

SECOND
EDITION

SHOOTING INCIDENT

RECONSTRUCTION

Michael G. Haag and Lucien C. Haag



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SECOND EDITION

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This second edition is dedicated to the many unsung seekers of fact (my wife, father, and many friends included) amidst the chaos that humanity brings upon itself. May we all endeavor to keep our sense of wonder and curiosity in the face of bureaucracy.

Also, to Luke and Sandi for a much-appreciated boost into a career I love, and to my wife, whose unswerving support in this wild profession has been a source of unbelievable strength.

Michael Haag

*For Sandi, Matt, and Mike for whom nearly every picnic or outing in our beautiful Arizona desert ended in gunfire.
And to the memory of Gene Wolberg.*

Lucien Haag

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Introduction

As I write this second edition of *Shooting Incident Reconstruction*, I reflect on my experiences with firearms and my professional experiences with investigations of shooting incidents. I was extremely fortunate to have grown up with two fantastic parents who encouraged inquisitiveness, thoughtfulness, and a sense of excitement for the unknown. Such characteristics are common in the individuals who have inspired me personally and professionally.

Of the volumes of information I have collected from my dad, there is one quote that I commonly find comforting when dealing with lawyers, investigators, and peers. It sums up a very pure thought and intention that should be a foundational belief of anyone in this profession: “*We aren’t in the happiness business.*” No matter what we find, someone will be unhappy. Unlike the many “CSI” programs that populate television these days, it is a fact of real life in forensics. One side or the other will want to find something to criticize in our work, and that is the nature of an adversarial legal system.

In the end, this is a good thing. It ensures that we are always on our toes as we attempt to improve the quality of our work. It also means that we should be open to new ideas and concepts because the way we investigate events is always changing (hopefully for the better). In an era in which ASCLD-ISO literature governing the accreditation of crime laboratories in the United States attempts to have the scientist act in a fashion that is oriented toward “customer” service, the correct forensic scientist will step back and repeat the mantra, “*I am not in the happiness business.*”

Take comfort in that, and know that while we should always keep an open mind to criticisms and new ideas, we are not driven to any conclusion to please a lawyer, police investigator, plaintiff, defendant, judge, or supervisor. Most carefully, we should guard against any belief that what we conclude is relevant to any sort of sense of *justice*. At the end of the day, we must all report only what we believe the evidence is telling us. This may mean a simple “I don’t know” or “Inconclusive”; that is, the result is the best we can glean from the available information. The scientists who do their job correctly are at peace with this, knowing that we are interpreters, and a voice, for otherwise mute physical evidence. We are not avenging angels, servants of a higher power, or puppets to simply repeat or publish what an attorney or police official would like to hear.

From my earliest years, I remember seeing both the positive and the negative effects of people’s use of firearms. Many of my weekends from grade school on were spent in the beautiful Arizona deserts and forests conducting experimental research or case investigations relating to firearms. These endeavors were often spawned from some horrific event created by one human being’s actions toward another, but the more important aspect of these times were the life lessons I learned from my parents with regard to personal use of firearms and respect for them.

While I was becoming familiar with the reconstructive aspects of firearms and of ammunition, as well as terminal and external ballistics, I was almost subconsciously learning about the great responsibilities that should

be associated with the ownership of firearms. These lessons of conscientiousness and responsibility should be, and are, common sense to most law-abiding owners of firearms. But there is a strange dichotomy in my life in that my work and passion—shooting incident reconstruction—is fueled by the antithesis of these tenets.

The first edition of this book was written by my father as a result of a life-long interest in and enjoyment of firearms: their power, their mystique, their ability to defend a life, to save a life, and to take a life. We are both passionate about the Second Amendment—in fact, all of the amendments to the U.S. Constitution—and are always very troubled by those who would pervert it, abolish it, or deny law-abiding citizens the ability to keep and bear arms in the defense of themselves and others.

For Luke also, an interest in firearms started when he was a boy. He grew up outside of Springfield, Illinois, where he received his first BB gun, a Red Ryder 500-shot lever-action blue-steel beauty that still today resides somewhere among the many firearms he has come to own.

During his high-school years in Lynwood, California, Luke became an avid hand loader for several centerfire rifles and handguns, joined the high school rifle team, and often spent his weekends in the Mohave Desert camping and enjoying informal target shooting. It was during these outings that he came to be more and more interested in the technical and scientific aspects of firearms. He began to ponder questions such as “How far do bullets travel?” “How far do ricocheted bullets travel?” “What do such bullets look like after they have ricocheted off a variety of surfaces?” “What do a bullet and a gunshot sound like when heard from a substantial distance downrange?” “How deeply do bullets penetrate into a variety of materials?”

Following the receipt of his Bachelor of Science degree from the University of California at Berkeley, Luke took several courses in criminalistics at California State College at Long Beach, where he first became aware that firearms identification was a part of this profession. A career in criminalistics and a position in a crime laboratory would be a way to apply his training in chemistry, math, and physics to tests and experiments with firearms.

This ideal arrangement was realized when he obtained a position as a criminalist for the City of Phoenix in June of 1965. His arrival there made the Phoenix Police Crime Laboratory a two-man organization. It was a classic case of being in the right place at the right time.

During the next decade, he worked in all sections of this growing crime laboratory, including the new firearms section. Sometime during the 1970s he became the supervising criminalist of the Phoenix lab. All the while, the firearms-friendly State of Arizona provided many locations and opportunities to carry out applied research, and he began writing and publishing papers in the forensic literature.

In 1982 Luke left the Phoenix laboratory to start his own consulting company specializing in the investigation of shooting incidents. He then continued to experiment, to publish, and to give training seminars related to firearms evidence and shooting scene reconstruction. These seminars and workshops ultimately became the book *Shooting Incident Reconstruction*, first published in 2005.

The dedication in the first edition has a somewhat tongue-in-cheek apology to my mother, my older brother Matt, and me for “subjecting” us to experiments that were nearly always a part of any outing in the desert or mountains of our state. My memories of my youth often involved some sort of experimenting. Soon I was helping my

father with his experiments, and my brother and I were presented with guns of our own from our trusting parents, along with instructions in the safe and responsible handling of same, as a classic right of passage into adulthood for an American boy.

In more ways than I can count, my dad's interest in "all things firearms" wore off on me. Those many weekends in grade school spent getting up before sunrise to trek out into the fantastic Arizona desert were sometimes grueling but always rewarding. And I mean that not just in the sense of learning about my future profession but, more important, in the sense of learning about work ethic, about responsibility (in more than just the use of firearms), and about my dad. Most in "the business" know him professionally, but I consider myself beyond privileged to also know his peculiar sense of humor and about the many things that he holds as imperatively sacrosanct.

ACKNOWLEDGMENTS

I feel that I have had an almost unfair advantage in this field because of my contact with my dad. I am always touched by the fact that I can travel halfway (or all the way) around the world and find investigator after investigator who he has helped in one way or another. He is always there to lend an ear and give a helpful suggestion. Especially considering all of his accomplishments, and the positive effect he has

had on the science of shooting incident reconstruction, he is the most humble man I know.

I would like to express my deep appreciation to the many law enforcement officers and crime scene investigators I have met and worked with who have the fortitude and integrity to conduct themselves professionally in the face of some of the worst acts human beings can commit on one another. While I have met my share of individuals in this profession I would not particularly care to associate with, the overwhelming majority have been some of the best people I will ever meet. Luck, fate, fortune, or destiny brought me to one of the finest police organizations in the country. I am grateful to have worked with the investigators, scientists, detectives, and supervisors of the Albuquerque Police Department.

As much as the first edition of this book was my dad's work, and this one is mine, none of it would have been possible without the strong backing of my wonderful wife Kimberly DaVia Haag, who is also a well-known and respected firearm and toolmark examiner. If I were to die tomorrow, I would feel proud and thankful to have had even a week in her company. For every bit of turbulence during the flight, she has been the tailwind making the journey better.

It is my sincere hope that readers of this text will share in my enthusiasm and passion for this work.

Michael G. Haag

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Introduction to First Edition

At the time this introduction was written, the author had been employed as a criminalist and forensic firearm examiner for more than 39 years, 17 of these with the Phoenix Arizona Police Department as a criminalist and later as technical director of that laboratory, followed by another 22 as a private consultant working for prosecutors; private attorneys; educational institutions; insurance companies; law firms; firearms manufacturers; and, on occasion, private individuals. I had always found the work interesting and challenging and still do.

The concept of how science might aid the court and jury in determining what did and did not happen in the matter at trial is still an exciting one for me. Although many of us in the field of forensic science frequently disparage lawyers and the legal process, it is the anomalous trial outcome that gains our attention and generates our scorn. Most of the time juries are able to grasp the evidence we present, and that should be all that matters. What they do with that information may be, at times, disappointing to us personally but their decision is not ours to make and it may often be made on some other basis than observations and opinions derived from the physical evidence.

Working within the legal system is also fascinating. I suspect nearly all of us enjoy a good courtroom drama. A trial can be high exciting, involving verbal and mental chess on the part of lawyers and witnesses. Lives, careers, futures, personal freedom, and, in civil cases, large amounts of money are often at stake. The side that calls us as expert witnesses will usually praise our work, but may

also pressure us to extend ourselves beyond where we should go in the furtherance of their cause. Our employer's cause must *not* become our cause. Our only advocacy must be for our analysis of the evidence carried out by scientifically sound means.

As well, the reader should remember that it is often our cross-examiner's mission to make us look like biased witnesses, fools, lackeys, mountebanks, or incompetents. The witness stand is a decidedly uncomfortable environment for most scientists, and one best observed in the movies or on television rather than from the actual site. It is, and should be, a stressful place, but it is one that I have become used to and have even come to enjoy for the reasons stated earlier.

At the risk of seeming a bit immodest, it occurred to me that some readers might be interested in how I became gainfully employed (indeed, well paid) shooting guns and shooting things for a living.

I grew up in the Midwest in the late 1940s and early 1950s. Guns—some of which were always loaded—were in almost every home and farmhouse I visited. My childhood friends all had access to firearms, and after school we could often be found in a field with a rifle or shotgun. This was with our parents' permission but without them necessarily being present. It was an age of trust on their part and personal responsibility on our part.

At the age of 6 or 7 I received my first Red Ryder BB gun from my father, and this is when my marksmanship training began. Neither I nor my friends ever considered using a gun to commit a crime or to endanger someone or damage property. We certainly

never discussed shooting at one of our classmates, our school, or our teachers.

My fondest memories of my father are of getting up before daybreak, having breakfast at some roadside truck stop, and then getting into the frosty woods at dawn with the sound of crunching autumn leaves underfoot and with *my* rifle or *my* shotgun in hand. It didn't much matter whether we got any squirrels or rabbits or whatever was the quarry of the day. We walked and talked, and I learned of nature.

My father taught me firearms safety and personal responsibility. I saw firsthand that firearms, even my diminutive .22 rifle, were capable of inflicting serious and fatal wounds. Guns were *not* toys or something to be handled carelessly. And my father trusted me with guns. That meant a lot. I wish he were here to read this now. His lessons were ones that I have carried with me all of my life and have since passed on to my sons.

The use of guns in films of that time was typically portrayed as on the side of good. The Lone Ranger, Red Ryder, Roy Rogers, Gene Autry, and all the other lesser-known heroes of the Saturday matinee seldom had to shoot anyone because they were so competent and proficient in the use of their Colt single-action revolver or their Winchester rifle. They usually either shot the gun out of the bad guy's hand or simply got "the drop" on them through their superiority in firearms handling. These were classic morality plays of good over evil in which firearms were an integral part. But today the blood-soaked films from Hollywood show guns creating unimaginable death, destruction, and mayhem in the shortest time possible. They are typically possessed by the psychologically flawed and unfit. It is difficult to think of a film in the past 20 years that depicts a gun on the side of right and in the hands of an honest person of character. It seems that we have forgotten that

our special knowledge and proficiency with firearms is why we are citizens and not subjects. It is why we rightfully honor men such as Alvin York and Audie Murphy—those who grew up with firearms and used them for hunting, sport, and recreation and later used them so effectively in the defense of freedom.

In their day and in my youth, firearms were *more* accessible and readily available with little or no restrictions (other than those imposed by our parents) than they are today. And there were no school shootings, gang shootings, drive-by shootings, or any of the other senseless acts of violence committed with firearms such as we see today. As Hugh Downs (a well-known television commentator) once pointed out in reference to the present-day misuse of firearms, "It's a software problem, not a hardware problem."

But what of my life-long interest in firearms and how it relates to this book and its subject matter? I did bring home my share of rabbits and squirrels from the fields and woods of central Illinois, but hunting was never a burning passion with me. I was more interested in how far and how accurately a bullet could be fired; what it looked like after it hit or penetrated something. Why did bullets make that fascinating whining sound when I straddled a railroad track and ricocheted bullets off the iron rail after an impact at a low incident angle? I shot up a box of cartridges just to hear the sound that the departing bullets made. I even heard some of these bullets impact the ground some distance downrange and subsequently searched many times, in vain, in an effort to find one just to see if its "new" shape corresponded to the gray elliptical smear of lead at the impact site on the rail. (These characteristic impact marks are discussed and can be seen in Chapter 6.)

While shooting at sticks floating down a slow-moving stream from an old covered

bridge, I noticed that the sound of the bullet's impact with the water changed at a recurring point downrange, and it became apparent that, whereas at closer distances the bullets were entering the water, at greater distances they were ricocheting. The phenomenon I was dealing with is *critical angle*—I just didn't know the name for it in 1952. In subsequent years, I also fired many bullets vertically upward on calm days in the deserts of California and Arizona with the misplaced hope of hearing one return to the ground. (I had previously measured the roundtrip time for BBs from my Red Ryder and a Crosman pellet gun in my back yard in Illinois.)

During my high school years in Southern California, I shot competitively on a church-sponsored rifle team. Yes, dear reader, at that time churches and schools and colleges sponsored rifle teams and even supplied many of the guns! Even the University of California at Berkeley had a rifle club when I started there in 1961. Firearms and the people (including the young) who enjoyed shooting them had not yet been portrayed as they are today. I also became an avid hand loader in my teenage years (and still am today), and many of my weekends during those years involved informal target practice in various remote locations in the Mojave Desert of California. All the time I was observing and learning things about firearms and ammunition that would become useful in later years and that are now incorporated between the covers of this book.

After receiving my degree in chemistry from Cal-Berkeley, I discovered the field of Criminalistics through several courses at California State University at Long Beach and realized for the first time that I could apply and utilize my interest in firearms professionally. I began interviewing and taking tests to join the staff of several crime laboratories in Southern California, where I was living at the time. In 1965 a position for a second person in the then small Phoenix

Police Crime Lab opened up. It was the classic case of being at the right place and the right time.

During the years I worked in the Phoenix Lab, I was able to apply my interest in firearms to casework. I quickly became a member of AFTE (the Association of Firearm and Tool Mark Examiners) and began giving presentations at annual meetings and writing articles for the *AFTE Journal*. I started assembling handout materials for classes and workshops dealing with firearms' evidence and the reconstruction of shooting incidents for various organizations.

Colleagues, students from these classes, and my wife Sandi all urged me to put these things together in the form of a book. This I have now done. But there is an additional reason and it arises as a consequence of my many years of reviewing the work of others who were most often employed by government laboratories. A very troubling change has been taking place in these laboratories over the last 30 years. They are taking on the properties of a clinical laboratory where the detective or investigator selects from a menu of tests (e.g., identify the fired bullet or cartridge case with the submitted gun, measure the trigger pull of the submitted gun, check the gun's safety system for proper operation).

In this strictly reactive role, the forensic scientist no longer functions as a scientist at all. Rather, his or her role has been reduced to that of a technician. Little or no discussion between the submitter and the laboratory examiner takes place regarding the details and issues associated with the case. The technician in this "clinical lab" is simply responding to the submitter's requests. He or she may be doing the requested tests correctly and in accordance with some approved, standardized, certified, or accredited methodology, but is not fulfilling the true role of a forensic scientist.

It is the author's hope that this book not only will acquaint the reader with the many reconstructive aspects of firearms evidence but will also inspire and reorient the forensic scientists who examine such evidence. Firearms, expended cartridge cases, fired bullets, the wounds they inflict, the damage they produce, and the damage they sustain all tell a story. This book is intended to serve as a guide to understanding their language.

A couple of abbreviated quotes from G.G. Kelly, the first arms and ballistics officer for the New Zealand Police, say it all:

The gun speaks . . . and the message of the gun is there to read by one who knows the language.

The gun is a witness that speaks but once and tells its story with forceful truth to the interpreter who can understand the language.

Everything that has a basis in physics is capable of being explained. All we have to do is to find the explanation.

Lucien C. (Luke) Haag

Reference and Further Reading

Kelly, G.G., 1963. *The Gun in the Case*. Whitcombe & Tombs, Ltd., Christchurch, NZ.



Sandra M. Haag and Lucien C. Haag

Case Approach, Philosophy, and Objectives

WHY THIS BOOK?

Many years ago I was rigorously cross-examined by an excellent attorney who had put considerable thought and preparation into his questions. My work on the case was totally reconstructive in nature, and my cross-examiner attempted to exclude my testimony on the basis that there was no such thing as “shooting reconstruction.” He went on to claim that the term was something that I had made up. At the time I could not name a single textbook entitled *Shooting Reconstruction* that dealt specifically with shooting scene reconstruction or that had “Shooting Reconstruction” in its title. Neither could I name a forensic science textbook that even had a chapter devoted to this subject.¹ To those who have familiarity with case law and tests of admissibility in the American legal system, the attorney’s argument was basically a *Frye* challenge (*Frye v. U.S.*, 1923).

With what has resulted because of the *Daubert* and *Kumho* decisions (*Daubert v. Merrell Dow Pharmaceuticals*, 1993; *Kumho Tire Co. v. Carmichael*, 1999), future challenges are likely to be raised where reconstructive efforts have been undertaken in a shooting case and the results are offered at trial. The idea for this book was the direct result of my cross-examination and is the product of nearly 40 years of applied research, casework, and trial experience in this specialized area of criminalistics.

¹There was in fact a book that dealt almost exclusively with shooting incident reconstruction when I was rigorously cross-examined some 20 years ago. Written by G.G. Kelly and first published in 1963, *The Gun in the Case* (Whitcombe & Tombs, Christchurch, NZ) is long out of print but a good read if you can find a copy. Kelly was the arms and ballistics officer for the New Zealand Police from 1929 to 1955. While I survived my cross-examiner’s attack and my testimony was allowed in the trial, I nonetheless wished that I had known of this fascinating book at the time.

RECONSTRUCTION: THE ULTIMATE GOAL OF CRIMINALISTICS

It may be useful to pause a moment and consider the very concept of reconstruction and whether it is a legitimate function of forensic science. Probably the best quotes on this subject come from a contemporary textbook on criminalistics by De Forest et al.² and are as follows:

p. 29: "Physical evidence analysis is concerned with identification of traces of evidence, reconstruction of events from the physical evidence record, and establishing a common origin of samples of evidence."

p. 45: "Reconstruction can assist in deciding what actually took place in a case and in limiting the different possibilities. Eyewitnesses to events are notoriously unreliable. People have trouble accurately remembering what they saw, particularly if a complex series of events takes place suddenly and unexpectedly. Reconstruction may provide the only 'independent witness' to the events and thus allow different eyewitness accounts to be evaluated for accuracy."

p. 294: "Crime-scene reconstruction techniques are employed to learn what actually took place in a crime. Knowledge of what took place and how or when it happened can be more important than proving that an individual was at a scene. A skilled reconstruction can be successful in sorting out the different versions of the events and helping to support or refute them."

