	1187	1324	1461	1603	1741	1878	2157	2432	2570	2986
3.175				.0802	.0939	.1081	1218	.1356	.1493	1635	1772	1910	2189	2464	2601	3018
3.962					.1001	.1142	1280	1417	1555	1696	1834	1971	2250	2525	2663	3079
4.775					.1064	.1206	.1343	1481	1618	1760	1897	2035	2314	2589	2726	3143
5.156						.1235	1373	1510	1648	1789	1927	2064	2344	2618	2756	3172
5.537								1540	1677	1819	1957	2094	2373	2648	2785	3202
5.944								1572	1709	1851	1988	2126	2405	2680	2817	3234
6.350								1603	1741	1883	2020	2157	2437	2711	2849	3265

EXAMPLE MATERIAL THICKNESS = 3.175 MM, INSIDE RADII = 6.35 MM R. WHERE THESE CROSS = .1356 MM IF THE INSIDE OF YOUR BEND IS 20° THE BEND ALLOWANCE (B/A) = 2.712 MM (.1356 X 20°) BEND ALLOWANCE (B/A) PLUS TOTAL OF STRAIGHT LENGTHS = DEVELOPED LENGTH

From Drafting for Trades and Industry—Basic Skills. Nelson. Delmar Publishers Inc.

Table 44

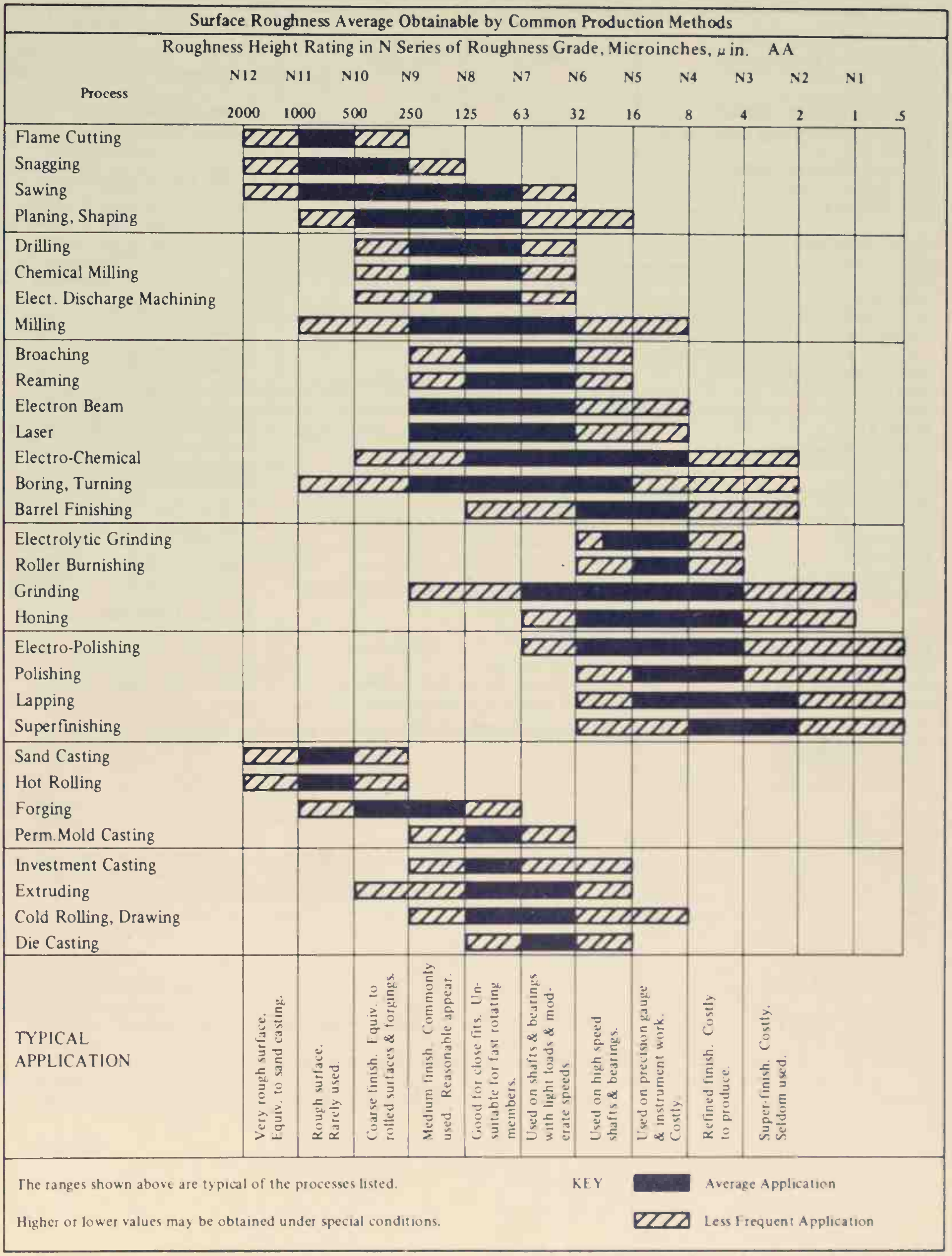
SPUR/PINION GEAR TOOTH PARTS

20 Degree Pressure Angles

Diametral Pitch	Circular Pitch	Circular Thickness	Addend.	Dedend.	Standard Fillet Radius
D.P.	C.P.	C.T.	A	D	
1	3.1416	1.5708	1.0000	1.2500	0.3000
2	1.5708	0.7854	0.5000	0.6250	0.1500
2.5	1.2566	0.6283	0.4000	0.5000	0.1200
3	1.0472	0.5236	0.3333	0.4167	0.1000
3.5	0.8976	0.4488	0.2857	0.3571	0.0857
4	0.7854	0.3927	0.2500	0.3125	0.0750
4.5	0.6981	0.3491	0.2222	0.2778	0.0667
5	0.6283	0.3142	0.2000	0.2500	0.0600
5.5	0.5712	0.2856	0.1818	0.2273	0.0545
6	0.5236	0.2618	0.1667	0.2083	0.0500
6.5	0.4833	0.2417	0.1538	0.1923	0.0462
7	0.4488	0.2244	0.1429	0.1786	0.0429
7.5	0.4189	0.2094	0.1333	0.1667	0.0400
8	0.3927	0.1963	0.1250	0.1563	0.0375
8.5	0.3696	0.1848	0.1176	0.1471	0.0353
9	0.3491	0.1745	0.1111	0.1389	0.0333
9.5	0.3307	0.1653	0.1053	0.1316	0.0316
10	0.3142	0.1571	0.1000	0.1250	0.0300
11	0.2856	0.1428	0.0909	0.1136	0.0273
12	0.2618	0.1309	0.0833	0.1042	0.0250
13	0.2417	0.1208	0.0769	0.0962	0.0231
14	0.2244	0.1122	0.0714	0.0893	0.0214
15	0.2094	0.1047	0.0667	0.0833	0.0200

Table 45

SURFACE TEXTURE ROUGHNESS



From Interpreting Engineering Drawings. Jensen. Delmar Publishers Inc

Table 46

PROPERTIES, GRADE NUMBERS, AND USAGE OF STEEL ALLOYS			
Class of Steel	*Grade Number	Properties	Uses
Carbon - Low 0.3% carbon	10xx	Tough - Less Strength	Rivets - Hooks - Chains - Shafts - Pressed Steel Products
Carbon - Medium 0.3% to 0.6% carbon	10xx	Tough & Strong	Gears - Shafts - Studs - Various Machine Parts
Carbon - High 1.6% to 1.7%	10xx	Less Tough - Much Harder	Drills - Knives - Saws
Nickel	20xx	Tough & Strong	Axles - Connecting Rods - Crank Shafts
Nickel Chromium	30xx	Tough & Strong	Rings Gears - Shafts - Piston Pins - Bolts - Studs - Screws
Molybdenum	40xx	Very Strong	Forgings - Shafts - Gears - Cams
Chromium	50xx	Hard W/Strength & Toughness	Ball Bearings - Roller Bearing - Springs - Gears - Shafts
Chromium Vanadium	60xx	Hard & Strong	Shafts - Axles -Gears - Dies - Punches - Drills
Chromium Nickel Stainless	60xx	Rust Resistance	Food Containers - Medical/Dental Surgical Instruments
Silicon - Manganese	90xx	Springiness	Large Springs

*The first two numbers indicate type of steel, the last two numbers indicate the approx. average carbon content – 1010 steel indicates, carbon steel w/approx. 0.10% carbon.