Events that arise out of the use or misuse of firearms offer some very special and unique opportunities from a reconstruction standpoint. The wide variety of firearms and ammunition types, the relatively predictable behavior of projectiles and firearms discharge products, the chemistry of many of these ammunition-related products, and certain laws of physics may be employed to evaluate the various accounts and theories of how an event took place. To some degree this is little different from the well-known principles of traffic accident reconstruction, where the "ballistic" properties of motor vehicles give rise to momentum transfer, crush damage, and trace evidence exchanges. These phenomena are routinely used to reconstruct such things as the sequence of events, the location of one or more impacts, approximate speeds of vehicles, and so forth.

In summary and in fact, there are many criminalists and forensic firearm examiners who perform various types of shooting scene reconstruction. A distance determination based on a powder pattern around a bullet hole is probably the simplest example of a reconstruction. A shotgun range-of-fire determination based on pellet pattern diameter represents another common example. This book is an effort to describe the various principles of scene reconstruction as they relate to shooting incidents.

BASIC SKILLS AND APPROACH TO CASEWORK

From the very onset, the true forensic scientist must be proactive by finding out what the case is about. From this, he or she must then make certain scientific assessments, define the

²*Forensic Science: An Introduction to Criminalistics* by Peter De Forest, Robert Gaensslen, and Henry Lee (McGraw-Hill, 1983).

important issues and questions in the case, ascertain what is in dispute, and then ultimately design a testing protocol based on the information derived from these previous efforts. He or she must focus on the issues in the case itself and not just the items of physical evidence.

The first step should not be placing an evidence bullet on a scale to get its weight or test-firing a submitted gun to verify its operability. Rather it should, and must, be a reasoning process after making inquiry into the facts and issues in the particular case. This has always been and remains within the forensic scientist's control even in a laboratory that has been reduced to a clinical model. It simply requires that the analyst pick up the telephone and call the submitting investigator or attorney handling the case to ask a few key questions such as:

- Tell me about this case.
- What are the issues?
- What do any witnesses to the incident say happened?
- Did the shooter provide an explanation?
- What is and what is not in dispute in this case?
- What are the competing hypotheses (theories)?
- What do you believe happened?
- What does the autopsy report (or medical records if a gunshot wound is not fatal) reveal?
- What other evidence has been collected beyond that submitted to the laboratory?

The last question is an important one that is often overlooked. It is not uncommon for investigators to select and submit only those items that they have concluded are relevant. This typically comes about from some restricted or narrow view that they have taken regarding the incident. Often the effect is to blindside the laboratory analyst.

It is scientific thinking, not the advanced technology now available in most laboratories, that is the means for solving problems. This book is about thinking and asking questions long before any effort is undertaken to answer them. Individuals addressing reconstructive issues must have good visualization skills and a fundamental understanding of firearms evidence, firearms design and operation, ammunition construction and basic ballistics (interior, exterior, and terminal), and the behavior of various materials when struck by projectiles.

A thorough study of the specific firearm(s) and ammunition involved in the case may be necessary. Once the issues have been defined, the forensic scientist should begin by asking this *question*: "Is there anything about the firearm(s), its (their) operation, the ammunition, the purported events involved in this case that will allow the competing explanations or theories to be tested and evaluated?"

Qualifications

Who should be doing this work and what should their qualifications be? In our view a degree in one of the physical sciences is desirable but not necessary. The advantage such a degree offers is a firm basis in scientific methodology and data evaluation, but it does not ensure that an analyst will use this knowledge. An individual who is both

firearms-knowledgeable and interested in firearms is a requirement. For the proper and successful performance of this work, the analyst must have special knowledge and experience in the following areas in order to comprehensively reconstruct the wide variety of shooting incidents:

- The method of operation of the firearm(s) involved and the class characteristics of the firearm(s)
- Small arms ammunition and projectile design characteristics critical to shooting reconstruction in general and to the case under investigation specifically
- Small arms propellants: their physical forms, basic chemical properties, and performance characteristics
- Gunshot/powder residue pattern production, analysis, and interpretation
- Fundamental exterior and terminal ballistics properties of projectiles, to include
 - “Bullet wipe”
 - “Lead splash”
 - Bullet deformation due to impact
 - Bullet destabilization due to intervening objects
 - Bullet deflection due to ricochet and/or impact with intervening objects
 - Cone fractures in glass and similar materials
 - Crater and/or spall production in frangible materials
- The nature of bullet perforation of thin materials such as sheet metal, glass, drywall, thin wooden boards, and vehicle tires
- Bullet ricochet from
 - Yielding surfaces (soil, sand, bricks, garden stepping-stones)
 - Nonyielding surfaces (concrete, stone, marble, heavy steel)
 - Frangible surfaces (cinderblocks, bricks, garden stepping-stones)
 - The concept of critical angle as it relates to ricochet
 - The examination and interpretation of ricocheted/deflected bullets
- The post-impact behavior of ricocheted/deflected bullets
- The recognition, examination, testing, and interpretation of bullet impact sites, to include directionality determinations in nonorthogonal impacts through lead-in marks, lead splash, pinch-points, and fracture lines in painted metal surfaces
- Trace evidence considerations and interpretation of recovered bullets and bullet impact sites
- The ability to use, and the skill with, various chemical reagents and tools associated with shooting incident reconstruction, to include
 - Chemical tests for propellant residues and bullet metals (copper, lead, and nickel)
 - String lines
 - Small, portable lasers
 - Specialized dowel rods (“trajectory rods”)
 - Plumb bob and line
 - Angle-measuring devices (inclinometers, angle-finders, special protractors)
- Methods for measuring and documenting the vertical and azimuth components of a projectile’s path
- Knowledge of basic trigonometric functions and calculations

- The proper use of the sodium rhodizonate test for lead and DTO and 2-NN tests for copper at or in suspected bullet impact sites
- Cartridge case ejection behavior, factors affecting cartridge case ejection, interpretation, and limitations associated with cartridge case location(s)
- Contemporary shotshell construction
- The exterior ballistic performance of shot, wads, shotcups, and buffering material
- Shotgun pellet pattern examination, extraction of pellet patterns on uneven surfaces, and/or nonorthogonal impacts
- Range-of-fire determinations in shotgun shootings
- Contemporary exterior ballistics programs and the forensic application, to include
 - An understanding of the basic forces acting on a projectile in flight
 - The concept and use of ballistic coefficients with exterior ballistics programs
 - Projectile flight path (trajectory profile), line of sight versus bullet path
 - The calculation of down-range velocity
 - The calculation of flight time
 - The concept of “lagtime”
 - Departure angle
 - Angle of fall
 - The potential effect of environmental parameters on a projectile’s flight
 - The proper documentation of results and report writing

GENERAL PHILOSOPHY

Question: What is it that we are setting out to prove in any case, whether it has reconstructive aspects or is a simple comparison of a bullet to a submitted firearm? Before the reader spends much time pondering this question, we will answer it: Nothing! We would urge every forensic scientist to heed the advice of two people. The first is Dr. P.C.H. Brouardel, a French medico-legalist, who wrote (ca. 1880):

If the law has made you a witness, remain a man of science. You have no victim to avenge, no guilty person to convict, nor innocent person to save. You must bear testimony within the limits of science.

The second is Dr. Ed Blake, the well-known forensic serologist, who once said:

If, in your analysis, you do not consider reasonable alternative explanations of an event, then what you are doing is not science.

Another useful approach to self-preservation in the courtroom is to contemplate your own cross-examination. As you work through the case, think of what questions you would ask if you were allowed to play “lawyer-for-a-day” and you wanted to expose any weaknesses or shortcomings in the analysis you conducted and the opinions you formed. After all, this is the basic mission of any attorney confronted with an opposing expert witness. Who better than the individual who did the analysis knows where you might have done a more thorough job? If the hypothetical cross-examination questions that you contemplate have merit and can be answered by some test or examination, you would be well advised to

ask them before issuing your report or appearing at trial. And if you have been thorough in this self-cross-examination process, virtually any questions that might be put to you at trial or deposition should pose no real challenge.

THE SCIENTIFIC METHOD

The topic of a philosophy of casework quite naturally leads into a discussion of the *scientific method*. Since this is the approach we should be using in our evaluation and analysis, it might do well to restate it. (Besides, it can be surprisingly difficult to find a description of the scientific method when requested to explain it.) As a reader of this book, you will now have a ready source should the need arise.

The scientific method is simply a way of thinking about problems and, ideally, solving them. In many instances the solution to a problem is so rapid and straightforward that the analyst may concede that he or she did not first set down a written protocol. In more complex situations, the analyst may be required to revise his or her hypothesis at the end of the process and modify the previous experiments or tests. This loop back to the initial steps of the method may take place several times after the latter steps have been completed. Nonetheless, the scientific method's steps will allow the problem, its analysis, and its solution to be explained in an orderly manner. The scientific method has at least five steps:

1. **Stating the Problem.** For example, can the distance from which a fatal shot was fired be determined?
2. **Forming a Hypothesis.** In doing so, the scientist considers what he or she knows about the problem. For example, at close range gunshot residues will be deposited around the bullet hole or entry wound and, with appropriate materials and methodology, the characteristics of such residues can be used to establish the approximate muzzle-to-object distance.
3. **Experimentation and Observation (Data Collection).** Identifying and evaluating the effect of any variables that reasonably stand to affect a result are often important initial considerations in the experimentation phase. In forensic science it is especially important that all observations be recorded or memorialized in some fashion so that the data can be reviewed by other scientists. In part, this is because it may not always be possible to repeat the test or experiment with certain types of evidence after the passage of time or after certain types of tests are performed. (e.g., powder patterns at selected distances with remaining evidence ammunition of a rare or unusual type).
4. **Interpreting the Data.** A careful study of the data (e.g., powder patterns from test firings) provides the scientist with a means to evaluate the effect of the variables (e.g., distance) associated with the problem. The data should also provide a means of evaluating the reproducibility of the testing procedure or experiment (e.g., multiple shots at a fixed distance).
5. **Drawing Conclusions.** A conclusion regarding the problem stated in Step 1 may be drawn from the results of Steps 3 and 4. In some instances, a redesign or modification of the test procedure or experiment may be deemed appropriate and additional data gathered before the scientist can draw meaningful conclusions.

The example of a distance determination is fairly straightforward. *Question (problem)*: What was the distance from which a fatal shot was fired? Alternatively, the criminalist/firearms examiner may be presented with two conflicting accounts of the incident: The shooter says that he fired from distance A, but an eyewitness says it was from range B. *Question*: Can one of these accounts be refuted and the other affirmed? Or is either of these accounts supported by an analysis of the physical evidence?

From experience and training, the forensic scientist knows how gunshot residues (GSRs) are produced during the discharge of a firearm and how they behave with increasing distance between the muzzle and a struck surface. (See the photographs in Chapter 2.) We know how to set up and carry out test firings with the responsible gun and like ammunition. The presence or absence of soot (smoke) deposits and the size of the powder pattern (diameter or radii), as well as the density of the powder pattern, are all related to range of fire for a particular gun–ammunition combination. These test patterns are compared with the GSR pattern on the decedent’s clothing or other surface, and the approximate muzzle-to-garment distance is estimated. All of these matters are easy to set up, control, reproduce, document, and retain.

In summary, a forensic scientist should be able to describe the essential steps of the scientific method. A useful memory aid might be “PhD IC”:

1. Problem
2. Hypothesis
3. Data gathering (experimentation/testing)
4. Interpretation
5. Conclusions

In addition to explaining the scientific method, the analyst should be able to explain how his or her analysis conforms to this basic protocol. This is, after all, the answer to the ultimate cross-examination *question*: “What method or procedure did you use in conducting your analysis and purported reconstruction of this incident?” Not only is the scientific method accepted for any scientific inquiry; it is the method for *all* such inquiries. Carried out and documented properly, it allows reviewers, critics, opposing experts, and ultimately a court to evaluate your approach to the case at hand, your testing procedures, your data, your findings, and your subsequent conclusions. The scientific method supersedes all procedural “cookbooks” and rigid checklists for the routine examination of physical evidence. It is from the scientific method that all such procedures originated.

SPECIFIC CONSIDERATIONS

The reconstruction of shooting incidents may call on one or more of the following:

- The presence of GSR deposits on skin, clothing, or other surfaces—such deposits may be limited to sooty materials or vaporous lead deposits, or they may include actual powder residue, unconsumed powder particles, and/or impact sites (stippling) produced by powder particles.
- The pattern and density of such GSR deposits.

- The physical form and/or chemical composition of the gunpowder in the ammunition associated with an incident and any powder present in a GSR deposit.
- The chemical composition of the primer mixture used in the ammunition.
- Trace evidence around a bullet hole or at a bullet impact site (e.g., primer constituents, bullet lubricants, bullet metal).
- Trace evidence on a recovered bullet (e.g., embedded glass particles, bone particles, paint particles, embedded fibers).
- The manufacturing features of the ammunition.
- The design of a particular bullet.
- The composition of a particular bullet (e.g., dead-soft lead, lead hardened with antimony, lead alloys, copper jackets, brass jackets, aluminum jackets, steel jackets).
- Trace evidence in or on a recovered firearm (e.g., blood and tissue in the bore).
- The cartridge case ejection pattern of a particular firearm (coupled with the location of each expended cartridge case).
- The special exterior ballistic properties of shotgun ammunition (e.g., pellet patterns, wad behavior over distance).
- The terminal ballistic behavior of specific projectiles (e.g., orientation at impact, depth of penetration, degree and nature of deformation or expansion experienced by the projectile during penetration).
- The nature and distribution of secondary missiles generated during projectile perforation of intervening objects (may result in pseudostippling, satellite injuries, and damage to other nearby objects).
- Ricochet behavior and characteristics of projectiles after impact with specific surfaces.
- Special attributes of some intervening objects that may permit the sequence of shots to be established (e.g., plate glass with intersecting radial fractures).
- Special characteristics of projectile-created holes that allow the direction of the projectile's flight to be established.
- The long-range exterior ballistic performance of specific projectiles in long-range shooting incidents.
- Visual considerations (e.g., presence or absence of muzzle flash for a particular gun-ammunition combination).
- The nature and setting of the sights on a firearm (normally only of importance in long-range shooting incidents).
- Acoustical considerations (recorded gunshots, the sound of a bullet's arrival or passage at some down-range location, and "lagtime").
- The operational characteristics of the firearm, to include any deficiencies or peculiarities.
- The configuration of the firearm when found and recovered.

The fundamental concepts for the reconstruction of any shooting incident are these:

- The relevant questions or issues must be identified early on and the potential reconstructive properties of the physical evidence recognized. Failing to do this may compromise or even obviate later efforts to reconstruct the incident.
- If you are to be a true forensic scientist, you must, for the moment, step out of your personal biases (we all have them). Neither believe nor disbelieve the account provided by the shooter and/or eye witnesses and ear witnesses.

- Do not immediately accept or reject proposed explanations (hypotheses) offered by investigators, the prosecutor/plaintiff, the defendant's attorney, or the defendant.
- Listen attentively to any theory, account, or explanation. Taking some notes at this point might not be a bad idea. At some later time (probably while you are on the witness stand or in a deposition), you will be asked questions such as:

"Did you consider the possibility that ____?" or "Did you evaluate the account given by Mr. ____?" Your answer, "No, I didn't" or "I wasn't asked to do that," may be truthful, but it is not a very good one. "That's not my job" ranks no better.

These answers will likely be followed by the question, "So you only did what you were asked to do by ____" (fill in the blank with one of the following choices: the police department, the prosecutor, the plaintiff's attorney, the defense attorney). Ask yourself these key questions:

- "What is in dispute and what is not in dispute?"
 - "What do we know about this incident?"
 - "How might the physical evidence resolve (support or refute) the various accounts and explanations (hypotheses) offered for the particular event?"
 - "Is there anything about this gun, this ammunition, this recovered bullet, and so forth, that would allow the various accounts (or hypotheses) regarding this incident to be tested?"
- The physical evidence should be a sounding board against which to test or evaluate the various explanations offered. Plausible explanations will resonate; implausible and impossible explanations will not.

A strong skepticism regarding eyewitness accounts is both justified and encouraged. It is quite common for individuals with no reason or motive for favoring one side or the other to be incorrect in one or more respects regarding their recollections of a shooting incident. Guns that were never there are "seen" and often "fired." The description of the actual gun given by a witness or victim is frequently fraught with errors, as is the number of shots recalled. The timing of events, the sequence of events, positions, and movements of participants, and the distances involved are often not supported by the physical evidence.

Shooters, victims, and witnesses frequently suffer temporal and auditory distortions when shootings occur. It is more often the exception than the rule that the physical evidence squares with the accounts of eye witnesses or ear witnesses in every respect. The degree of agreement between recollection and physical facts shows little if any improvement when one examines the accounts provided by the actual participants in a shooting incident. This includes law enforcement officers of long experience.

The sincerity and seeming credibility of one or more witnesses and/or participants cannot be regarded as "the truth" of the matter. This being the case, what need do we have for the laboratory? It is not that you should regard the witness as incompetent, dishonest, or, worse, a liar. Rather, it goes to the very heart of a forensic scientist's role—to simply, objectively, and dispassionately test each account or hypothesis offered. It will also serve you well to think again of Dr. Blake's warning and use your own intellectual skills in postulating any reasonable alternative explanations when you design your testing protocol for the matter under investigation.

It should also be recognized that seldom can each and every event in a shooting incident be completely reconstructed. The discharge of a firearm and the subsequent flight of a

bullet over relatively short distances, followed by the bullet's impact and penetration into a medium, typically occur in very short intervals amounting to a few hundredths or even thousandths of a second. These intervals are much too short to be observed by the human eye and recorded by the brain. However, the behavior of projectiles in flight and during object penetration follows certain laws of physics and generates unique physical features and characteristics. Preserved in the static aftermath of the incident, these physical features and characteristics can often be utilized to reconstruct the flight path of the particular bullet.

Such shot-by-shot reconstructive efforts in a multishot incident should be thought of as photographic snapshots, where the object(s) struck appears to be stationary even though it might have been in motion at the time. Although the events taking place between shots can seldom be ascertained from these ballistic snapshots alone, many questions can be answered by integrating the snapshots with other information or evidence. It may be possible, for example, to exclude certain theories or accounts of a shooting incident and to support others. In the ideal case, it will be possible to eliminate all but one theory or explanation of an incident and to arrive at a point where all available physical evidence supports only the remaining explanation or account. It should also be kept in mind that a thorough evaluation of an incident and examination of the physical evidence may permit future questions and future hypotheses.

Finally, we would remind the reader that the foregoing paragraph is nothing more than a restatement of the scientific method. For those looking for a simpler means of stating the method, we might suggest Sir Arthur Conan Doyle and his classic Sherlock Holmes mystery, *The Sign of Four*. "Eliminate all other factors, and the one which remains must be the truth," Holmes tells Dr. Watson. When Watson forgets, this advice at a later point in the story, Holmes says, "How often have I said to you that when you have eliminated the impossible, whatever remains however improbable, must be the truth?" Still good advice more than a hundred years later.