From Drafting for Trades and Industry—Mechanical and Electronic. Nelson. Delmar Publishers. Inc

Table 47

AMERICAN NATIONAL STANDARDS OF INTEREST TO DESIGNERS, ARCHITECTS, AND DRAFTERS

TITLE OF STANDARD	
Abbreviations	Y1.1-1972
American National Standard Drafting Practices	
Size and Format	Y14.1-1980
Line Conventions and Lettering	Y14.2M-1979
Multi and Sectional View Drawings	Y14.3-1975(R1980)
Pictorial Drawing	Y14.4-1957
Dimensioning and Tolerancing	Y14.5M-1982
Screw Threads	Y14.6-1978
Screw Threads (Metric Supplement)	Y14.6aM-1981
Gears and Splines	
Spur, Helical, and Racks	Y14.7.1-1971
Bevel and Hyphoid	Y14.7.2-1978
Forgings	Y14.9-1958
Springs	Y14.13M-1981
Electrical and Electronic Diagram	Y14.15-1966(R1973)
Interconnection Diagrams	Y14.15a-1971
Information Sheet	Y14.15b-1973
Fluid Power Diagrams	Y14.17-1966(R1980)
Digital Representation for Communication of Product Definition Data	Y14.26M-1981
Computer-Aided Preparation of Product Definition Data Dictionary of Terms	Y14.26.3-1975
Digital Representation of Physical Object Shapes	Y14 Report
Guideline — User Instructions	Y14 Report No. 2
Guideline — Design Requirements	Y14 Report No. 3
Ground Vehicle Drawing Practices	In Preparation
Chasis Frames	Y14.32.1-1974
Parts Lists, Data Lists, and Index Lists	Y14.34M-1982
Surface Texture Symbols	Y14.36-1978
Illustrations for Publication and Projection	Y15.1M-1979
Time Series Charts	Y15.2M-1979
Process Charts	Y15.3M-1979
Graphic Symbols for:	
Electrical and Electronics Diagrams	Y32.2-1975
Plumbing	Y32.4-1977
Use on Railroad Maps and Profiles	Y32.7-1972(R1979)
Fluid Power Diagrams	Y32.10-1967(R1974)
Process Flow Diagrams in Petroleum and Chemical Industries	Y32.11-1961
Mechanical and Acoustical Element as Used in Schematic Diagrams	Y32.18-1972(R1978)
Pipe Fittings, Valves, and Piping	Z32.2.3-1949(R1953)
Heating, Ventilating, and Air Conditioning	Z32.2.4-1949(R1953)
Heat Power Apparatus	Z32.2.6-1950(R1956)
Letter Symbols for:	
Glossary of Terms Concerning Letter Symbols	Y10.1-1972
Hydraulics	Y10.2-1958
Quantities Used in Mechanics for Solid Bodies	Y10.3-1968
Heat and Thermodynamics	Y10.4-1982
Quantities Used in Electrical Science and Electrical Engineering	Y10.5-1968
Aeronautical Sciences	Y10.7-1954
Structural Analysis	Y10.8-1962
Meteorology	Y10.10-1953(R1973)
Acoustics	Y10.11-1953(R1959)
Chemical Engineering	Y10.12-1955(R1973)
Rocket Propulsion	Y10.14-1959
Petroleum Reservoir Engineering and Electric Logging	Y10.15-1958(R1973)
Shell Theory	Y10.16-1964(R1973)
Guide for Selecting Greek Letters Used as Symbols for Engineering Mathematics	Y10.17-1961(R1973)
Illuminating Engineering	Y10.18-1967(R1977)
Mathematical Signs and Symbols for Use in Physical Sciences and Technology	Y10.20-1975

Table 48

Glossary

Absolute System A type of numerical control system in which all coordinates are located from a fixed or absolute zero point
Acme Screw thread form
Actual Size Actual measured size of a feature
Acute Angle An angle less than 90°
Addendum Radial distance from pitch circle to top of gear tooth
Allen Screw Special set screw or cap screw with hexagon socket in head
Allowance Minimum clearance between mating parts
Alloy Two or more metals in combination, usually a fine metal with a baser metal
Alphanumeric Refers to the totality of characters that are either alphabetic or numeric
Aluminum A lightweight but relatively strong metal; often alloyed with copper to increase hardness and strength
Ammonia A colorless gas used in the development process of diazo and sepia prints
Angle Iron A structural shape whose section is a right angle
Angularity Tolerancing of a feature at a specified angle from another feature
Anneal To soften metals by heating to remove internal stresses caused by rolling and forging
Anodizing The process of protecting aluminum by oxidizing in an acid bath using a direct current
Application A definable set of drafting tasks to be accomplished in a given drafting area; may be accomplished partly through manual procedures and partly through computerized procedures
Arc A part of a circle
Arc-weld To weld by electric arc; the work is usually the positive terminal
Artificial Intelligence The ability of a machine to improve its own operation or the ability of a machine to perform functions that are normally associated with human intelligence such as learning, adapting, reasoning, self-correction, and automatic improvement
Assembly Drawing A drawing showing the working relationship of the various parts of a machine or structure as they fit together
Automated Assembly Assembly by means of operations performed automatically by machines that are controlled and monitored by computers
Automated Process Planning Using a computer in developing a process plan
Automation The conversion of a process or system to automatic operation
Auxiliary View An additional view of an object, usually of a surface inclined to the principal surfaces of the object to provide a true size and shape view
Axes Plural of axis
Axis An imaginary line around which parts rotate or are regularly arranged