SUMMARY AND CONCLUDING COMMENTS

A considerable variety of interior, exterior, and terminal ballistic phenomena, reconstruction techniques, microchemical test procedures, trace evidence considerations, and laboratory examinations are presented in the subsequent chapters of this book. In one way or another they are all directed toward an effort to evaluate what did and what did not occur in a shooting incident.

The various objectives of shooting incident reconstruction are the following.

- The range from which a firearm was discharged
- The position of a firearm at the moment of discharge
- The orientation of a firearm at the moment of discharge
- The position of a victim at the moment of impact
- The orientation of a victim at the moment of impact
- The number of shots in a multiple-discharge shooting incident
- The sequence of shots in a multiple-discharge shooting incident
- The presence and nature of any intervening material between the firearm and the victim or struck object

- The effect of any intervening material on the subsequent exterior/terminal ballistic performance of projectiles
- The probable flight path of a projectile
- The manner in which a firearm was discharged
- Other exterior and/or terminal ballistic events that may have special significance in a particular case

CHAPTER KNOWLEDGE

- Name some texts that relate to shooting incident reconstruction.
- How long has shooting incident reconstruction been a viable aspect of forensic science?
- Who should be conducting shooting incident reconstructions?
- What is the scientific method?

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Working Shooting Scenes

INTRODUCTION

The fresh crime scene can be an almost surreal place for the modern investigator. For those working in law enforcement, it is commonly known that such a fresh scene is a fluid, unstable environment, where new information is regularly being inserted into the workings of the investigation. Avenues of investigation originally thought to be valid may be found to be fruitless. Avenues first thought to be unimportant become the main focus. The adrenaline is pumping, and the excitement of creating some semblance of order from the scattered pieces of the event can be fascinating.

The initial security of the scene is out of the hands of the crime scene teams. Before these personnel arrive, the scene will be secured by the first responders, who are hopefully trained to cordon off the largest reasonable area possible. The scene can always be collapsed down, but it is difficult to expand. During investigation of the scene, the perimeter should be controlled by law enforcement officers in such a way that the team can focus on the job at hand. Interestingly, these preliminary investigation concepts are not a worldwide standard. Experience has shown that failure to enforce early scene security measures can be the termination of an otherwise promising investigation of the physical evidence.

The number of law enforcement administration and political personnel at, and particularly in the vicinity of, a shooting event should be restricted. Individuals higher in the chain of command tend to congregate, particularly around high-profile and officer-involved shootings. Agencies would be wise to enforce strict guidelines, clearing a scene entirely of all such personnel so that the shooting reconstructionist and the crime scene team can effectively do their jobs without interference or alteration of the scene.

Authors' Note. Both authors have the benefit of having worked for law enforcement agencies and as private forensic scientists, in criminal and civil cases, for plaintiffs, defendants, and prosecutors. The observations and opinions in this chapter are largely the result of our years of experience across the United States and internationally.

THE TEAM

It is critical to clarify the difference between operating as a scientist and operating as a technician. The technician identifies evidence, documents its location, and collects it for others to analyze. Many departments operate at this level, thinking of themselves as a reconstructive team. A true reconstructive team uses experience and resourceful thinking to evaluate what is observed in order to interpret the physical properties of the scene. Operation at this level allows shooting scene investigations to flow where the evidence is directing them because there is an evaluation process in the midst of the work. For example, whereas the technician sees a bullet jacket fragment on the ground, photographs it, bags it, and carries it away, the scientist will examine the fragment and decide what other objects in the scene it may have impacted, and will be led to these other impacts.

The “hot” live scene is a place of chaos to which the good investigator seeks to bring order. While much information can be gleaned from old or stale scenes, the importance of a thorough first investigation cannot be underestimated. Once the team leaves the fresh scene, it is usually impossible to go back to it in the same condition. No checklist ever made will substitute for open-minded evaluation of what is and is not important in the scene. The investigator operating in the scientific mode should understand this and be prepared to explain why decisions were made as they were.

A team composed entirely of technicians will miss critical leads to important evidence and conclusions. This is not to say that even the best reconstruction team will not miss concepts or items. The very fundamental nature of the scientific method is the repetition of a process to find an answer. We should always be open to new developments or information. This applies to the scene and the laboratory. Many times the examination of evidence in the lab has led to a revisit of the scene. This is not something to be hidden, and it should not be viewed as a failure. The failure would be not to re-evaluate a conclusion.

To those who have never been part of a major crime-scene team effort, the scene may appear to be chaos, but in fact this is far from the truth with a team that is well run. I have been extremely fortunate in my law enforcement career to have worked with unquestionably honest, professional, and thoughtful investigators. It has been my observation that there are three critical factors to an effective shooting scene team:

- A lack of ego (“What do you think about...?”)
- An unbiased sense of duty to the physical evidence (“The physical evidence is/is not consistent with Individual A’s statement.”)
- The ability to use the null hypothesis (“I do not know the answer with the available information.”)
- Knowledge (“Given this physical evidence, I would expect to see a specific subsequent phenomenon.”)

The last two factors may seem contradictory; however, they are simply a reflection of the overall capabilities of the individuals on the team. It is much better to say, I don’t know, than to extend one’s opinion beyond what can be logically or empirically supported.

Supervisors and administrators carry the responsibility to make sure that teams are adequately trained and equipped to function as reconstructionists instead of simply evidence

collectors. Reconstructionists carry the burden of ensuring that they remain enthusiastic and proactive in their thinking and investigation techniques.

If the team has found what appears to be all the pieces of the puzzle, a shooting scene can be the most exciting and rewarding place on earth. On the other hand, if you are desperately searching for five out of six bullet impact sites, it can be the most frustrating.

AT THE SCENE

Each scene is different and must be approached as such. Typical callouts begin with a late-night phone call alerting the investigator that he or she is about to become sleep deprived. Given the modern legal aspects of search and entry, many callouts are hurry-up-and-wait operations. The overall time for a moderate-sized callout should be expected to be at least 12 hours. Teams usually consist of a minimum of two individuals but, depending on the size and complexity of the incident, may swell to five or more.

There is usually a designated primary investigator and a camera operator, and many teams support the shooting aspect of the callout with specialists in shooting incident reconstruction. These specialists are often called a shoot team. Agencies also often have specialists trained in and assigned to officer-involved shootings (OISs) because of the enhanced public scrutiny and civil litigation associated with these incidents.

There are many procedures that investigators learn over the years that can assist in the reconstruction of shooting events. One of the most fundamental when dealing with revolvers is marking the orientation of the cylinder prior to opening. This provides useful information on many levels:

- If a suicide is suspected, a fired cartridge casing should be under the hammer.
- If the cylinder is out of alignment, this may be a clue to a malfunction of the gun.
- Because rotation of the cylinder can be determined, the sequence of shots fired can be determined, particularly if each cartridge fired had a different style of bullet loaded.

These concepts will be revisited in Chapter 3, on the limited universe.

Either scene or lab investigators should also be looking for flares on the front face of a revolver cylinder (see Figure 2.1). The best definition of a flare is a deposit of visible gunshot residues around the forward face of a chamber that resembles a halo. The meaning of a flare can best be described as evidence of the minimum number of times a shot was fired from the revolver since the last thorough cleaning. These visual cues will be more apparent when plain lead bullets are used, as opposed to jacketed bullets, because of the significantly greater amount of lead vapor produced when a jacket is not insulating the core.

One of the most simple tricks of the trade is to organize the item designators in a scene into a logical, descriptive form than the common #1, #2, #3 system. Having reviewed many cases in the United States and internationally, we find it incredibly frustrating to see designators such as these that give no information as to what they represent. It only becomes more confusing if an item from a scene is suddenly given an additional identification number in the lab, so that field-tagged Item #5, say, is now also referred to as Item #701 or Q6. This is confusing and difficult to follow for a training investigator, let alone for a judge, attorney, or juror.



FIGURE 2.1 Front face of the cylinder of a Smith & Wesson revolver. Note the multiple flares, or halos.

A more logical, descriptive system is to use alphanumerics that describe the type of evidence being indicated. While the possibilities are vast, one system we learned from law enforcement is as follows:

- a = ammunition
- b = blood
- c = fired cartridge casing
- d = document
- f = firearm
- h = hair
- i = impact site
- k = knife
- m = miscellaneous
- n = drug
- p = projectile or fragment

With this method, two guns from a scene would be f-1 and f-2. A sequence of impact sites from a single bullet would be i-1, i-1a, i-1b, and so on. This system does not imply any sort of chronological order, but it clearly, quickly, and easily identifies the types of items of interest to be captured in images or presented in a diagram.

Crime Scene Photography

Thorough, clear photography of shooting scenes should be a top priority at a shooting scene. Although many teams have designated photographers, it is important for the shooting

incident investigator to be able to shoot good photographs for himself. The reason for this is that the shooting reconstructionist has a clearer understanding of exactly what needs to be documented. This is not an insult to competent photographers but rather a simple fact of life. When appropriate, the reconstructionist needs to be able to show an attorney or jury the basis for a conclusion, and if this basis can be demonstrated in a photograph that can only be taken at one time and at one location, it is best to make sure this happens correctly.

Almost all law enforcement departments use digital photography now, which has greatly improved the quality of the images produced at scenes. Image quality can be evaluated immediately, and the overall cost of operating digitally is much less. But with digital photography come some side effects. For one, a photo log is now a waste of time in most instances. Camera settings, time of photo, and many other pieces of information are commonly stored automatically. The file-naming structure associated with digital images allows the photographer to create storyboards with sequential images, beginning with distant shots and proceeding through medium shots to close-ups. The sequence might begin with an overall view of a room, followed by a medium-range shot of a bullet hole in a far wall. The final shot in the sequence would be a close-up, frame-filling image of the perforation with a scale.

The specific photography of firearms in shooting scenes is worthy of mention. Let us take the example of a firearm lying on a dresser. Assuming that the sequence just described has been completed, the investigator should take a good frame-filling image of the gun. After this, a minimum of four low-angle shots capturing the condition of the top, two sides, and bottom of the gun should be taken. At this point in the investigation when evidence can be moved, taking care not to destroy fingerprint evidence, the gun should be flipped over and the sequence of straight-on and low-angle shots should be repeated. This may seem like overkill, but it is a good way to ensure that any unknown safeties, load indicators, cocked indicators, and the like, are captured before the gun is unloaded. Remember, no one knows everything about all firearms, and photo documentation is the best way to capture a gun's original condition.

The number of photographs taken at a scene should increase because of the ease and cost of digital photography compared to 35mm. This point cannot be stressed enough. A moderate-sized shooting scene can easily have 800 photos. A shooting incident involving five guns, 80-plus shots fired, and more than five city blocks should not have only 100 scene images associated with it. The digital format is cheap, and the photographer can see if the product is good, so there is no excuse not to have as many images as possible.

Photography of Firearms at Shooting Incident Scenes

One area of shooting incident reconstruction that is often overlooked is the documentation of the firearm itself at the scene. This topic is partly discussed in other chapters, but the point here is that examination at the scene can never be redone. Therefore, a comprehensive photographic collage documenting the condition of two different firearms is presented.

A Shooting Scene Photo Budget

Because no investigator is familiar with every type of firearm in existence, the photo budget described in the following sections was developed in an attempt to help the investigator document the condition of safeties and loads and trace evidence. By following this



FIGURE 2.2 A distance shot that leads viewer toward the area of interest.



FIGURE 2.3 A closer range shot gives viewers the ability to orient themselves to the precise location of the firearm. In this type of shot, an item designator should be apparent.

recommendation, the shooting incident reconstructionist has a good chance of documenting items of interest without knowing it or having to consciously think about it.

REVOLVERS

A distant shot leading the viewer into the area of interest is desirable (Figure 2.2). With a closer-range shot, viewers have the ability to orient themselves to the precise location of the firearm. In this shot, the item designator should be apparent (Figure 2.3).

An orthogonal photo showing the gun in the plane of the field of view is the next logical step (Figure 2.4). This is also a good time to introduce a scale. The photographer should then drop down to a shallow angle and circle the firearm when able. This provides



FIGURE 2.4 This photo shows the gun in the plane of the field of view. It also introduces a scale.



FIGURE 2.5 In this series of shots, the photographer dropped down to a shallow angle and circled the firearm when able. This provides documentation of top (a), bottom (b), front (c), and back (d).

documentation of top, bottom, front, and back—see Figures 2.5(a) through (d). If more than the four basic angles are captured, all the better.

Next, with gloved hands and with potential latent fingerprints in mind, the analyst should gently flip the gun over so the opposite side can be photographed (Figure 2.6). The cylinder should be scribed on both sides of the top strap with a permanent marker to show



FIGURE 2.6 Keep potential latent finger prints in mind while gently flipping gun over to photograph opposite side.



FIGURE 2.7 For revolvers, scribe the cylinder with a permanent marker on both sides of the top strap to show its orientation before opening.

its orientation prior to opening (Figure 2.7). Once the cylinder is open, an overall shot showing the cartridge casing headstamps in relation to the top strap's location should be taken (Figure 2.8).

A close-up of the headstamps and the presence of any firing pin impressions (or lack thereof) is next (Figure 2.9). Finally, one or more photographs showing the front of the cylinder should capture the presence of any flares/halos and potentially the types of projectiles loaded in the cartridges. Any unexpected, unknown, or unique characteristics or materials should also be documented (Figure 2.10).

SEMI-AUTOMATIC PISTOLS

A distant shot leading the viewer into the location of interest should be taken (Figure 2.11); that should be followed by the close-up shot providing orientation and indicator



FIGURE 2.8 After opening the cylinder, take an overall shot to show the cartridge casing headstamps in relation to the top strap's location.



FIGURE 2.9 Next is a close-up of the headstamps and the presence of any firing pin impressions.

(Figure 2.12). An orthographic photograph with scale puts the pistol in the plane of view (Figure 2.13).

A minimum of four photographs from low angles (see Figure 2.14) should be taken to show the top, front, rear, and bottom of the gun so that the viewer can view the area around the pistol. Next the pistol is flipped over carefully, in this case exposing a failure to feed (Figure 2.15). The area of interest can now be photographed much more closely to specifically detail the orientation of the jammed cartridge—see Figures 2.16(a) and (b). Another close-range photograph documents not only the jam but also the serial number and the safety's position (Figure 2.17).



FIGURE 2.10 One or more photographs showing the front of the cylinder captures the presence of any flares/halos, and potentially the types of projectiles loaded in the cartridges.



FIGURE 2.11 Take a distant shot to lead the viewer into the location of interest.



FIGURE 2.12 This close-up shot provides the orientation and indicates where the gun is located.



FIGURE 2.13 This photograph orthographically shows the gun with a scale that puts it in the plane of view.

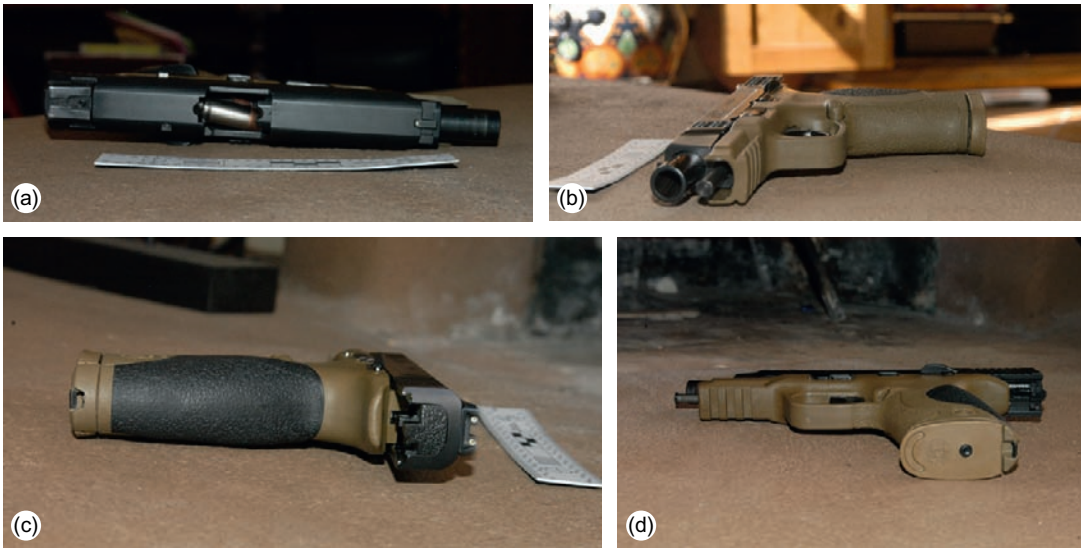


FIGURE 2.14 A series of low-angle photographs showing the top (a), front (b), rear (c), and bottom (d) of the gun takes the viewer around the gun.

Any trace evidence, such as the very small fiber adhering to the front of the lower above the utility rail, should be carefully photographed as well (Figure 2.18). Once the pistol is unloaded, a layout such as this clearly shows which cartridge (or casing) was in the chamber or jammed. The emptied magazine can be laid next to the gun with the cartridge removed from it in the order each was removed (Figure 2.19). Close-up photographs of the individual headstamps may also be desirable.

Besides the common examples just given, there are other, more specific items that can be photographically documented. The brightness and intensity of the holographic sight shown



FIGURE 2.15 Photograph of the pistol after being flipped over carefully, and in this case, a failure to feed is exposed.



FIGURE 2.16 Here the area of interest is photographed much more closely to show the orientation detail (a) of the jammed cartridge (b).



FIGURE 2.17 This close-range photograph shows the jam and the serial number and safety's position.

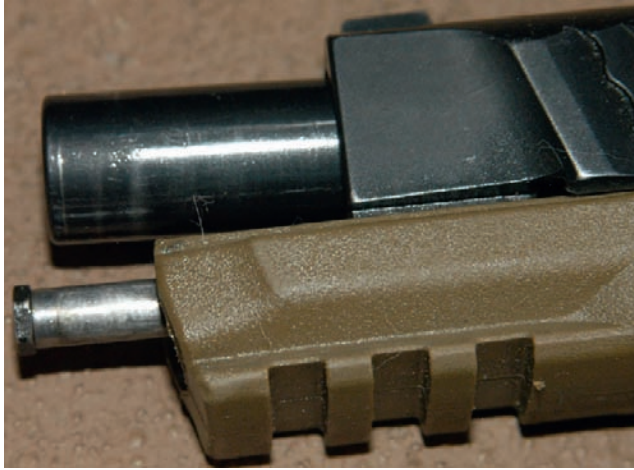


FIGURE 2.18 Trace evidence, such as the very small fiber adhering to the front of the gun, should be carefully documented.



FIGURE 2.19 After unloading the pistol, lay out the cartridge (or casing) that was in the chamber or jammed (*top*). Then lay the emptied magazine next to the gun in the order each was removed.

in Figure 2.20 is captured in comparison with the ambient light. A picture like this should be taken as close to the time of the incident as possible, or even the next day at the time of the incident.

The two images shown in Figure 2.21 contrast a cocked and ready-to-fire pistol and a pistol with the striker forward or broken. Note the presence (a) and absence (b) of the small nub at the back of the slide in the center of the circular retention post.

Without the shallow-angle views of this pistol, even a seasoned investigator may miss the position of the bolt handle before opening it to check the load condition. Figure 2.22(a) shows the gun on safe, while Figure 2.22(b) clearly shows the bolt handle further out from the receiver, in the fire condition.



FIGURE 2.20 The brightness and intensity of this holographic sight is captured in comparison to the ambient light.



FIGURE 2.21 Here the two images contrast a cocked and ready to fire pistol (a) and one with the striker forward or broken (b).



FIGURE 2.22 (a) A gun on safe is shown here and (b) clearly shows the bolt handle further out.

INVESTIGATION TEAMS AND LABORATORY WORK

There is no perfect system, and some teams seem to operate best as all sworn groups whereas others tend to operate more smoothly as all-civilian scientist investigators. In our opinion, mixed teams offer the most balanced resources in most cases, but the effect of personality conflicts on an investigation team cannot be understated. Shooting scene investigators with experience are usually an undervalued commodity of law enforcement agencies. Some sworn teams never seem to develop as seasoned investigators because officers, after receiving large amounts of training, are able to easily transfer to other units. Some civilian teams never seem to gain an intuitive grasp of the realities of shooting events. The boundary between field work and laboratory work is defined differently from jurisdiction to jurisdiction.

Additionally, it is becoming common in the United States to see a significant communication gap between crime scene investigators and laboratory personnel who later examine the physical evidence. In some locations this is the result of sworn-versus-civilian issues. In other locations, this is the result of tremendous backlogs on the lab examination side. State and federal systems can be at an even greater disadvantage because of physical and bureaucratic separation. Some laboratories have been cut off entirely from reconstructionists or investigators by management that does not see the critical value of discourse between these investigative branches. It has also become common in laboratory work to only do cases going to trial. In the most critical of cases, it can be the examination of the evidence that determines if a case even goes to court. How can a reconstructionist or DA proceed without such information?

Currently in the United States, there is a significant push by administrators to have crime laboratory units accredited. There are certainly positive aspects to having laboratory accreditations and individual certifications, but there are also what we see to be dangerous trends in submitting blindly to this process. Many departments view such achievements as an assurance of quality work. This could not be further from the truth. One of us has been asked repeatedly for checklist procedures for lab and scene work, with the intent of being sure not to miss anything in an investigation. It is a brutal truth that such lists are a fallacy that instills in the uninitiated a false sense of security. The best investigations are those that are fluid. And the best investigators are those who do not get tunnel vision. Highly specific checklists tend to encourage tunnel vision and discourage interactive thought.

In the end, there is no perfect system, and it is a fact of life that items of evidence can be missed or unrecognized. We should, of course, be vigilant to avoid such misses, but the truth is that no one except those few who have been scene investigators will understand the difficulty of the task before us. It is important to note that the reconstruction of shooting incidents, like any scientific process, is subject to review. Conclusions are made based on the available evidence and information. Should new information become available, the scientific mind must reassess the conclusion. Some look on this as a failure, but it is not. It is actually the essence of the scientific method.

NEW TECHNIQUES IN SHOOTING SCENE INVESTIGATIONS

The most common tools for the shooting incident investigator at a scene used to be cameras, tripods, tape measures, trajectory rods/probes, chemical kits, and myriad hand tools. This remained constant for decades, until the introduction in the early 2000s of an

engineering and surveying method known as 3D laser scanning, which provides a whole new level of scene capture. There are two predominant types of scanners: time-of-flight and phase-based. At the current time, phase-based scanners are better suited for closer ranges while time-of-flight scanners have greater range and a more general application. Time-of-flight scanners operate on the same basic principle as laser range finders in that they launch a bullet of light and then measure how long it takes for a reflection to return. The scanner can precisely orient the direction in which the beam is projected in both azimuth and elevation so that the individual laser light returns can be plotted in a simulated three-dimensional space. The resolution of the various scans can be adjusted depending on the area of interest. An even greater advantage is that numerous scan positions can be blended, creating large seamless, virtual crime scenes.

There are several huge benefits of using a 3D scanner at a shooting incident scene. First, an overwhelmingly greater amount of data is collected. Using tape measures at a small-sized crime scene, an investigator might leave the scene with a few hundred measurements. At the same scene, a 3D laser scanner might capture several million or more data points so that, when the investigator leaves the scene, it is almost as if he were taking it with him. This is valuable when later, unforeseen developments or statements make a physical relationship between objects important. With manual tape measure methods, some objects may not have been accurately located within the scene, whereas with laser scanning, objects that were within the line of sight of the instrument will have been documented. Moreover, all recording of item locations is done in a hands-off manner with 3D laser scanning. Instead of the shooting reconstructionist stepping in, over, or around blood, casings, shoe prints, or other fragile evidence while holding out a tape measure, a scanner spins quietly on its tripod collecting the data needed.

Second, the level of accuracy and precision of measurement using a scanner is enormously superior to that of hand measurement devices. The Leica Geosystems scanner shown in Figure 2.23, which we are familiar with, has a range greater than 100 meters and a published accuracy of plus or minus 6 millimeters at 50 meters. This level of precision and accuracy is unimaginable when compared to any reasonable assessment of accuracy associated with the use of tape measures or roller wheels.

Third, the ability and process required to produce a timely, clear, and accurate presentation for interested parties is accelerated. A direct presentation of raw data can be created within minutes of completing scans of a shooting scene (see Figure 2.24). Using raw data collected with tape measures can take days or weeks to assemble into a cohesive diagram for presentation. Even then, the product is typically two-dimensional. With scan data, a three-dimensional product that allows viewpoint positioning in any location can be produced in hours. Cleaner, more thorough presentations can be modeled and ready in days.

Three-dimensional laser scanning is of particular interest to the shooting incident reconstructionist because it is so powerful in displaying both simple and complex trajectories. The ability to visually demonstrate bullet paths as soon as one leaves a scene, in three dimensions, is immeasurably valuable. Numerous types of presentations have been created from scanner data, ranging from raw data (known as point clouds) to highly stylized moving computer animations. The basic methodology of trajectory rods is unaltered, as one simply scans the probes and extrapolates the path. However, several more advanced techniques have been developed involving layered scanning and a connect-the-dots process (refer to

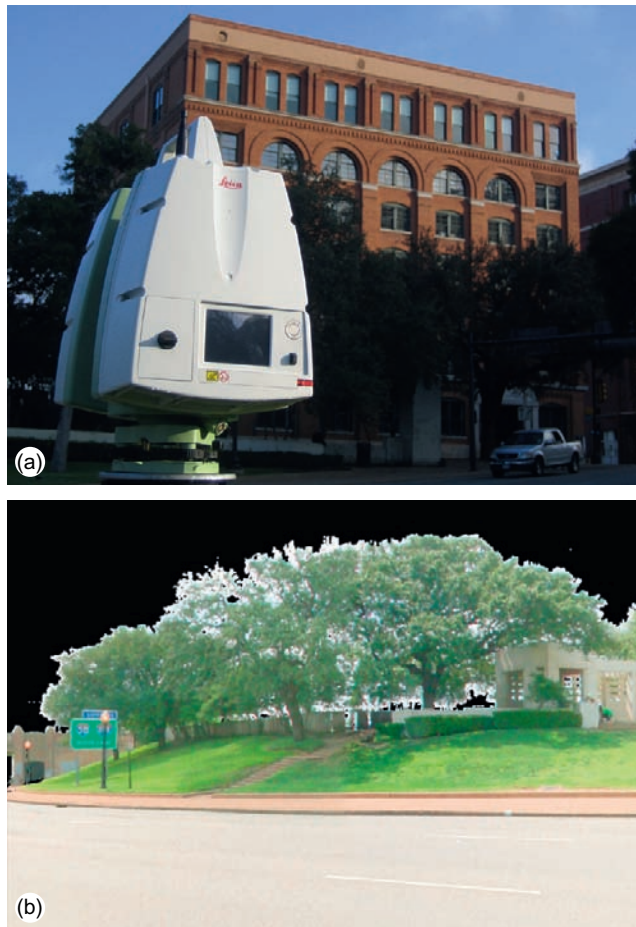


FIGURE 2.23 (a) Leica Geosystems ScanStation C10 scanner at one of the most famous shooting scenes in history: Dealey Plaza in Dallas, Texas. (b) This image shows the actual cloud point data of the “grassy knoll” street scene. This one view has more than a million data points, each one accurately positioned in a virtual 3D world. Any point can be used to measure to any other point.

Figures 2.24a and b). These become crucial in cases where bullets have impacted many branches in a shrub or when two impacts from the same bullet are separated by a large distance such as a window perforation and the subsequent impact across a room.

CASE EXAMPLES

Case 1

In a high-profile shooting incident the shooter’s position was concluded to have been on the passenger side of a car, to the rear of the vehicle, based on the location of a fired cartridge casing.

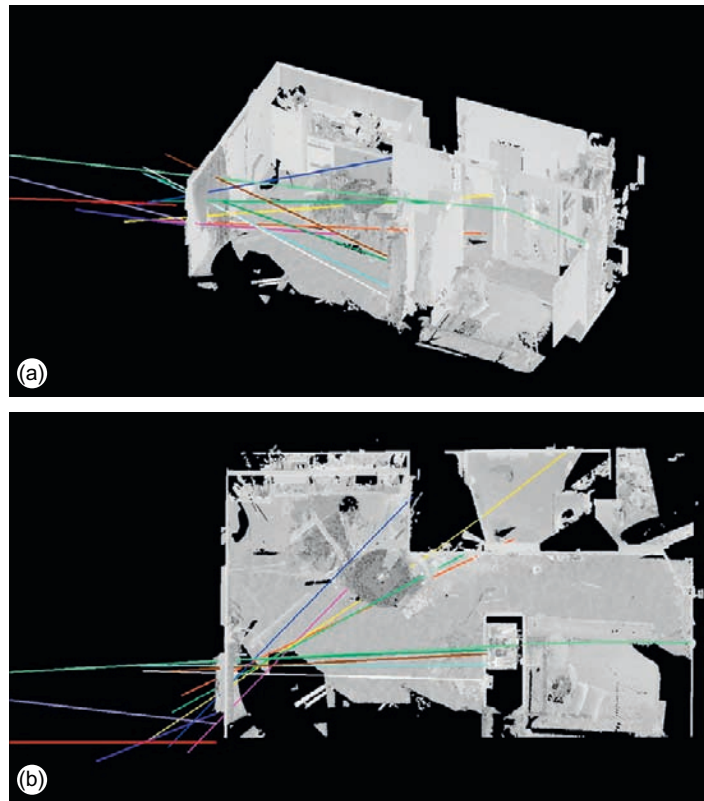


FIGURE 2.24 (a) An oblique angle view of a multishot shooting incident. Here the trajectories are represented as lines for clarity and separation, while normally a ± 5 -degree cone is aligned coaxially along this path to give a measure of uncertainty of measurement. (b) A bird's-eye view of the same scene. 3D laser scanning allows viewing from any angle desired. Raw data such as this can be simplified into extremely accurate 2D diagrams, or transformed into more realistic models.

The decedent was concluded to have been shot directly in the head just forward of the passenger door based on a large blood pool where he died. The vehicle in the scene was undamaged and released to the owner. Later examination of the bullet and of the perforation of a hat indicate to the examiner that the bullet was indeed unstable when it struck the decedent. No impacts had been observed on the car, but the bullet shows clear unyielding surface impact damage. In fact, the surface struck is incredibly smooth, based on the texture of the damage to the bullet. All of these observations led to only one shooting scenario, of the shooting, that the shooter and decedent had been on opposite sides of the car, and the bullet had ricocheted from the windshield without penetrating the surface.

Some investigators may not believe such a thing possible, and others may simply not have experienced this phenomenon, but it has been demonstrated in shooting reconstruction courses

many times and observed in casework as well. The impact marks from such events are sometimes so faint that they can be, and are, missed.

As a private expert, I was hired to examine a shooting scene between two rows of single-story apartment buildings where a 45 ACP bullet had perforated an eave at an approximate 45-degree upward angle. Law enforcement investigators testified that the shooter of the bullet had been approximately 20 yards from an area where a scuffle over a gun reportedly had taken place; however, a trajectory rod later placed through this perforation pointed almost directly to the scuffle area, where cartridge cases and bloody clothing were collected. The police investigator testified that the pistol bullet was deflected because of the impact with the wooden eave. This testimony clearly contradicted the physical evidence and supported a preconceived, and incorrect, idea of what had occurred.

Case 2

The shooter in a multishot event claimed that all of the shots had been fired indoors. The scene was cleared and the evidence sent to the lab. The examination of one fragmented copper jacket reveals an extremely small area of nose-to-base striae at the heel. This damage is in the shape of a parabola. For those who have not read ahead to the section on ricochets, this is a classic indication of a bullet that has impacted an unyielding surface while in stable flight. A visit back to the scene, and a thorough search of the driveway area, yielded a barely visible discolored area that tested positive for copper and lead. Similar to the bullet ricochet mark on the windshield in the previous example, the mark on the concrete was exceedingly difficult to spot, even for seasoned investigators.

Case 3

A shooting event took place in which numerous shots were fired through a bush, impacting a brick wall behind it. Standard use of trajectory rods would not have yielded an accurate result because attempts to move branches and hold rods in place would have shifted the orientation of the bush and the associated impacts. Using a 3D laser scanner, the bush's front face was scanned, followed by numerous scans as the bush was trimmed down in approximate 4-inch increments. Using this technique, the various impact sites inside the bush were documented in their natural position. The individual bullet paths could then be recreated simply by connecting the impact sites in order through the bush, winding up at the brick wall impacts. This hands-off measurement can be highly advantageous in numerous types of scenes.

SUMMARY AND CONCLUDING COMMENTS

The critical factors influencing the effectiveness of a shooting investigation team at a scene include experience, training, enthusiasm, team effort, communication between units, and administrative support. For those teams lucky enough to have all of these factors in their favor, the shooting scene is a fantastic place to work. Without them, the success of the team's mission is in question.

CHAPTER KNOWLEDGE

- Assess any methods you use currently at scenes or that you would use. Do you see room for improvement?
- Think about, or act out, the photography of a firearm in a shooting scene. What trace evidence would you be wary of? How would you document the load condition of firearms?
- For those with scene experience, reflect on techniques or methods you used in the past that have become outdated. Has your methodology and approach to crime scenes become stagnant, or are there advances on the horizon?
- For active investigators, do you function as a technician or as a scientist? Bear in mind that letters after one's name (or the lack thereof) have nothing to do with this question.

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The Reconstructive Aspects of Class Characteristics and a Limited Universe

BULLET DESIGN AND CONSTRUCTION

Class characteristics consist of the intended features of an object. The class characteristics of bullets would include obvious things such as caliber, weight, method of construction, composition, design and location of any cannellures, base shape, heel shape, nose shape, and any number of more subtle features. In our normal laboratory efforts these provide a ready sorting process that can quickly pare down the choices of source for a fired bullet. Although not ordinarily thought of as a means of identification, in situations where we are presented with a limited universe, class characteristics can provide definitive answers in shooting reconstruction cases.

Figures 3.1(a) and 3.1(b) show two views of a selection of unfired 38 caliber and 9mm bullets. From left to right, these are a cannellured Winchester aluminum-jacketed bullet, a nickel-plated Winchester jacketed hollow-point (JHP) bullet, a Russian full-metal-jacketed (FMJ) bullet with a copper-washed finish over a steel jacket, a Remington JHP bullet with a scalloped jacket, a Federal Hydra-Shok bullet, a Winchester Black Talon bullet with a black copper oxide finish, a CCI-Blount Gold Dot JHP bullet, and a Remington Golden Saber bullet with a brass jacket. Each of these bullets exhibits certain distinguishing class characteristics.

Figure 3.2 shows each bullet from Figure 3.1 after discharge and recovery from a tissue simulant. This reveals some additional manufacturing features of potential value for certain bullets, such as the central post in the Federal Hydra-Shok and the “talons” on the Winchester Black Talon (subsequently renamed the Ranger SXT).

The following case examples employ the concept of a *limited universe*. A limited universe represents a situation where there are a finite number of choices for an event. In these cases the analyst is typically presented with two or three types and brands of ammunition whose sources are known or have been established. It is understood that these limited choices are



FIGURE 3.1 Two views of a selection of unfired 38 caliber and 9mm bullets.

(a) Profile view and (b) oblique (base) view of eight representative bullets. From *left to right*: cannellured Winchester aluminum-jacketed bullet; nickel-plated Winchester JHP bullet; Russian FMJ bullet with copper-washed finish over steel jacket; Remington JHP bullet with scalloped jacket; Federal Hydra-Shok bullet; Winchester Black Talon bullet with black copper oxide finish; CCI-Blount Gold Dot JHP bullet; Remington Golden Saber bullet with brass jacket.



FIGURE 3.2 Selection of bullets from Figure 3.1 after discharge into a tissue simulant. *Top row*: unfired specimens. *Middle and bottom rows*: two examples and views of each bullet after discharge. Note the unique, surviving characteristics of many of these bullets.

the *only* ones for the particular event. An eliminative process for all but one contender and subsequent correspondence in class characteristics of this only remaining choice establish an identity of the source where there is a limited universe of candidates.

CASE EXAMPLES

Case 1

Consider a situation where an innocent bystander was killed by an errant shot in a multiagency police operation. Three law enforcement agencies were involved in the attempted arrest of an armed and highly dangerous subject. One or more members of each agency ultimately fired shots

during an exchange of gunfire with the subject. The fatal bullet passed through the victim and was never found. A portion of the bullet's jacket was recovered from the wound track, however. The initial laboratory report describes this item as a fragment of a bullet jacket that lacks any rifling impressions and is therefore *not* suitable for identification purposes.

Agency A carries and fires 9mm Winchester SilverTips; Agency B, Federal Hydra-Shoks; and agency C, Remington Golden Sabers. The armed subject fired a revolver loaded with plain lead bullets.

Given the limited universe for the source of this fatal injury, this case can be solved on the basis of the differing jacket compositions for these three bullets: nickel-plated gilding metal for the SilverTip, plain gilding metal for the Federal Hydra-Shok, and brass for the Remington Golden Saber.

Case 2

Let us modify Case 1 to the extent that the innocent bystander lives and has a partially expanded bullet in her body (visible on X-rays). This bullet is in an area where the treating doctors conclude that it is safer to leave it in her body rather than to remove it. Four agencies fired their handguns in this hypothetical example using the following ammunition: Winchester SilverTip, Winchester Black Talon, Federal Hydra-Shok, and Remington Golden Saber. As before, the armed suspect fired a revolver loaded with plain lead bullets. How might the question of responsibility be resolved in this situation?

A possible solution resides in a pair of X-ray films: one in the lateral view and one in the anterior/posterior (A/P) view. It would be quite surprising if such films did not already exist in the victim's medical records. If this is the case, lateral and A/P films should be requested with a concerted effort to get the clearest possible views of the projectile. If they do not exist, then additional X-rays should be prepared. If either the barb-like talons of a Black Talon or the central post of the Hydra-Shok can be seen in one of these films, the question is answered. It would also be answered upon the appearance of the classic profile of an unexpanded, round-nose lead bullet of the type from the suspect's revolver. Given the differences in jacket composition of the law enforcement agencies' ammunition, scanning electron microscopy–energy dispersive spectroscopy (SEM/EDS) analysis of the “bullet wipe” around the entry hole in the outermost garment can also result in a resolution of this case.