Babbitt A soft alloy for bearings, mostly of tin with small amounts of copper and antimony
Backlash Lost motion between moving parts, such as threaded shaft and nut or the teeth of meshing gears
Baseline Dimensioning A system of dimensioning where as many features of a part as are functionally practical are located from a common set of datums
Basic Dimension A theoretically "perfect" dimension similar to a reference or nominal dimension. It is used to identify the exact location, size, or shape of a feature.
Basic Size The size from which the limits of size are derived by the application of allowances and tolerances
Bearing A supporting member for a rotating shaft
Bend Allowance The amount of sheet metal required to make a bend over a specific radius
Bevel An inclined edge; not a right angle to joining surface
Bilateral Tolerances Tolerances that are applied to a nominal dimension in the positive and negative directions
Bisect To divide into two equal parts
Blanking A stamping operation in which a press uses a die to cut blanks from flat sheets or strips of metal
Blueprint A copy of a drawing
Bolt Circle A circular center line on a drawing, containing the centers of holes about a common center
Bore To enlarge a hole with a boring bar or tool in a lathe, drill press or boring mill
Boss A cylindrical projection on a casting or a forging
Brass An alloy of copper and zinc
Braze To join with hard solder of brass or zinc

Broach A tool for removing metal by pulling or pushing it across the work; the most common use is producing irregular hole shapes such as squares, hexagons, ovals or splines
Bronze An alloy of eight or nine parts of copper and one part of tin
Buff To finish or polish on a buffing wheel composed of fabric with abrasive powders
Burr The ragged edge or ridge left on metal after a cutting operation
Burnish To finish or polish by pressure upon a smooth rolling or sliding tool
Bushing A metal lining which acts as a bearing between rotating parts such as a shaft and pulley; also used on jigs to guide cutting tool

CAD (Computer-aided drafting) The use of computers and peripheral devices to aid in the documentation for design projects
Callout A note on the drawing giving a dimension, specification or machine process
Calipers Instrument for measuring diameters
Cam A rotating shape for changing circular motion to reciprocating motion
Carburize To heat a low-carbon steel to approximately 2000°F in contact with material which adds carbon to the surface of the steel
Case Harden To harden the outer surface of a carburized steel by heating and then quenching
Center Drill A special drill to produce bearing holes in the ends of a workpiece to be mounted between centers
Central Processing Unit (CPU) A unit of a computer that includes circuits controlling the interpretation and execution of instructions
Chain Dimensioning Successive dimensions that extend from one feature to another, rather than each originating at a datum
Chamfer A bevel on an external edge or corner, usually at 45°
Character A letter, digit or other symbol that is used as part of the organization, control, or representation of data
Chase To cut threads with an external cutting tool
Chill To harden the outer surface of cast iron by quick cooling, as in a metal mold
Chuck A mechanism for holding a rotating tool or workpiece
Circularity A tolerance that controls elemental tolerance zones around a circular feature that is independent of other features
Circular Pitch The length of the arc along the pitch circle between the center of one gear tooth to the center of the next
Circular Runout A tolerance that identifies an infinite number of elemental tolerance zones on a feature when the feature is rotated 360° for each element
Clearance Fit A condition between mating parts in which there is always a clearance assembly
Clockwise Rotation in the same direction as hands of a clock
Coin To form a part in one stamping operation
Cold Rolled Steel Bessemer steel containing .12% to .20% carbon that has been rolled while cold to produce a smooth, quite accurate stock
Collar A round flange or ring fitted on a shaft to prevent sliding
Concentric Having a common center as circles or diameters
Concentricity A tolerance in which the axis of a feature must be coaxial to a specified datum regardless of the datum's and the feature's size
Configuration A group of machines, devices, parts, etc. that makes up a system
Coordinate An ordered set of data values, either absolute or relative, that specifies a location
Coordinate Dimensioning A type of rectangular datum dimensioning in which all dimensions are measured from two or three mutually perpendicular datum planes; all dimensions originate at a datum and include regular extension and dimension lines and arrowheads
Cope The upper portion of a flask used in molding
Core To form a hollow portion in a casting by using a dry-sand core or a green-sand core in a mold
Counterbore The enlargement of the end of a hole to a specified diameter and depth
Countersink The chamfered end of a hole to receive a flat head screw
CPU Central processing unit
Cursor (1) On CRT, a movable marker that is visible on the viewing surface and is used to indicate a position at which an action is to take place or the position on which the next device operation would normally be directed. (2) On digitizers, a movable reference, usually optical cross hairs used by an operator to indicate manually the position of a reference point or line where an action is to take place.
Cylindricity A tolerance that simultaneously controls the surface of revolution for straightness, parallelism, and circularity of a feature, and is independent of any other features on a part