Case 3

An armed subject was being chased by two law enforcement officers down a long dark alley. In one location, Officer A fired a single shot of Federal 9mm + P + ammunition loaded with Hi-Shok bullets from his Glock model 17, 9 × 19mm-caliber pistol. After an additional 200 feet of foot chase, Officer B fired a single shot of Federal 9mm Luger ammunition loaded with Hydra-Shoks from his Glock model 19, 9 × 19mm-caliber pistol. The subject escaped the foot chase for a short period of time before being dropped off at a local emergency room. Figure 3.3 shows a lead core that was collected from the scene in the alley, and Figure 3.4 shows a bullet removed from the subject in the emergency room.

Which officer was responsible for shooting the individual, and which officer missed? Purposefully, some information was given that should have made the reader think about, but dismiss, as an option in a limited universe. Specifically, while the models are different, both officers shot Glock 9 × 19mm-caliber pistols, which share the same general rifling characteristics. The lands and grooves on these bullets will not separate out the individual who shot the subject.



FIGURE 3.3 Lead Federal Hi-Shok bullet core. The nose is to the left; the base, to the right as viewed. Raised ribs on the inside of the jacket create the furrows in the lead core.



FIGURE 3.4 Federal Hydra-Shok bullet. As with many higher-end bullets, there are distinct and unique manufacturing characteristics to be seen. Here, the telltale lead post emerges from the mushroomed nose.

In this specific limited universe scenario, even if only one of these bullets was recovered, the correct answer is Officer B. While no one knows all the various manufacturing characteristics associated with individual bullets, it is the responsibility of investigators of shooting incidents to know as much as possible about, and to be interested in, their subject matter. The bullet core from the alley shows some key rib marks down the long axis of the bullet that are common to Federal Hi-Shoks. Conversely, the bullet in the specimen vial has a clearly identifiable Hydra-Shok post.

CLASS CHARACTERISTICS AND FIRED CARTRIDGE CASINGS

Without being a firearm and tool mark examiner, it is possible to begin to get an idea of the *minimum* number of firearms involved in a shooting. By looking at the class characteristics of the breech face impression on the casings, we can separate out which are in agreement and which are different. Some of the fundamental things to look at are firing pin aperture shape, breech face mark direction and pattern, and firing pin shape. Other marks that are usually visible with the naked eye, but which may be intermittently produced, should not be used to make early categorization determinations. These include, but may not

be limited to, firing pin drag marks, ejection port dings, and ejector marks. Additionally, while the overall relationship and positioning of ejector and extractor marks are usually fairly consistent from the same gun, there is a degree of inaccuracy due to the motion of the gun and casing during the cycle of fire. In other words, a gun with an ejector set at the 8-o'clock position may leave ejector markings on a fired cartridge case at 7 o'clock, 8 o'clock, or 9 o'clock. The same concept applies to extractor mark positions.

EXAMPLE

Consider a *very* common scenario in which we have an unknown number of guns involved in a shooting event. In some cases, there may be clusters of casings that are physically separated, suggesting that separate firearms were used for different clusters or that motion took place between the two locations. Examine Figures 3.5 and 3.6, paying special attention to the firing pin impression shape and firing pin aperture flow-back shape. Both of these casings are the same brand and basic style, but the marks left by the guns used to fire them are very different. In the first figure we see a slightly rectangular firing pin aperture and an elliptical firing pin impression; in the second figure we see evidence of a hemispherical firing pin impression and a circular firing pin aperture.

For this example let us say that one cluster of casings, all possessing markings represented in Figure 3.5, was recovered from the front yard of a residence, while the other cluster of casings, like that in Figure 3.6, was collected in the street in front of that residence. Both are shown with the extractor mark set to 3 o'clock as viewed. With these two sample cartridge casings from each group, the on-scene shooting reconstructionist can be certain that a *minimum* of two firearms were



FIGURE 3.5 Fired cartridge casing displaying a rectangular firing pin aperture and an elliptical firing pin impression. Only Glock pistols and early Sigma-style pistols are known to have this set of class characteristics.



FIGURE 3.6 Second fired cartridge casing showing circular firing pin aperture back flow and a hemispherical firing pin impression. While these class characteristics are relatively common, the arced breech face markings narrow the possible firearm types involved.

involved in the incident. This type of determination can usually be done with the naked eye. A word of caution, however: The fact that a group of casings from a scene all share these general characteristics does *not* mean that they are from the same gun. A thorough examination at the lab with a comparison microscope would be needed to complete that aspect of the investigation.

Let us add one more layer to this hypothetical investigation and say that as the investigation of the scene is wrapping up, detectives take into custody three suspects in a vehicle several miles away who confess to being involved in the shooting. The detectives relay that three pistols were collected: a 9mm Luger-caliber H&K USP, a 9mm Luger-caliber Beretta 92FS, and a 9mm Luger-caliber Glock 17. Once again, a thorough examination using a comparison microscope will be needed to determine if these are the *specific* firearms used in the event, but some preliminary conclusions can be made.

Hopefully, if the reader is a seasoned shooting scene reconstructionist, the breech faces of the listed guns will be in memory. The uninitiated can refer to Figures 3.7 through 3.9. Immediately, the Glock breech face should stand out from the other two. Given this limited universe of possibilities, the casings represented by Figure 3.5 are in agreement with the

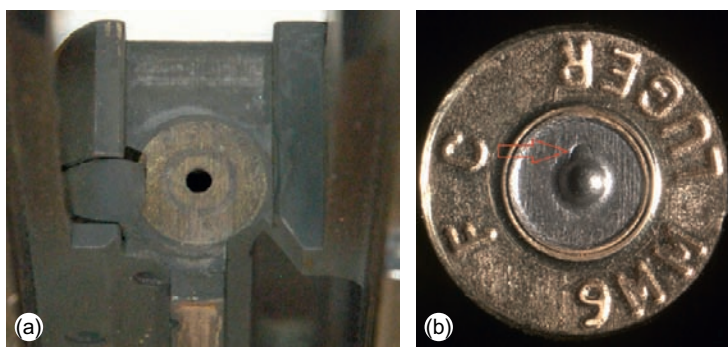


FIGURE 3.7 H&K USP pistol. (a) Breech face of pistol. (b) Sample cartridge casing fired in pistol.

Note the firing pin drag mark emerging from the central firing pin impression. A recoil-operated pistol with a falling barrel design can, but not always will, leave such a mark. However, a recoil-operated pistol, such as a Beretta 92FS, that does not have a falling barrel will not leave such a mark.



FIGURE 3.8 Breech face of a Beretta 92FS pistol.

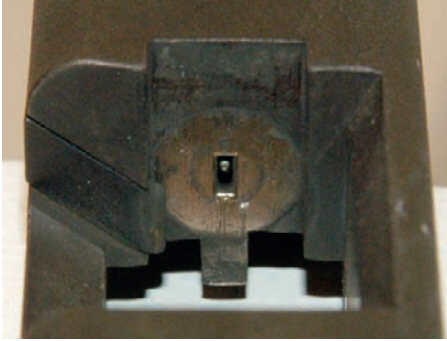


FIGURE 3.9 Breech face of a Glock 17 pistol.

class characteristics of the Glock pistol. It may be more difficult to discern the other set of casings from the Beretta and HK pistols because they both possess circular firing pin apertures and hemispherical firing pins.

To see an example of how complex such investigations can be, however, refer to Figure 3.7(a). Once again the cartridge casing is oriented with the extractor at 3 o'clock as viewed but, more important, note the small drag mark coming up and out of the firing pin impression. This firing pin drag indicates that the firearm used to discharge this cartridge casing is recoil-operated with a falling-barrel design. It is *critical* to understand that this mark may not always be present on casings from falling-barrel guns but should *not* be present if the firearm used does not have a falling-barrel design. In the limited universe scenario given previously, *only* the HK USP is a recoil-operated pistol with the class characteristics of a circular firing pin aperture and a hemispherical firing pin.

CLASS CHARACTERISTICS AND FIRED BULLETS

Another example of the use of the limited universe at scenes is general rifling characteristics imparted to bullets when they are driven down barrels with differing numbers of lands and grooves. Two notes of caution relating to this type of examination: (1) Be aware of and careful not to cause cross-contamination of different bullets when a trace evidence examination or DNA is needed later in the investigation; (2) be careful in the evaluation of patterns when the potential for deformation of the bullet or fragment is high. This latter point is especially critical when rifle bullets striking hard materials are at issue. If significant fragmentation has occurred, a laboratory examination may not even be particularly fruitful, let alone a field examination. For those cases where a relatively pristine set of bullets can be compared, the most simple way to proceed is to place the items base to base. In this manner, a rough idea of the following class characteristics can be compared: caliber, direction of twist, number of lands and grooves, and widths of lands and grooves.

EXAMPLE

Keeping in mind that this examination will only yield the *minimum* number of guns involved in the incident, let us take the case of a shooting event with no suspects, no firearms recovered,

and no leads. Six bullets of the same caliber and FMJ style are recovered from a decedent. They are in pristine condition, and since they are all from the same body, no DNA examination is needed. Placing the bullets base to base allows us to see if the impressed rifling characteristics cross smoothly from one to the other.

First examine Figure 3.10. Both bullets have the same overall *number* of lands and grooves, six, but the direction of the bullet on the left is *left twist* while that of the bullet on the right is *right twist*. These two could *not* have been fired through one barrel. The resulting V shape at the junction of the bases is the easy way to spot differing directions of twist.

Next, look at Figure 3.11. Here the direction of twist is in agreement, so the pattern flows smoothly from one side to the other; however, notice that whereas one edge of a land impression is aligned at the closest point as viewed, the alignment quickly falls apart as one travels down the side. On the left is a 6-right bullet; on the right is a 12-right bullet. The bullet on the right was fired through yet a *third* barrel. Now examine Figure 3.12. Finally we have an example where caliber, direction of twist, number of lands and grooves, and widths of lands and grooves agree. These two bullets *could have been* fired through the same barrel.



FIGURE 3.10 Two bullets of the same caliber, with the same number of lands and grooves but with differing direction-of-twist rifling. These bullets *must* have been fired through two different barrels.



FIGURE 3.11 Two bullets of the same caliber fired through two different barrels based on the differing *number* of lands and grooves. Here the direction of twist is the same.



FIGURE 3.12 Two bullets that *could* have been fired through the same barrel, but comparison microscopy is needed to be certain.

If we tally up the total number of varied general rifling characteristics, we see that the *minimum* number of barrels for this incident, commonly phrased as the minimum number of firearms, is four. One barrel rifled 5 right, one barrel rifled 12 right, one barrel rifled 6 right, and one barrel rifled 6 left. With some care, it is certainly possible to then evaluate the rifling characteristics of firearms in the field as well.

One final note: Can you spot the single visible difference in *manufacturing* characteristics between one of the bullets and the remaining five? It is important to also realize that it does *not* matter if some of the bullets are total metal jacketed, hollow point, or plain lead. *If* the samples being observed are pristine enough to compare and the issue of deformation has been ruled out, this tool can be very powerful at the scene.

Propellant Morphology

A distance determination based on a powder pattern around a bullet hole in clothing was previously cited as a simple example of a shooting reconstruction. Figure 3.13 illustrates the conical expulsion of partially burned and unburned powder particles from the muzzle of a handgun at discharge. It is this predictable and reproducible phenomenon that has served criminalists and firearm examiners as the basis of such distance determinations for decades. These powder particles also possess (and frequently retain) physical attributes that can be exploited to solve certain shooting reconstruction questions.

Although it is beyond the scope of this book to describe the various manufacturing methods and the chemistry of classic and modern small arms propellants, the common physical forms are easily illustrated in Figures 3.14(a) through (i). These figures show seven distinct forms of contemporary smokeless gunpowder followed by four granulations of black powder and Pyrodex RS (a black powder substitute) on 1/8-in. grids. Because no firearm–ammunition combination is 100% efficient in burning all of the powder in a cartridge, a few too many particles of unburned and partially burned propellant may be left behind in the fired cartridge case, in the chamber in which the cartridge was fired, in the bore of the firearm, and, of course, deposited on objects or surfaces in close proximity to the muzzle. The cylinder gaps of revolvers also represent a source of such deposits that have special reconstructive value, as will be pointed out later in this chapter.



FIGURE 3.13 Gunshot residue production from a semiautomatic pistol.

The bullet is just a few inches beyond the muzzle. Numerous particles of partially burned gunpowder have emerged from the muzzle in a conical distribution. A cloud of soot or “smoke” is also visible in the muzzle area. A faint plume of sooty material can also be seen escaping upward from the chamber area. The slide of this semiautomatic pistol has just started to move rearward and the fired cartridge is still in the chamber.

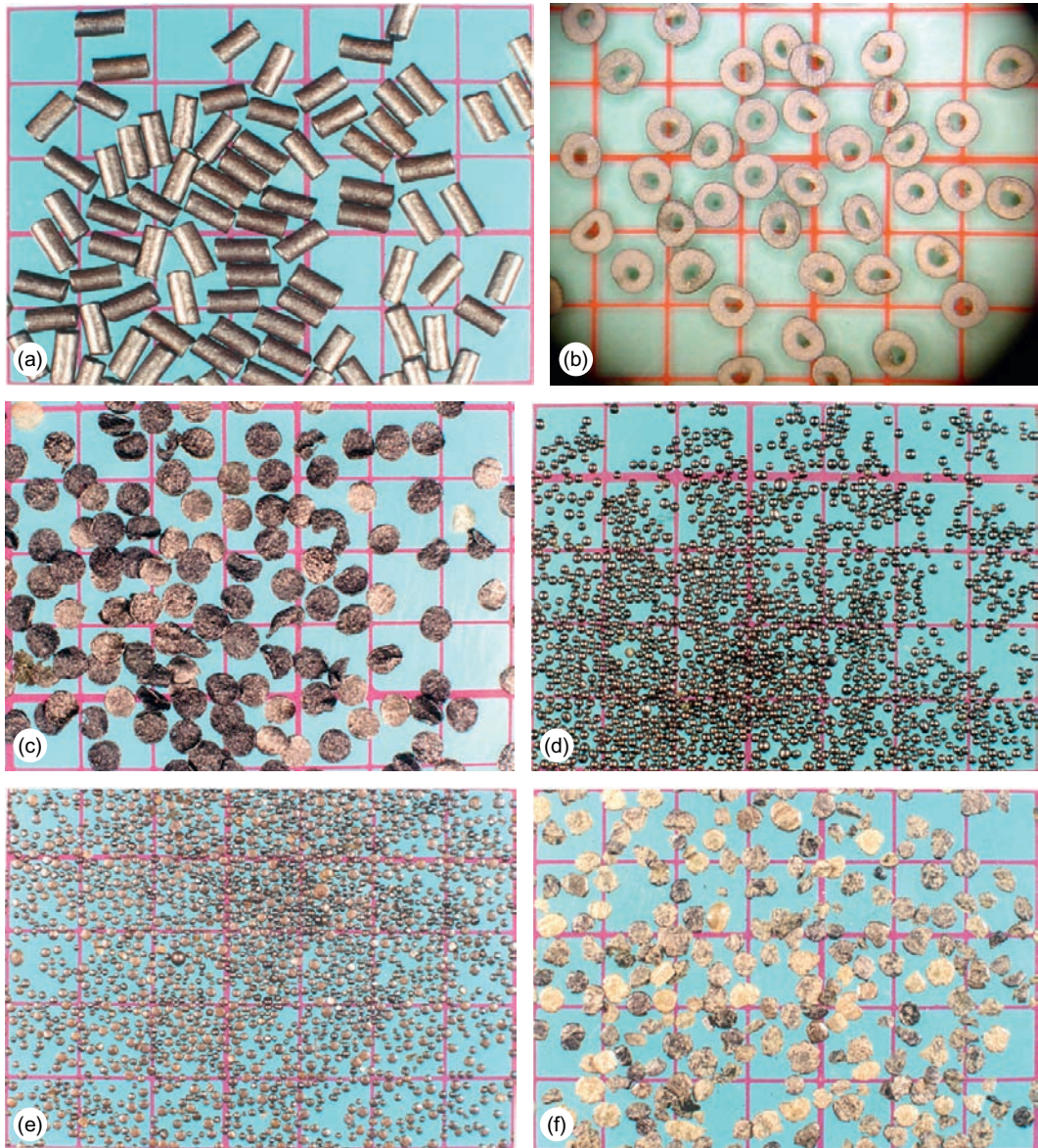


FIGURE 3.14 Common physical forms of contemporary smokeless gunpowder, black powder, and Pyrodex RS on 1/8-in. grids: (a) extruded tubular powder; (b) Trail Boss; (c) Hercules unique unperforated disk-flake powder; (d) spherical ball powder-Remington 38SPL JHP; (e) Accurate #7 (manufactured by IMI) flattened ball powder; (f) Winchester 231 cracked ball powder; (g) Lamels 6.5 x 55 mm Swedish Mauser powder; (h) four granulations of black powder—4F, 3F, 2F, and “Ctg.”; and (i) Pyrodex RS (1990s, current form).

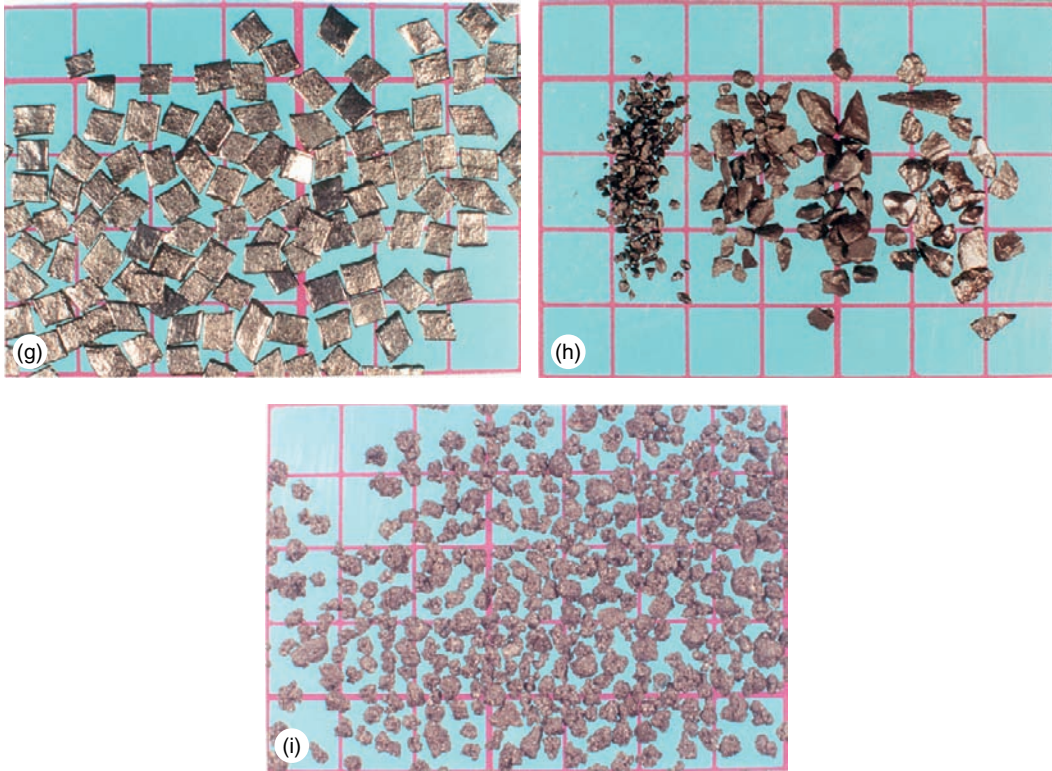


FIGURE 3.14 (Continued)

CASE EXAMPLES

Case 1

The following hypothetical case is an example of the application of propellant morphology to shooting reconstruction.