Data A representation of facts, concepts or instructions in formalized manner suitable for communication, interpretation or processing by human or automatic means
Datum Points, lines, planes, cylinders and the like assumed to be exact for purposes of computation from which the location or geometric relationship (form) of features of a part may be established
Datum Feature A feature that is used to establish a datum
Datum Identification Symbol A special rectangular box that contains the datum reference letter

Dedendum The radial distance between the pitch circle and the bottom of the tooth
Delineation Pictorial representation: a chart, a diagram or a sketch
Design Size The size of a feature after an allowance for clearance has been applied and tolerances have been assigned
Detail Drawing A drawing of a single part that provides all the information necessary in the production of that part
Development Drawing of the surface of an object unfolded on a plane
Deviation The variance from a specified dimension or design requirement
Diagram A figure or drawing which is marked out by lines; a chart or outline
Diameter The length of a straight line passing through the center of a circle and terminating at the circumference on each end
Diazo Material that is either a film or paper sensitized by means of azo dyes used for photocopying
Die Hardened metal piece shaped to cut or form a required shape in a sheet or metal by pressing it against a mating die
Die Casting Process of forcing molten metal under pressure into metal dies or molds, producing a very accurate and smooth casting
Die Stamping Process of cutting or forming a piece of sheet metal with a die
Digitize To use numeric characters to express or represent data
Digitizer A device for converting positional information into digital signals; typically, a drawing or other graphic is placed on the measuring surface of the digitizer and traced by the operator using a cursor
Dimension Measurements given on a drawing such as size and location
Direct Numerical Control (DNC) The use of a common host computer for distribution of part programs to remote machine tools
Display A visual presentation of data on an output device
Dowel A cylindrical pin, commonly used to prevent sliding between two contacting flat surfaces
Draft The tapered shape of the parts of a pattern to permit it to be easily withdrawn from the sand or withdrawn from the dies
Drag Lower portion of a flask used in molding
Draw To temper steel
Drill To cut a cylindrical hole with a drill; a blind hole does not go through the piece
Drill Press A machine for drilling and other hole-forming operations
Drop Forge To form a piece while hot between dies in a drop hammer or with great pressure

Eccentric Not having the same center; off center
Extrusion Metal which has been shaped by forcing it in its hot or cold state through dies of the desired shape

Fabrication A term used to distinguish production operations from assembly operations
Face To finish a surface at right angles, or nearly so, to the center line of rotation on a lathe
FAO Finish all over
Fastener A mechanical device for holding two or more bodies in definite positions with respect to each other
Feature A portion of a part, such as a diameter, hole, keyway or flat surface
Ferrous Having iron as a metal's base material
File To finish or smooth with a file
Fillet An interior rounded intersection between two surfaces
Fin A thin extrusion of metal at the intersection of dies or sand molds
Finish General finish requirements such as paint, chemical or electroplating, rather than surface texture or roughness (see surface texture)
Fit The clearance or interference between two mating parts
Fixture A special device for holding the work in a machine tool
Flange A relatively thin rim around a piece
Flask A box made of two or more parts for holding the sand in sand molding
Flatbed Plotter A plotter that draws an image on a data medium such as paper or film mounted on a table
Flat Pattern A layout showing true dimensions of a part before bending; may be actual size pattern on polyester film for shop use
Flatness A tolerance that controls the amount of variation from the perfect plane on a feature independent of any other features on the part
Flute Groove, as on twist drills, reamers, and taps
Forge To force metal while it is hot to take on a desired shape by hammering or pressing
Form Tolerancing The permitted variation of a feature from the perfect form indicated on the drawing
Fusion Weld The intimate mixing of molten metals