A subject known to have been in an altercation with three armed individuals in the parking lot of a bar was shot and killed by a single perforating gunshot wound to the chest. Three suspects were quickly apprehended and found to have the following guns: a 7.65 mm Walther PPK, a Lorcin .32 automatic, and an Iver Johnson .32 S&W revolver. All three admitted to firing a shot but each claimed to have discharged a “warning shot” into the air. The fatal bullet was never recovered.

Two fired .32 automatic pistol cartridges were found near the body. Initial laboratory examination establishes that a Geco-brand cartridge was fired in the Walther PPK and that a Winchester-brand cartridge was fired in the Lorcin. The Iver Johnson .32 S&W revolver was found to have one expended Remington-brand cartridge under the hammer. All of these findings substantiate the admissions of the three suspects insofar as their having discharged their pistols. Live rounds of the corresponding brands were also found in each pistol.

The medical examiner's autopsy report describes some powder stippling around the entry wound. The charging bureau at the prosecutor's office wants to know who to charge with murder and who to charge with lesser offenses related to firearms violations.

Analytical Approach

At this point we will expose the reader to a theme that will be repeated many times in this text. *What do we know about the problem?* It is the beginning step in the scientific method. All three firearms in this example are essentially of the same caliber. Given the uncertainty associated with estimating the caliber of the responsible firearm from bullet hole size in the victim's shirt, and given the same problem with the diameter of entry wounds in skin, such measurements *cannot* lead to a valid resolution of this incident.

The mention of powder stippling by the medical examiner offers considerable hope because the intervening clothing stands to have filtered out some of the powder particles. If the fatal wound was sustained in bare skin, the medical examiner's retention of some representative powder particles from the stippled area is critical to the solution of this case. In this hypothetical example, subsequent examination of the victim's shirt reveals numerous particles of spherical ball powder around the bullet hole—see Figure 3.14(d).

Examination of the Geco-brand ammunition, the fired Geco cartridge, and the bore of the Walther pistol all reveal lamel-form powder residues—see Figure 3.14(g). The Iver Johnson revolver and its Remington ammunition show unperforated disk-flake powder—see Figure 3.14(c). Examination of the fired Winchester cartridge from the Lorcin pistol reveals ball powder residues, as does a tight-fitting cleaning patch pushed through the bore of this pistol prior to any test firing. The disassembly of several of the live Winchester cartridges from the Lorcin's magazine also reveals the propellant to be spherical ball powder. By simple inspection of the class characteristics of the propellants and propellant residues, the Geco and Remington shooters are *excluded* and the shooter of the Winchester ammunition is *included*.

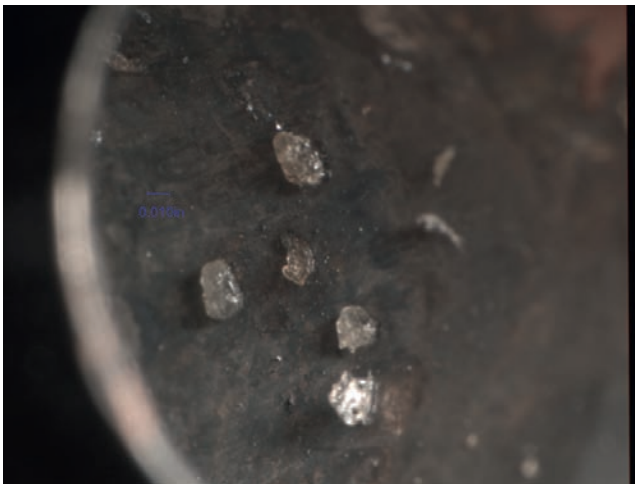


FIGURE 3.15 View of the inside of a fired cartridge casing. The scale bar represents 1/100th of an inch.

Case 2

The reader should consider for a moment an alternate to the previous hypothetical example. In the homicide in this case, two firearms and one fired cartridge casing were recovered at the scene from each gun. There was a single, fatal, through-and-through gunshot wound to the decedent; however, no projectiles were recovered. One fired cartridge casing is a Winchester brand, and the other is a Federal brand. The morphology of the powder particles on the decedent's clothing determines them to be ball powder. Figure 3.15 at the bottom of the previous page shows what is observed inside the mouth of the Federal brand cartridge casing.

Which of the two cartridge casings in this limited universe scenario is associated with the fatal gunshot wound? If the Winchester cartridge casing has remnants of ball-type powder, the correct answer is that it is associated with the fatal gunshot wound. No matter what is found in the Winchester cartridge casing, however, the particles in Figure 3.15 are clearly not ball. They are either disc flake, or flattened/cracked ball. This effectively *excludes* the Federal casing as being related to the fatal shot. If (1) these two cartridge casings are the only *realistic* possibilities for the source of the fatal bullet, (2) no residues are found in the Winchester cartridge casing, and (3) the Federal cartridge casing is excluded, the conclusion is that the Winchester is the only option by default.

REVOLVERS AND THE LIMITED UNIVERSE

Revolvers offer another source and dimension insofar as gunshot residue (GSR) and powder deposits are concerned. Such residues not only emerge from that muzzle but also emerge in an oval or fan-shaped pattern from the right and left sides of the cylinder gap. As Figure 3.16 shows, these hot and highly energetic gases can blast or burn a characteristic pattern into almost any surface immediately adjacent to the cylinder gap. Figures 3.17(a) and (b) illustrate the reconstructive value of muzzle and cylinder-gap deposits. Cylinder-gap deposits are of special value in possible suicide cases, in alleged struggles over a

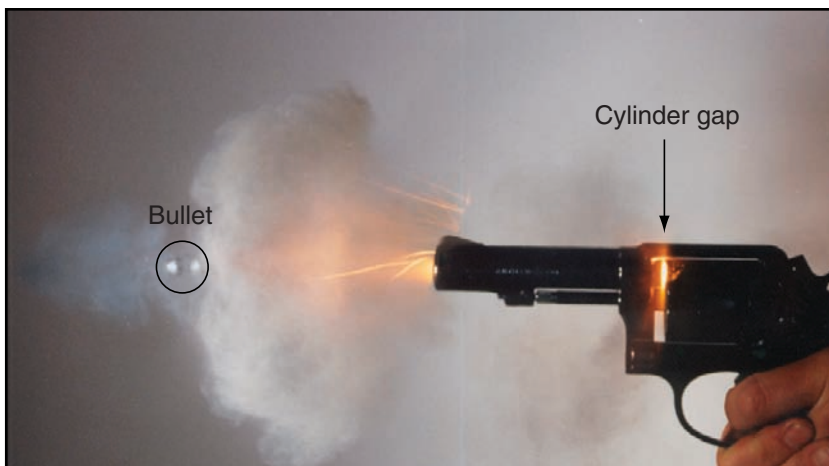


FIGURE 3.16 Gunshot residue production from a revolver.

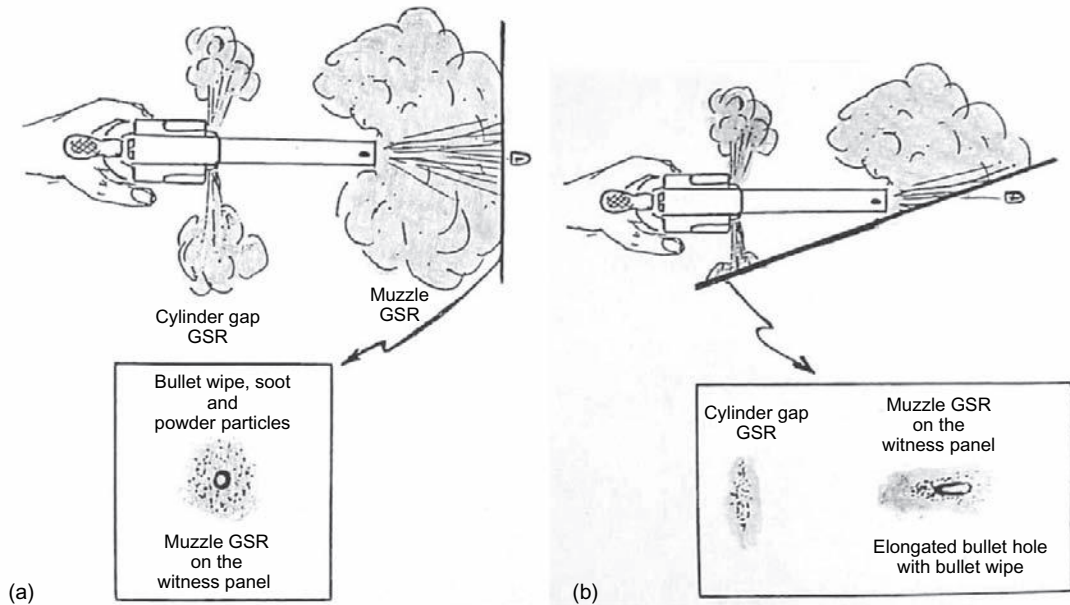


FIGURE 3.17 Gunshot residue deposition from a revolver.

revolver, in purported accidental discharges in holsters, or when the revolver in question was placed on or against some surface where, it is claimed, it discharged. This subject will be revisited in a later chapter.

THE WORTH OF WEIGHT

To some readers this topic may seem inappropriate to the subject of reconstruction. Others may conclude that it is so elementary as to be insulting. But sometimes it is the simplest of things that can solve a case. Something as basic as the weight of a projectile, a bullet core, or a fragment of a projectile can answer a reconstructive question. A number of otherwise very competent examiners have occasionally overlooked the obvious and simple solution to some of the following questions:

- Is a bullet fragment part of a particular fragmented bullet or some other bullet? *Answer:* If the weights of the two items exceed the weight of the intact bullet, the fragment is from some other projectile.
- Of what value is the weight of a severely deformed 22 rimfire bullet? *Answer:* A long-rifle bullet can be differentiated from a 22 short or 22 long bullet.
- Are cast bullets from the same mold all of the same alloy? *Answer:* Differences in alloy composition will produce significant differences in bullet weights for bullets cast in the same mold.

- What is the weight of an unfired bullet based on the weight of either a separated core or a separated bullet jacket? *Answer:* For each manufacturer, there is a relationship between the total weight of a bullet, its lead or lead alloy core, and its jacket. (See the table of core and jacket weights in the Appendix.)
- How can the total weight of live cartridges be useful? *Answer:* Consistency (or inconsistencies) in loading can *quickly* be detected. Significant differences (such as two different bullet weights, a missing powder charge, or a double powder charge) in otherwise visually indistinguishable ammunition can be detected by weighing the intact cartridges.
- Of what value is the weight of intact cartridge cases versus fragments of burst or separated cartridge cases? *Answer:* Weight can serve as a means of ascertaining whether the entire burst cartridge is represented by the fragments presently in the examiner's possession.
- How can the weight of deformed shot pellets, buckshot, and/or spherical projectiles be useful?

The last question deserves special attention. The predischARGE *size* (shot size number or diameter) of shotgun pellets from badly deformed, but otherwise intact, pellets can be determined from their weight. Table 3.1 lists the nominal weights in grams and milligrams for American shot sizes. It also gives the approximate diameter of these shot sizes in English and metric units.

It might also be useful at this point to recall that the diameter of American shot sizes in inches can be derived from this equation:

$$\text{diameter (in.)} = [17 - \text{shot size \#}] \div 100$$

For example, #6 shot gives 0.11 inches for its diameter from this equation.

The diameter of deformed spherical lead projectiles such as those fired from muzzle-loading rifles and cap-and-ball revolvers can also be determined from their weight, as will be demonstrated. This is especially useful to the battlefield archeologist. Prior to the mid-1800s nearly all firearms fired spherical lead projectiles. Some firearms continued to employ such projectiles during and immediately after the American Civil War. The majority of these

TABLE 3.1 Shot and Buckshot Sizes and Average Weights per Pellet

Shot Size	T	BBB	BB	1	2	3	4	5	6	7	7½	8	8½	9
Diameter (in.)	.20	.19	.18	.16	.15	.14	.13	.12	.11	.10	.095	.09	.085	.08
Diameter (mm)	5.08	4.83	4.57	4.06	3.81	3.56	3.30	3.05	2.79	2.54	2.41	2.29	2.16	2.03
Weight: Pb (mg)	771	663	561	394	325	265	211	167	128	96	82	71	59	49
Weight: Fe (mg)	541	465	394	276	228	186	148	117	90	68				
Buckshot Size	000	00	0	No. 1	No. 2	No. 3	No. 4							
Diameter (in.)	.36	.33	.32	.30	.27	.25	.24							
Diameter (mm)	9.14	8.38	8.13	7.62	6.86	6.35	6.10							
Weight: Pb (g)	4.49	3.46	3.16	2.60	1.90	1.51	1.33							

Note: The weights of shot are in milligrams and those of buckshot are in grams.

TABLE 3.2 Properties of Interest for Metals Used in Projectiles

Metals	Steel/Iron (Fe)	Copper (Cu)	Tungsten (W)	Lead (Pb)	Bismuth (Bi)	Antimony (Sb)
Atomic number	26	29	74	82	83	51
Atomic weight	55.8	63.5	183.8	207	209	121.8
Melting point (°C)	1535	1083	3410	327.5	271.3	630
Specific gravity (@20°C)	7.874	8.96	19 (approx.)	11.35	9.747	6.68 (@25°C)
Density (% of Pb)	69.4	78.9	167	—	85.9	58.8
Hardness (Mohs*)	4.5	2.5–3	6.5–7.5	1.5	2–2.5	3.0–3.3

*Mohs hardness scale sets talc as 1 and diamond as 10.

were percussion (cap-and-ball) revolvers. They quickly faded from the scene with the introduction of cartridge-firing arms. However, renewed interest in historic firearms has led to the manufacture of numerous, fully functional replicas. On rare occasions such guns have been involved in accidental shootings and even employed in the commission of crimes.

Insofar as modern arms are concerned, spherical lead projectiles are almost exclusively associated with shotgun ammunition in the form of buckshot and the smaller shot sizes primarily used for bird and small game hunting. Also, some pistol and revolver cartridges are available that are loaded with small shot. The compositions presently available are lead (both dead soft and hardened), steel, bismuth, and tungsten-impregnated polymer spheres. Table 3.2 describes some of the physical properties of interest for these metals. Copper has been included because of its use in bulletted ammunition and contemporary frangible projectiles. Antimony is added in relatively small amounts (typically 0.5–5%) to harden lead.

Derivation of Sphere Diameter from Weight

In the case of lead spheres, the formulas that follow, derived from the equation for the volume of a sphere and the density of lead, are quite useful in calculating the original diameter of a lead ball. The weight of a sphere composed of any of these metals is directly related to its diameter. This relationship is forensically useful because projectiles, particularly soft ones such as lead, will often deform upon impact. If no metal has been lost during terminal ballistic deceleration, the *weight* of a deformed spherical projectile can be used to derive its original diameter or caliber. Table 3.1 revealed how this would be useful for deformed shot from shotguns. Any loss of material can usually be determined by a careful inspection of the deformed lead ball under the stereomicroscope. The diameter of a lead ball is closely related (but usually not identical) to the caliber of the muzzle-loading firearm from which it was discharged. This concept will be revisited later in this section.

The mathematical derivation for the relationship between the weight of a spherical projectile and its diameter is as follows: The formula for the volume (V) of a sphere is $4/3\pi r^3$, where r is the radius of the sphere. This formula can be rewritten on the basis of diameter ($d = 2r$) and simplified to give

$$V = 0.5236d^3 \quad (3.1)$$

TABLE 3.3 Commercially Manufactured Spherical Lead Balls

Diameter (in.)	Rifle/Pistol (caliber)	Sources*	Calculated Weight (gr)	Measured Weight (gr)
.310	32	H,C,W	44.8	45
.350	36	H,S,D,W	64.8	65
.375	36 revolver	H,S,W	79.3	80
.395	40	H,W	92.7	93
.440	45	H,S,D,C,W	128	128
.445	45	H,S,D,W	133	133
.451	44 revolver	H,S,W	138	138
.454	44 revolver	H,S,W	141	141
.457	44 revolver	H,S,W	144	143
.495	50	H,S,W	182	182
.530	54	H,S,D,W	224	225
.535	54	H,S,W	230	230
.570	58	H,S,W	279	278
.690	69/73	D,W	494	494
.735	75	W	597	593

*Hornady (H), Speer (S), Denver Bullet Co. (D), CVA (C), and Warren Muzzleloading (W).

From the simple relationship between weight, density, and volume (that is, $W = D(V)$), a general expression relating the weight (W) of a spherical projectile to its diameter (d) is

$$W = 0.5236d^3(D) \quad (3.2)$$

Lead Spheres

The density of pure lead in *grains per cubic inch* is 2873.5. These units have been selected because American calibers are usually given in inches and projectile weights in grains. The metric equivalent for the density of lead in *grams per mm³* is 0.011345. This value is useful for projectiles weighed in grams with their diameters measured in millimeters. For *lead* spheres, Eq. (3.2) can be further reduced by inserting these density values to give

$$W \text{ (in grains)} = 1504.6d^3 \text{ (in inches)}$$

or

$$d = 0.08727W^{1/3} \quad (3.3)$$

The metric equivalent for d in millimeters and W in grams is $W = 0.005940d^3$, or

$$d = 5.522W^{1/3} \quad (3.4)$$

Table 3.3 provides a partial list of commercially produced lead balls for flintlock and percussion rifles, pistols, and revolvers. It illustrates the value of these equations and provides

some insight into the varied sizes and sources of such projectiles as well as a check of the calculated weights (in grains) versus the actual weights.

The lead spheres listed in Table 3.3 are contemporary, *swaged* balls from various commercial sources. “Bullet” molds, both contemporary and historical, for casting round balls are readily available. Some of them cast balls in sizes that fall between the values in the table. Projectiles made in this manner (as opposed to the modern swaging process) are likely to show a casting seam and a sprue mark. Additionally, cast balls may be alloyed with other metals such as tin and antimony, both of which will lower their density. Lyman’s No. 2 bullet metal, for example (a popular lead alloy composed of 90 parts lead, 5 parts tin, and 5 parts antimony), has a density that is 95.7% that of pure lead and a hardness of 15 on the Brinell scale. This compares to a Brinell hardness number (BHN) of 4 for pure lead.

The diameters of spherical lead balls and their relationship to the caliber of the muzzle-loading firearms used to fire them can be somewhat confusing. Muzzle-loading single-shot pistols and rifles were most often loaded with a *patched* ball, that is, a swatch of cloth, usually circular and on the order of 0.015 in. thick. Pillow ticking and fine woven linen were common choices for patching material. Very thin deer skin or other animal skins were also known to have been used during the era of muzzle-loading firearms.

With these firearms the ball is slightly *undersized* and held in place against the powder charge by the snug-fitting patch. With a properly selected patch and powder charge, the ball never directly contacted the bore of the gun during loading or discharge. At best, only faint vestiges of the rifling might print through the patch and onto the ball. The weave of the patch fabric may be embossed in the side or at the base of the fired ball. The patch itself survives the discharge process and represents important physical evidence. At very close range (a few inches) it will follow the projectile into a wound track. At more distant ranges, it will be found within a few yards of the location of the gun’s discharge.

Percussion revolvers, with their front-loading cylinders, use a very different approach. A lead ball of a slightly *larger* diameter than that of the cylinder’s chambers is mechanically forced down into the opening of each chamber with the revolver’s ramming arm. (It should be noted that the front of the ball typically receives a distinct and often identifiable imprint from the face of the ramming arm during the loading process and that this mark may survive impact with “soft” targets such as muscle or other tissues.) The rammer imprint should *not* be confused with imprints that might be left on a ball by a ball starter or ramrod used with muzzle-loading rifles and single-shot pistols. The seated ball retains its position in the chamber of percussion revolvers prior to discharge because of the forced fit it undergoes.

The bore into which this ball will be driven during discharge is slightly *smaller* than the chamber from which it is expelled. Such a projectile makes *direct* contact with the bore of a percussion revolver (unlike the patched ball method) and shows land and groove marking around its contacting circumference. The projectile has a diameter (before any impact deformation) equal to that of the bore of the gun.

Whether fired from a percussion revolver or from a muzzle-loading pistol or revolver, the exterior ballistic performance of spherical lead projectiles is poor compared to that of conical projectiles of the same caliber. In this context “poor” refers to a sphere’s high drag and correspondingly poor ballistic coefficient. It does not suggest that spherical projectiles are inherently inaccurate.

TABLE 3.4 Sphere Diameter (in.) from Weight in Grains for Three Metals

Lead	$d = 0.08727W^{1/3}$ *
Bismuth	$d = 0.09180W^{1/3}$
Steel	$d = 0.09857W^{1/3}$

*The cube root of a number can be determined on most contemporary pocket calculators possessing scientific keyboards.

Steel and Bismuth Spheres

The previous equations can be recalculated utilizing the densities of steel and bismuth. For mild steel/iron of 7.87 g/cc (1994 gr/in.³), the relationships are $W_{gr} = 1044d^3$, where d (diameter) is in inches and W (weight) is in grains:

$$d = 0.09857W^{1/3}$$

For bismuth with a density of 9.75 g/cc (2469 gr/in.³), the relationships are $W_{gr} = 1293d^3$, where d (diameter) is in inches and W is in grains:

$$d = 0.09180W^{1/3}$$

The more useful of these equations is the latter one, relating the diameter of out-of-round or deformed spheres of lead, steel, or bismuth to the cube root of their weights. These have been restated along with the expressions for lead in Table 3.4.

SUMMARY AND CONCLUDING COMMENTS

The various design and compositional features of projectiles can lead to the absolute exclusion of certain sources of shots and the identification of the specific source of a shot, even though such projectiles or projectile fragments are not identifiable by traditional comparison microscopy. This is possible through the concept of a limited universe.

The propellants used in small-arms ammunition are seldom completely consumed during the discharge process and often leave recognizable particles in the bore of the firearm, in the fired cartridge case, and on any object or victim in proximity to a firearm’s discharge. Their varied physical forms and their exterior ballistic properties provide a means of reconstructing certain shooting incidents.

Everything from the casing to the bullet to the unfired cartridge itself may have potential value in shooting incident reconstruction. The investigator should be at least passably knowledgeable about the many types of available ammunition and their components.

The simple matter of the weight of a bullet fragment, a separated bullet jacket, or a deformed spherical projectile can resolve important questions in certain shooting incidents. Weight determination is a quick, nonconsumptive measurement that has often been overlooked or not fully appreciated.

CHAPTER KNOWLEDGE

- What class characteristics of fired bullets can you think of?
- What class characteristics of fired cartridge casings can you think of?
- What class characteristics might be of value with regard to *unfired* cartridges?
- How many bullet types can you name from memory?
- When was the last time you looked at the wide variety of available ammunition types with the sole purpose of understanding the subtle differences from one to the next?

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Is It a Bullet Hole?

THE QUESTION OF HOLES

Is a particular mark on, or a hole in, an object caused by a bullet? This can be a relatively common question for crime scene technicians and the forensic laboratory. The answer is easy when a tracking through the hole leads to a projectile. It may not be easy when an investigator is presented with a defect in some object and no bullet is clearly associated with it. The answer to the question relies in part on some basic properties of projectiles and principles of physics and in part on a fundamental concept in forensic science: Last things first.

Locard's Exchange Principle stands for the proposition that, in theory, there will be a mutual exchange between two objects that come in contact with each other. Pressing your hand against a chalky blackboard (now you have some idea how old one of us is) results in the transference of chalk dust to your hand and the deposition on the blackboard of visible body oils and perspiration. The mutual exchange of material between two objects that come in contact is the guiding principle in trace evidence analysis. This conceptual model is equally important and just as useful in the reconstruction of certain shooting incidents.

The various metals used to manufacture most bullets are all relatively soft (e.g., lead, copper, copper–zinc alloys, aluminum). Moreover, the bearing surface of a fired bullet has been galled and abraded as a result of its rather violent journey through the gun barrel. This will further promote the transference of bullet metal to a subsequent impact site. The bearing surface of a fired bullet also possesses a coating of gunshot residue (GSR) that is rich in primer constituents and carbonaceous soot from the propellant. All these factors combine to produce and promote the transference of material from the bullet to nearly any impacted surface. Traces of these materials will almost always be deposited around the margin of a bullet hole or left in an impact site. This is particularly true in materials such as cloth, leather, or wood that the bullet essentially pushes its way into and through. These circumferential deposits are referred to as *bullet wipe*.

Bullet wipe takes the form of a dark ring around the margin of the bullet hole, as shown in Figures 3.17(a) and (b) and in a number of photographs in this chapter. Exceptions to the transference of bullet wipe are frangible and brittle surfaces that shatter or flake away as the projectile makes its way into them. Sheet metal is another medium that generally does not take up (i.e., absorb) bullet wipe well, even though metal transfers from the penetrating or

perforating bullet may be present. Certain fabrics and garments take up or retain bullet wipe to differing degrees. Cotton takes up and retains it well whereas some synthetic fabrics do not.

It may be desirable in those situations where no bullet wipe can be seen or detected with optical and simple chemical methods to examine some selected and representative fiber ends from around the margin of the suspected bullet hole under an scanning electron microscope (SEM) equipped with an energy-dispersive X-ray spectrometer (EDX) attachment. This instrumentation can locate and identify extremely small amounts of adhering GSR in situ, without consuming or altering any of it.

Beyond the mere transference of trace materials to a struck surface, bullets possess considerable kinetic energy in flight that is going to be applied to a relatively small area at the impact site. This not only enhances transference of trace material from the bullet but also typically leads to characteristic damage to commonly encountered materials (wood, sheet metal, cloth, leather, plastic, rubber, glass, etc.).

The case of nylon and polyester fabrics deserves special mention. The brief but intense frictional and crushing action of a projectile forcing its way through either of these fiber compositions produces a unique change at the severed ends of the individual fibers. This change takes the form of enlarged or swollen clublike ends around the hole margin, which can be seen with a stereozoom microscope. When viewed microscopically, the strong birefringence present in the unaltered nylon or polyester fibers will be nearly or totally relieved at the bullet-severed fiber ends as a result of the momentary melting or softening of the fibers during bullet passage. This effect can be easily demonstrated with a few test shots and is quite different from what will be seen by simply poking a hole in a nylon or polyester garment with some object (e.g., a pencil or even by burning a hole in the fabric with a cigarette).

Depending on the nature of the struck object, the responsible bullet will correspondingly suffer damage associated with the object's surface and frequently will acquire trace evidence or characteristic imprints from it. This is the other half of Locard's Exchange Principle in action. Bullets that strike the ground, concrete, or asphalt, or that perforate wood, glass, drywall, or fabrics, will all take up adhering traces of these materials. The physical damage that such bullets suffer will also bear a relationship to the nature of the struck surface.

Fabric imprints in lead that survive subsequent terminal ballistic events are often so clear that the particular weave and thread type can be seen and compared to any perforated garments or fabrics. Examples of a number of these interactions will be illustrated in Chapter 7, dealing with bullet penetration and perforation of materials, and Chapter 9, dealing with ricochet.

Determining Direction of Travel

Some types of materials (e.g., painted sheet metal) have unique properties that commonly allow determination of a projectile's direction of travel. However, it is worth reviewing and establishing some basic principles that allow us to tell in which direction a bullet was going when it struck an object. For entrances, here are some common features that should be documented and photographed as indicators of direction of travel:

- Smooth edges and bullet wipe (detected either visually or chemically) are good clues that you are dealing with a place of entrance. The image in Figure 4.1 depicts an entrance perforation in drywall or gypsum.

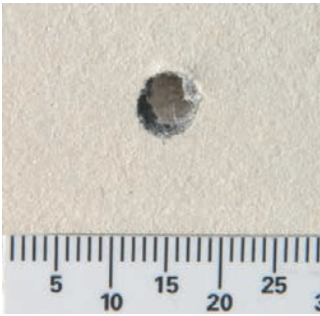


FIGURE 4.1 Entrance hole in a wall. Notable characteristics are the smooth edges, bullet wipe, and circular shape.



FIGURE 4.2 Entrance hole in plywood. Note the parabolic shape on the left side and the lead-in mark or partial bullet wipe on the acute side of the impact.

- Shallower angle entrances will commonly have a parabolic shape that may have bullet wipe or a lead-in mark. Whether parabolic or circular, these characteristics are commonly the basis for describing a bullet hole as “regular” versus “irregular.” The image in Figure 4.2 illustrates how even a textured, fibrous material, such as plywood, will show these features.

The next general rule should be taken with a large grain of salt, especially when dealing with gunshot wounds in people: The entrance will commonly be smaller than the exit. This can be readily observed in materials such as plywood and drywall. Malleable materials that deform plastically, such as sheet metal, will be bent in the direction of travel of the projectile (see Figure 4.3). The investigator should be interested in the presence of any gunshot residues from the muzzle of the firearm, as these residues will of course be on the entrance/firearm side of the perforation (see Figure 4.4).

In contrast to many of the aforementioned characteristics, exits may have rough, or “blown-out,” edges with no bullet wipe. Caution should be used when dealing with plain lead bullets or heavily fragmented lead cores because they may create smears at exits or secondary impact sites that might be confused with bullet wipe. Figure 4.5 is a set of images showing entrances in the top pane and the associated exits in the bottom pane. The regular, circular entrances from near orthogonal impacts are in stark contrast to the rough, irregular,



FIGURE 4.3 Deformation typically flows with the direction of travel for malleable materials that deform plastically.



FIGURE 4.4 Shallow angle perforation at the center of the image, with a large amount of visible gunshot residue to the *upper right*. The trajectory through the wood, as well as the orientation of the GSR, indicates that the trajectory is from upper right to lower left.

blown-out appearance of the holes in the lower pane. The image in Figure 4.6 gives a close-up view of what can be expected at exits from drywall. Similarly, the image in Figure 4.7 shows a frayed, conical exit commonly observed in plywood.

There are certainly exceptions to these rules, and the scientifically minded investigator should not jump to hasty conclusions. Two common exceptions come from wound ballistics and high-velocity impacts on thick steel. In the wound ballistic realm, some pathologists will steadfastly cling to the mantra “Small entrance, large exit.” This may hold true most of the time, but in cases where high-velocity rifle bullets have been destabilized, the entrance can be significantly larger than expected and, in many cases, larger than the exit. When high-velocity rifle bullets strike unhardened, thick steel such as that found on car wheels, the entrances will have a “crowned” effect that can easily be confused with an exit because of the flowing of the

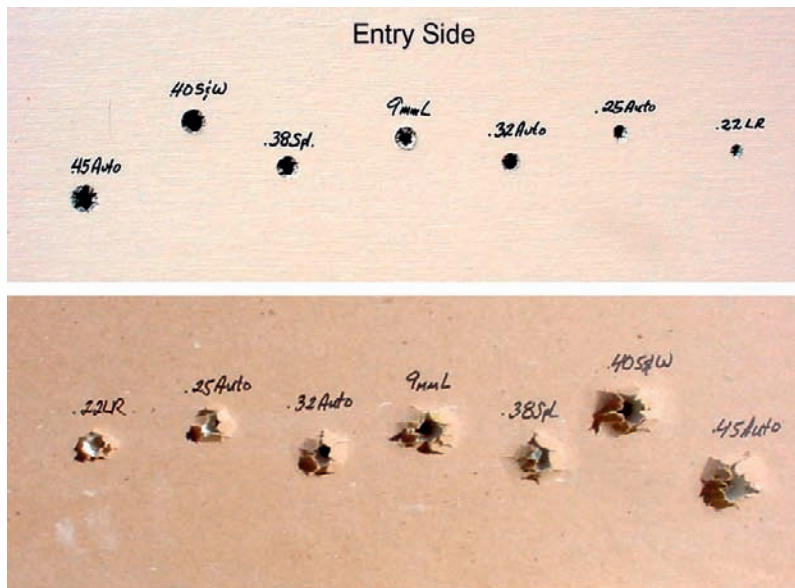


FIGURE 4.5 Entrance holes (*top*) and corresponding exits (*bottom*) for several different calibers.



FIGURE 4.6 Typical exit from drywall with ragged edges and a noticeable lack of bullet wipe.

metal in the direction from which the bullet came. The image in Figure 4.8 shows an *entrance* from a 5.56 bullet on the outside of a steel wheel.

Empirical Testing

The characteristic damage to an impacted surface produced by a bullet should be relatively easy to discriminate from impacts of other objects such as stones, debris, irregular fragments from explosive devices, and so on. As will often be the case, the examiner may



FIGURE 4.7 As expected, the edges of an exit from wood are ragged, irregular, and lacking bullet wipe.



FIGURE 4.8 Counterintuitive entrance of a rifle bullet into a thick, mild steel wheel. A “crown” of metal is visible flowing from the hole.

need to carry out some empirical testing to be satisfied as to the specific characteristics of bullet damage to the material under evaluation. This may ultimately include one or more test shots into a section or area of the actual evidence material as a definitive means of evaluating the bullet damage caused by the specific type of bullet, the Locardian transference of trace evidence between the bullet and the material, and any corresponding damage to the bullet. The use of an area in the evidence material for a test shot is justifiable on the basis of reducing or eliminating variables that could be present when using other seemingly similar materials for such tests. Such a site in a portion of the evidence material for empirical testing should be chosen and prepared with great care to ensure that subsequent tests do not alter or compromise the actual evidence site.

Although some readers may think that empirical testing is time-consuming and perhaps unnecessary, it is strongly recommended for other reasons. First of all, it can be an integral part of the scientific method. Second, it can be very useful in persuading a skeptical court and/or jury that your analysis, your evaluation of the evidence, and your subsequent opinions have merit and validity. In designing or selecting a test protocol, start with what is known about the incident under investigation. The following example should be useful.

CASE EXAMPLE

Bullet Holes in Wood

A putative bullet hole was found in a wooden fence board where a shooting incident had taken place. It is important to know (1) whether it is indeed a bullet hole and (2) if it can be associated with one of two subjects known to have fired their guns toward the fence. Shooter A is known to have fired a 38 Special revolver loaded with 158-gr lead round-nosed bullets. Shooter B fired a 9 mm semiautomatic pistol loaded with 124-gr (gilding metal: 95% copper, 5% zinc) full-metal-jacketed (FMJ) bullets. The shape and diameter of these bullets are quite similar, so the *size* of the hole in the board will *not* allow a resolution of this inquiry. Figures 4.9(a) and (b) show entry and exit holes from these two bullet types in a soft pine board.

Considerations and Solution

The physical features of a hole caused by bullets perforating a wooden board are straightforward and easy to recognize. The margin of the entry hole will be relatively smooth, often with visible bullet wipe, whereas the exit hole typically will have chips of wood dislodged from its margin and no bullet wipe. A simple test for lead, the *sodium rhodizonate test*, will show the presence of lead around the margin of this hole *if* in fact it was caused by a bullet. The procedures for preparing this reagent and carrying out this chemical test are described in the next chapter.

Optical inspection or photography in the infrared spectrum will typically reveal the IR-absorbent carbon in the bullet wipe. This technique is particularly useful when the background or surface is dark and any bullet wipe that might be present cannot be observed under normal lighting. Combined with the physical attributes of the hole in the fence board and the circumferential deposits of lead and carbon residues, the question *Is it a bullet hole?* can be answered in the affirmative.

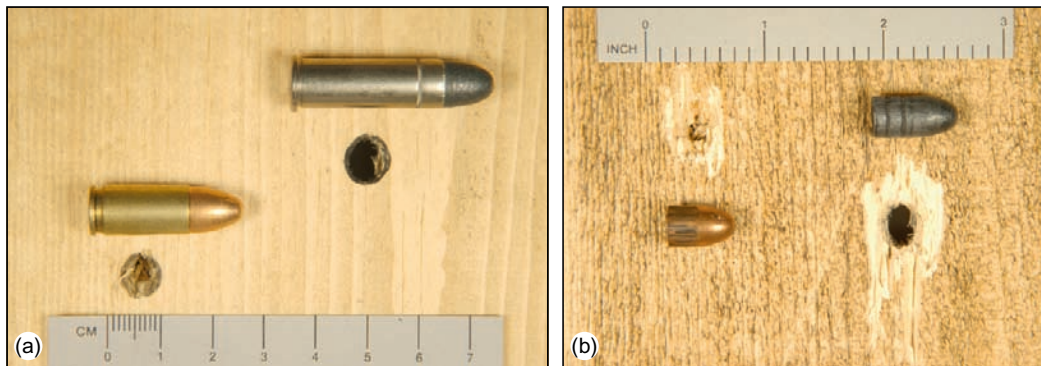


FIGURE 4.9 Entry and exit bullet holes in a soft pine board produced by (a) 9mm and (b) 38 caliber bullets.

Note how the wood fibers have closed in to a much greater degree in the bullet hole produced by the FMJ 9mm bullet (*left*) than in that produced by the LRN 38 Special bullet (*right*). The lead bullet has deposited a much darker ring of bullet wipe, as one would expect. The internal surface of the track produced by the lead bullet is coated with dark gray lead deposits (not visible in these photographs), whereas the track produced by the FMJ bullet is free of any visible deposits.

However, the sodium rhodizonate test will be positive for bullet holes in soft wood whether they were produced by a lead round-nosed bullet or by an FMJ bullet. This is true because the bullet wipe from the FMJ contains lead from the priming mixture (i.e., lead styphnate and possibly other lead-containing primer constituents) as well as lead eroded from the open base of the FMJ bullet and redeposited on its bearing surface. Such bullets typically pick up lead residues from a previously fouled bore.

Carbonaceous material also stands to be present in bullet wipe from both plain lead and jacketed bullets. The question of discriminating a bullet hole by a jacketed bullet from one produced by a lead bullet of similar caliber cannot be answered by the sodium rhodizonate test. A test for copper, on the other hand, will allow discriminating the source (given the very limited universe of choices in this example), since only the 9 mm FMJ bullet will have copper residues in the bullet wipe. The sodium rhodizonate test for lead will still be useful in verifying that the hole was caused by a bullet.

The proper protocol for tests and the preparation of reagents will be discussed in the next chapter. It should be pointed out that the plain lead bullet will leave considerable lead along the interior surface of its track through the wood, whereas the FMJ bullet will leave little or no detectable lead in this area. Therefore, there may come a point in such an investigation that the interiors of each of the bullet holes may need to be tested for lead with the sodium rhodizonate reagent.