Gage The thickness of sheet metal by number
Galvanize To cover a surface with a thin layer of molten alloy, composed mainly of zinc
Gasket A thin piece of rubber, metal or some other material, placed between surfaces to make a tight joint
Gate The opening in a sand mold at the bottom of the sprue through which the molten metal passes to enter the cavity or mold
Geometric Dimensioning and Tolerancing A means of dimensioning and tolerancing a drawing with

respect to the actual function or relationship or part features which can be most economically produced; it includes positional and form dimensioning and tolerancing

Grind To remove metal by means of an abrasive wheel, often made of carborundum, used where accuracy is required

Group Technology Grouping of parts into families based on similarities in design or production processes

Gusset A small plate used in reinforcing assemblies

Hard Copy A copy of output in a visually readable form (e.g., printed reports, listings, documents, summaries, and drawings)

Harden To heat steel above a critical temperature and then quench in water, oil or air

Hardness Test Techniques used to measure the degree of hardness of heat-treated materials

Heat Treat To change the properties of metals by heating and then cooling

Hexagon A polygon having six angles and six sides

Hone A method of finishing a hole or other surface to a precise tolerance by using a spring-loaded abrasive block and rotary motion

Horizontal Parallel to the horizon

Inclined A line or plane at an angle to a horizontal line or plane

Incremental System A system of numerically controlled machining that always refers to the preceding point when making the next movement; also known as continuous path or contouring method of NC machining

Input The transfer of information into a computer or machine control unit (see "output")

Intelligent Robot Robot that can make decisions based on data received from sensing devices

Interchangeable Refers to a part made to limit dimensions so that it will fit any mating part similarly manufactured

Intermediate A translucent reproduction made on vellum, cloth or film from an original drawing to serve in place of the original for making other prints

Involute A spiral curve generated by a point on a chord as it unwinds from a circle or a polygon

Isometric Drawing A pictorial drawing of an object so positioned that all three axes make equal angles with the picture plane, and measurements on all three axes are made to the same scale

Jig A device for guiding a tool in cutting a piece

Journal Portion of a rotating shaft supported by a bearing

Kerf Groove or cut made by a saw

Key A small piece of metal sunk partly into both shaft and hub to prevent rotation of mating parts

Keyseat A slot in a shaft to hold a key

Keyslot The slot machined in a shaft for Woodruff-type keys

Keyway A slot in a hub or portion surrounding a shaft to receive a key

Lathe A machine used to shape materials by rotating against a tool

Layout Lines drawn on material as guides for subsequent operations

Least Material Condition (LMC) A condition of a feature in which it contains the least amount of material

Light Pen A hand-held data-entry device used only with refresh displays. It consists of an optical lens and photocell, with associative circuitry mounted in a wand. Most light pens have a switch allowing the pen to be sensitive to light from the screen.

Limit Dimensions A tolerancing method showing only the maximum and minimum dimensions that establish the limits

Limits The maximum and minimum allowable sizes of a feature

Location Tolerance A tolerance that specifies the allowable variation from the perfect location

Lug An irregular projection of metal, but not round as in the case of a boss; usually with a hole in it for a bolt or screw

Magnaflux A nondestructive inspection technique that makes use of a magnetic field and magnetic particles to locate internal flaws in ferrous metal parts

Main Storage The general-purpose storage of a computer; usually, main storage can be accessed directly by the operating registers

Malleable Casting A casting that has been made less brittle and tougher by annealing

Material Handling The movement and handling of materials, either manually or through the use of powered equipment

Maximum Material Condition (MMC) When a feature contains the maximum amount of material; that is, minimum hole diameter and maximum shaft diameter

Menu A list of options which are displayed on the CRT or a plastic or paper overlay

Microcomputer A computer that is constructed using a microprocessor as a basic element of the CPU; all electronic components are arranged on one printed circuit board

Mill To remove material by means of a rotating cutter on a milling machine

Modifier The application of MMC or RFS to alter the normally implied interpretation of a tolerance specification

Mold The mass of sand or other material that forms the cavity into which molten metal is poured

Neck To cut a groove called a neck around a cylindrical piece
Nonferrous A description of metals not derived from an iron base or an iron alloy base; nonferrous metals include aluminum, magnesium, and copper, among others
Normalize To heat steel above its critical temperature, and then cooling it in air
Normalizing A process in which ferrous alloys are heated and then cooled in still air to room temperatures to restore the uniform grain structure free of strains caused by cold working or welding
Numerical Control A system of controlling a machine or tool by means of numeric codes that direct commands to control devices attached or built into the machine or tool

Oblique Drawing A pictorial drawing of an object so drawn that one of its principal faces is parallel to the plane of projection, and is projected in its true size and shape; the third set of edges is oblique to the plane of projection at some convenient angle
Obtuse Angle An angle larger than 90°
Octagon A polygon having eight angles and eight sides
Ordinate The Y coordinate of a point; i.e., its vertical distance from the X axis measured parallel to the Y axis; the vertical axis of a graph or chart
Orthographic Projection A projection on a picture plane formed by perpendicular projectors from the object to the picture plane; third-angle projection is used in the United States and first-angle projection is used in most countries outside the United States
Output Data that have been processed from an internal storage to an external storage; opposite of "input"

Parallel Having the same direction, such as two lines which, if extended, would never meet
Parallelism A tolerance controlling interdependent surfaces and axes that must be an equal distance from a datum plane or axis
Part Individual component of an assembly
Pattern A model, usually of wood, used in forming a mold for a casting
Peen To hammer into shape with a ballpeen hammer
Pentagon A polygon having five angles and five sides
Perpendicular Lines or planes at a right angle to a given line or plane
Perpendicularity A tolerance controlling surfaces and axes which must be at right angles with a datum axis
Perspective Drawing A pictorial drawing in which receding lines converge at vanishing points on the horizon; the most natural of all pictorial drawings
Pickle To clean forgings or castings in dilute sulphuric acid
Pilot A piece that guides a tool or machine part
Pilot Hole A small hole used to guide a cutting tool for making a larger hole
Pinion The smaller of two mating gear
Pitch The distance from a point on one thread to a corresponding point on the next thread; the slope of a surface
Pitch Circle An imaginary circle corresponding to the circumference of the friction gear from which the spur gear is derived
Plane To remove material by means of a planer
Plate To coat a metal piece with another metal, such as chrome or nickel, by electrochemical methods
Polish To produce a highly finished or polished surface by friction, using a very fine abrasive
Polygon A plane geometric figure with three or more sides
Positional Tolerancing The permitted variation of a feature from the exact or true position indicated on the drawing
Position Tolerance A tolerance that controls the position of a feature as related to a datum or datums
Precision The quality or state of being precise or accurate; mechanical exactness
Printed Circuit Board A special board on which a predetermined pattern of printed circuits has been formed and to which electronic components have been attached
Printer A device that prints the output of a computer
Prism A solid whose bases or ends are any congruent and parallel polygons, and whose sides are parallelograms
Prismatic Pertaining to or like a prism
Processor The computer in a CAD system
Profile of a Line A tolerance that controls the allowable variation along an elemental tolerance zone with regard to a basic profile
Profile of a Surface A tolerance that controls the allowable variation of a surface from a basic profile or configuration
Program A set of step-by-step instructions telling the computer to solve a problem with the information input to it or contained in memory
Projected Tolerance Zone A tolerance zone that applies to the location of an axis above the surface of the feature being controlled
Punch To cut an opening of a desired shape with a rigid tool having the same shape

Quench To immerse a heated piece of metal in water or oil in order to harden it

Rack A flat bar with gear teeth in a straight line to engage with teeth in a gear
Raster The coordinate grid dividing the display area of a graphics display

Reference Dimension A non-toleranced dimension used for information purposes only, which does not govern production or inspection operations
Refresh Display A CRT device that requires the refreshing of its screen presentation at a high rate so that the image will not fade or flicker
Regardless of Feature Size (RFS) The condition where tolerance of position or form must be met irrespective of where the feature lies within its size tolerance
Relief An offset of surfaces to provide clearance
Rendering Finishing a drawing to give it a realistic appearance; a representation
Resistance Welding The process of welding metals by using the resistance of the metals to the flow of electricity to produce the heat for fusion of the metals
Rib A relatively thin flat member acting as a brace or support
Rivet To connect with rivets or to clench over the end of a pin by hammering
Rotate To revolve through an angle relative to an origin
Round An exterior rounded intersection of two surfaces
Runout The composite variation from the desired form of a part surface of revolution during full rotation of the part on a datum axis

Sandblast To blow sand at high velocity with compressed air against castings or forgings to clean them
Scrape To remove metal by scraping with a hand scraper, usually to fit a bearing
Sectional View A view of an object obtained by the imaginary cutting away of the front portion of the object to show the interior detail
Shape To remove metal from a piece with a shaper
Shear To cut metal by means of shearing with two blades in sliding contact
Shim A thin piece of metal or other material used as a spacer in adjusting two parts
Size Tolerance A tolerance that specifies how far individual features may vary from the desired size
Software A set of programs, procedures, rules, and possibly associated documentation concerned with the operation of a CAD system
Solder To join with solder, usually composed of lead and tin
Specification A concise statement of the requirements of a material, an item, or a service, and of the procedure to be followed to determine if the requirements have been met
Spin To form a rotating piece of sheet metal into a desired shape by pressing it with a smooth tool against a rotating form
Spline A keyway, usually one of a series cut around a shaft or hole
Spotface To produce a round spot or bearing surface around a hole, usually with a spotfacer; similar to a counterbore
Spot Weld A resistance-type weld that joins pieces of metal by welding separate spots rather than a continuous weld
Sprue A hole in the sand leading to the gate which leads to the mold, through which the metal enters
Straightness A tolerance that controls the allowable variation of a surface or an axis from a theoretically perfect plane or line
Stress Relieving To heat a metal part to a suitable temperature and holding that temperature for a determined time, then gradually cooling it in air; this treatment reduces the internal stresses induced by casting, quenching, machining, cold working or welding
Stretchout A flat pattern development for use in laying out, cutting and folding lines on flat stock, such as paper or sheet metal, to be formed into an object
Stylus A penlike device that provides input or output of coordinate data usually for the purpose of indicating where the next entered character will be displayed
Surface Texture The roughness, waviness, lay, and flaws of a surface
Swage To hammer metal into shape while it is held over a swage or die that fits in a hole in the swage block or anvil
Sweat To fasten metal together by the use of solder between the pieces and by the application of heat and pressure
Symbol A letter, character or schematic design representing a unit or component

Tabular Dimension A type of rectangular datum dimensioning in which dimensions from mutually perpendicular datum planes are listed in a table on the drawing instead of on the pictorial portion
Tap A tool used to produce internal threads by hand or machine
Taper Pin A small tapered pin for fastening, usually to prevent a collar or hub from rotating on a shaft
Taper Reamer Produces accurately tapered holes, as for a taper pin
Temper To reheat hardened steel to bring it to a desired degree of hardness
Template A guide or pattern used to mark out the work
Tensile Strength The maximum load (pull) a piece supports without breaking or failing
Tin A silvery metal used in alloys and for coating other metals with tin plate
Tolerance Total amount of variation permitted in limit dimension of a part
Tooling Standard and/or special tools for producing a particular part, including jigs, fixtures, gauges, cutting tools, etc.

Torque The rotational or twisting force in a turning shaft

Total Runout A tolerance that simultaneously controls a surface related to a datum in all directions

Trammel An instrument consisting of a straightedge with two adjustable fixed points for drawing curves and ellipses

Transition Fit A condition in which two parts are toleranced so that either a clearance or an interference can result when the parts are assembled

Translucent A quality of material that passes light but diffuses it so that objects are not identifiable

True Position The basic or theoretically exact position of a feature

Truncated Having the apex, vertex or end cut off by a plane

Turn To produce on a lathe a cylindrical surface parallel to the center line

Typical This term, when associated with any dimension or feature, means the dimension or feature applies to the locations that appear to be identical in size and shape

Uniform Having the same form or character; unvarying

Unilateral Tolerance A tolerance that allows variations in only one direction

Upset To form a head or enlarged end on a bar by pressure or by hammering between dies

User A person who operates a CAD system

Vector A directed line segment which, in computer graphics, is always defined by its two end points

Vernier Scale A small movable scale, attached to a larger fixed scale, for obtaining fractional subdivisions of the fixed scale

Vertex The highest point of something; the top; the summit; plural: vertices

Vertical Perpendicular to the horizon

Virtual Condition A condition of a feature in which all tolerances of location, size and form are considered

Web A thin flat part joining larger parts; also known as a rib

Welding Uniting metal pieces by pressure or fusion-welding processes

Woodruff Key A semicircular flat key

Working Drawings A set of drawings which provides details for the production of each part, and information for the correct assembly of the finished product

Workpiece A part in any stage of manufacturing before it becomes a finished part

Workstation The assigned location where a worker performs his or her job (i.e., the keyboard and the system display)

Wrought Iron Iron of low carbon content; useful because of its toughness, ductility, and malleability

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