The wood fibers in the channel of a bullet's path through wood often close in after the bullet's passage so that it may not be possible to see through such a hole. Any probes passed or forced through such a hole should be chosen carefully so as not to alter the path created by the projectile or to transfer lead or copper deposits to any of the wood.

Note: Plain lead bullets, because they are much softer, will *not* pick up sufficient copper residues from previously discharged jacketed bullets to produce detectable levels of copper in the bullet wipe from lead bullets.

BULLET HOLES IN TYPICAL MATERIALS

Figures 4.10(a) through (f) provide a representative sampling of bullet holes produced in some common materials and reproduced to the same scale. All of these holes were produced with the same 9 mm Ruger P-85 pistol. In all of the figures, 124 gr round-nose FMJ and 124-gr JHP bullets with 0.22-in. diameter hollow points were used (see Figure 4.11). The specific behavior of small-arms bullets as they strike, penetrate, and perforate many of these common materials and the response of these materials will be discussed in a later chapter.

Nylon and Polyester Fabrics and Garments

Representative bullet holes in cotton cloth are shown in Figure 4.10(b). The general size and shape of a defect in almost any type of clothing, overlying an entry gunshot wound in concert with the presence of bullet wipe around the margins of the hole, make its identification as the result of a bullet relatively straightforward. This determination requires a little more caution if there is no gunshot wound that can be aligned or reasonably associated with

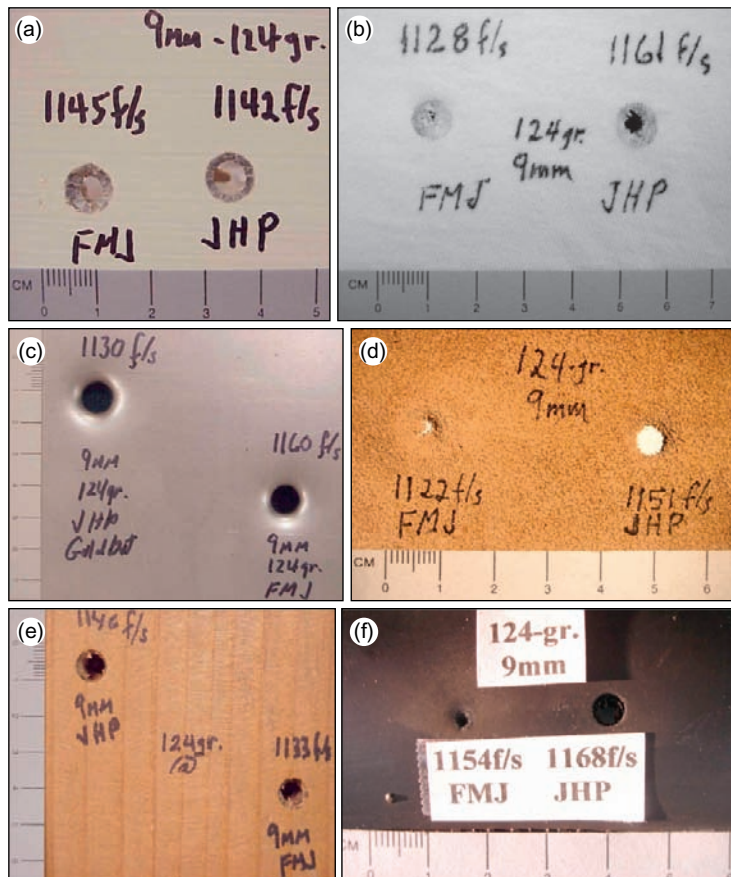


FIGURE 4.10 Entry bullet holes in typical materials produced by round-nose and hollow-point bullets: (a) painted sheetrock; (b) cotton cloth; (c) 22-gauge sheet metal; (d) suede leather; (e) pine board; and (f) tire sidewall. These materials were all shot using the same Ruger P85 9 mm pistol and the two types of bullets shown in Figure 4.11. Each target material was positioned just beyond a ballistic chronograph located 15 feet beyond the pistol muzzle. The line of fire was orthogonal to each target. The velocity values in feet per second have been written on all targets. A centimeter scale is included in each photograph, and all scales are printed to the same size so the reader can make direct visual comparisons between bullet holes. Note the “cookie-cutter” effect produced by the hollow-point bullet in cloth, leather, and rubber.

the defect in the garment. However, the presence of obvious bullet wipe, with its attendant chemistry of carbon, bullet metal, and primer residues, effectively establishes causation.

Still, bullet wipe can be removed in some situations (e.g., washing of the garment, long exposure to the weather, burial in certain types of soil, prolonged submersion), or it may not have been deposited due to the projectile’s passing through some intervening object. In these situations it may not be possible to identify the source of the defect from the physical attributes alone, with two exceptions: nylon and polyester. The frictional forces and crushing action of a projectile passing through fabrics made of, or blended with, these



FIGURE 4.11 Two styles of 9mm pistol bullets used to prepare bullet-hole examples.

The bullets in these 9mm cartridges consist of a full-metal jacketed round nose design (FMJ-RN) on the *left* and a JHP design on the *right*. The diameter of the hollow point cavity is 0.22 in.

synthetic fibers undergo a unique and characteristic transformation. We have given multiple presentations on this phenomenon and have used it in a number of cases, but we never got around to reducing it to an article in any scientific journal, so this chapter would seem the appropriate place.

The severed ends of nylon or polyester momentarily soften or melt and take on a swollen, clublike appearance. This can be seen with a stereomicroscope adjusted to the higher powers of magnification (e.g., 30x to 40x), but the ultimate tool is the polarizing microscope. Both fibers are highly birefringent when viewed under the polarizing microscope using crossed polars, but the properties that cause this are relieved by this momentary frictional heating so that the enlarged ends of the fibers around the margin of a bullet hole *lack* any birefringence.

This phenomenon is best viewed and photographed with normal illumination followed by insertion of the polarizer and/or the 1-wave plate; see Figures 4.12(a) and (b). It is distinctly different from the mere severance of the fibers by other means or even from the burning of a hole in such fabrics with something similar to a cigarette. Neither will forcing objects, such as a pencil, through the fabric or garment produce this characteristic effect.

The use of nylon and polyester is not limited to clothing, but can be found in duffle bags, baseball caps, sleeping bags, tents, and a host of other items. The material does not need to be composed entirely of nylon or polyester. The polyester fibers in cotton/polyester blends respond in the same manner. Unlike the effects of bullet wipe and gunshot residue, the thermal-mechanical effects on the projectile-severed ends of nylon and polyester do not wash out or deteriorate with time. They will be present at entry bullet holes, and, if the energy and velocity of exit are sufficient, may be produced in exit holes as well. While shoring of the nylon- or polyester-containing fabric aids in the production of these characteristic fiber ends, it is not required.

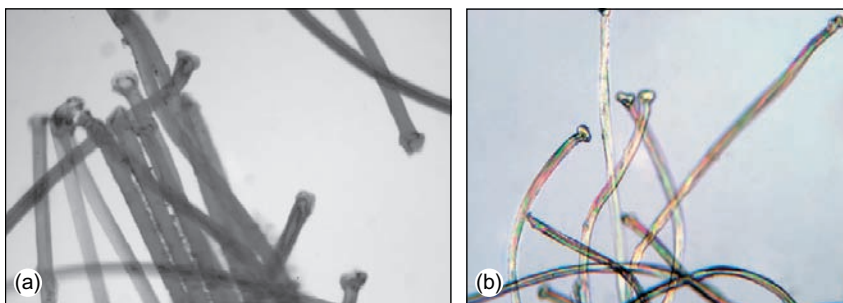


FIGURE 4.12 Bullet-severed fiber ends at the margin of bullet holes in nylon and polyester fabrics. Photomicrographs taken through a polarizing microscope at 100x. (a) Nylon fibers severed by a lead hollow-point 22LR Stinger bullet. (b) Polyester fibers severed by an FMJ 30-Carbine bullet.

There is one final application of this phenomenon that may be overlooked. Fibers snagged by a bullet or punched out by one as it passes through a nylon- or polyester-containing material, with a little searching under the microscope, will display this effect. This is useful in differentiating such fibers from others that are simply debris or artifacts from the environment in which the bullet was recovered. Those wishing to study this effect need merely acquire some remnants from a fabric store and carry out ballistics testing followed by the necessary microscopy.

SUMMARY AND CONCLUDING COMMENTS

With training and experience, the physical properties of bullet holes and bullet impact sites in most materials are readily distinguishable from defects produced by other objects. The determination is easy when a recognizable projectile is ultimately recovered and the end of a channel in the struck object is known. In the absence of an embedded bullet, the transference of bullet metal and bullet wipe to the margins of many bullet holes and impact sites provides a means of verification through chemical or instrumental methods.

Empirical testing with comparable ammunition offers a useful and graphic way to illustrate the specific properties of bullet holes or impact sites in the evidence material.

CHAPTER KNOWLEDGE AND CONCLUDING COMMENTS

- What are some of the characteristics you would look for in determining direction of travel at a perforation site?
- This chapter discussed rifle bullets that have perforated mild steel wheels, but what about aluminum wheels or wheels of other, unknown, materials? How would you be sure you were coming to the correct conclusion when you have not seen this particular combination of ammunition and substance?

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Some Useful Reagents and Their Application

INTRODUCTION

As pointed out in Chapter 4, one of the common questions that arise in the investigation of shooting scenes is whether a hole in, or a mark on, some object was produced by a bullet. If it can be established as bullet-caused, additional questions may arise. For example, what can be said about the nature of the bullet that caused the hole? Was it lead or copper-jacketed? Can directionality be determined? Can anything be deduced about the velocity or energy associated with the projectile's impact from the nature or pattern of any bullet metal deposits? From the amount of damage? From the degree of penetration or lack thereof?

Two reagents properly formulated and properly applied can usually answer most of these questions. A third reagent may be necessary in certain situations. Use of these reagents does not require the examiner to be a degreed chemist. Some training and practice, along with some procedural controls, will allow the examiner to successfully apply these reagents in the field and make reliable assessments concerning the nature of a questioned bullet impact or perforation site.

TESTING FOR COPPER, LEAD, AND NICKEL

The two most common tests are dithiooxamide (DTO), for traces of copper, and sodium rhodizonate, for lead. A supplemental reagent for copper detection is 2-nitroso-1-naphthol (2-NN). These tests come out of well-known and long-established microchemical methods for the detection of copper, lead, and nickel, and have been adapted to forensic situations. Of the tests, sodium rhodizonate is the most useful and common, but DTO can usually resolve issues where it is important to know if the bullet was copper-jacketed as opposed to some type of plain lead. The structures of these three reagents and their reactions with lead and copper are shown in Figures 5.1 through 5.3.

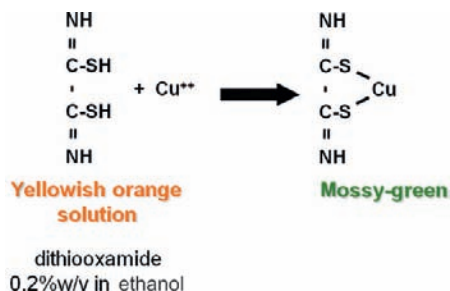


FIGURE 5.1 Dithiooxamide test for copper.

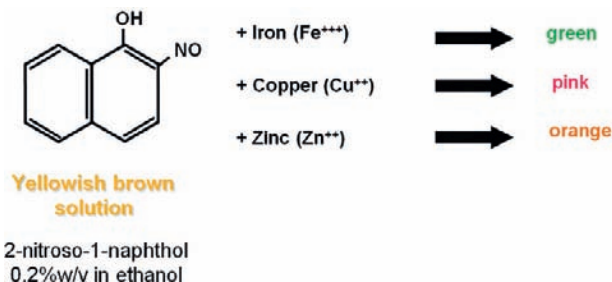


FIGURE 5.2 Here is the 2-nitroso-1-naphthol test for copper.

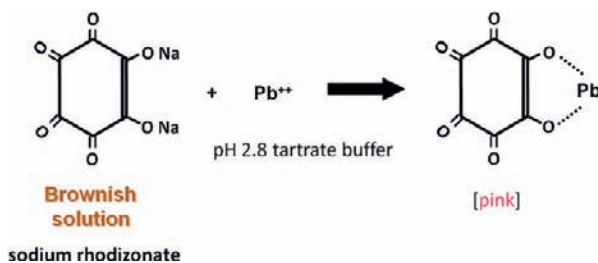


FIGURE 5.3 Sodium rhodizonate test for lead.

As pointed out in the hypothetical example of bullet holes in a wooden fence (Chapter 4), lead will be present in nearly all bullet impact marks (including those from full-metal-jacketed (FMJ) bullets) and in the wiping around bullet holes. This is because the primer mix of nearly all present-day centerfire ammunition contains lead (most commonly from lead styphnate). Some of the lead-containing residue from the discharge of the cartridge finds its way onto the bearing surface of the bullet as it makes its way down the bore of the firearm. This is true even for the first shot through a previously cleaned bore with a jacketed bullet. Subsequent shots with jacketed bullets will typically have a higher concentration of lead as a result of “pick-up” from the fouled bore. FMJ bullets with their lead cores exposed at the base also generate substantial lead residues during discharge through erosion by the hot powder gases. The temperatures of these gases are on the order of 3000°C, which is well



FIGURE 5.4 Example of lead splash.

Shown is a plain lead 22 long rifle bullet just after it has impacted a thick aluminum plate. The bullet approached from the lower right corner of the photograph. The impact velocity was approximately 1100 fp, and the incident angle was 85° (5° off perpendicular). Gray deposits of partially vaporized lead can be seen on the aluminum plate just above the impact site. Numerous small fragments of lead and the major bullet fragment can also be seen fanning out at low departure angles relative to the surface of the aluminum plate.

Source: Digital image by forensic photographer Stan Obcamp, Phoenix, AZ.

above the melting (327°C) and boiling (1749°C) points of lead. Some of this vaporized lead becomes a part of the residue on the bullet's bearing surface and will usually transfer to the impacted surface depending on the nature of the material struck.

In summary, the presence of lead around the margins of a hole or in an apparent graze mark may establish the hole as bullet-caused but not necessarily as the consequence of a lead bullet.

Another phenomenon called "lead splash," detectable with the sodium rhodizonate test, quite literally adds another dimension to the analyst's reconstructive efforts. When lead or jacketed bullets with exposed lead tips impact a surface, some of the lead may be partially vaporized and then condensed on the much cooler adjacent surface. Figure 5.4 shows an example of lead splash for a 22 long rifle bullet striking a thick aluminum plate at about 1100 feet per second. If the bullet's intercept angle is shallow, the pattern of the splash can show the directionality of the responsible bullet (see Figure 5.5). Proper use of the sodium rhodizonate and DTO tests employing either a "lifting" or direct-application technique (depending on the nature of the surface) can render these deposits and their distribution visible. These results should be photographed and the lift retained if the transfer method has been used.



FIGURE 5.5 Lead splash as a result of a low-incident-angle impact and ricochet.

A visible ricochet mark (from the 3-cm to the 7-cm mark) on a brick sidewalk has been “lifted” with tartrate-treated filter paper (shown above the gray ricochet mark), then sprayed with saturated sodium rhodizonate solution. The pink color is due to the presence of lead. The approximate boundary of the ricochet mark has been outlined with a black marking pen on the BenchKote filter paper. Vaporized and minute particulate deposits of lead have fanned out from the actual contact area of the projectile and show the direction of the bullet’s travel from left to right.

Suggested procedures for the copper and lead tests are given in the following pages. The materials and reagents are readily available from several chemical suppliers. A complete field kit for copper and lead testing is available from at least one source.

Authors’ note: At the time of this edition (2011), lead-free primer mixtures are becoming more and more common; however, lead contamination of bores previously fouled with lead-containing ammunition and primer mixtures will still result in lead-positive bullet wipe for many (e.g., 25–50 shots) subsequent shots of the newer lead-free ammunition. This is due to the very tenacious nature of lead residues in the bores of firearms from previous firings.

THE DITHIOOXAMIDE TEST FOR COPPER RESIDUES

By way of background, dithiooxamide (also known as rubeanic acid) is a specific colorimetric reagent for copper. Several chemical reactions have been proposed for the coupling of copper ions with DTO. The one proposed by Jungreis was shown in Figure 5.1. The more important matter is DTO’s specificity for copper. The reaction produces a color that has been variously described as mossy gray-green to charcoal-green in the presence of trace amounts of copper. Because copper is much harder than lead, there is no such thing as “copper splash” with common small arms projectiles, and any positive response will only occur in locations where the copper-jacketed bullet made direct contact with the surface tested, with one and possibly two exceptions:

- The first exception relates to the fact that in close-range discharges (inches to several feet), small particles of copper-jacketing material may be stripped from the bullet during discharge and become part of the overall gunshot residue deposited around a bullet hole.

- The second exception relates to the appearance of certain brands of special-purpose frangible ammunition that are intended for indoor ranges and training situations. A number of bullets used in this type of ammunition either contain or are composed of powdered copper in a plastic matrix. The firing of such bullets generates numerous particles of copper that often appear to be and behave like partially burned powder particles expelled from the muzzle of the gun. The DTO reagent would, of course, react with such particles, raising the possibility of using this test in conjunction with the sodium rhodizonate test and the Modified Griess Test in a distance determination procedure.

Important note: If both the lead and copper tests are to be carried out, the dithiooxamine (DTO) test for copper *must* be done *first*. The reason for this is that the mild acidic solution used to transfer lead residues will *also* transfer copper residues. If the lead test were carried out first and it seemed to be important to then carry out the copper test, any copper in the bullet impact site would likely have been previously removed by the lead test.

The mildly alkaline (basic) ammonium hydroxide solution used with either test for copper (DTO or 2-NN) will *not* remove lead residues because they are insoluble in it. Copper will be selectively removed or rendered reactive by the ammonium hydroxide solution, leaving the lead behind for subsequent detection by the sodium rhodizonate test. The DTO and/or 2-NN reagents and materials described here allow copper-containing residues in bullet impact sites to be detected and made visible through a simple color-complexing reaction and a lifting technique.

As previously mentioned, lead and jacketed bullets with exposed lead noses can produce lead splash on impact and leave much greater quantities of lead on the impacted surface. An example of this type of bullet was shown in Figure 3.1(a) (fourth from left). Even FMJ bullets have been known to produce lead splash where the impact energy is sufficiently high to tear the jacket and expose the bullet's inner lead core.

Fiegl's 1958 work describes the DTO test as about 15 times more sensitive than the sodium rhodizonate test for lead, but several competing factors in shooting investigations tend to offset its sensitivity. These include the greater hardness and higher boiling point of copper over lead and the ability of bullets with exposed lead to splash on impact and overwrite the underlying copper deposits. Additionally, the color produced from the complexing of DTO with copper ions is not very exciting or conspicuous, and it can, at times, be difficult to see against anything but a clean white background. As little as 0.1 μg of copper can be detected in a 1-cm spot on white filter paper with DTO. This is also the case for 2-NN.

Pretest Considerations

Before *any* testing is carried out, the examiner should give some thought to the case, the nature of the surface to be tested, and what can be seen at and in the questioned impact site.

Testing for both copper and lead is *not* required to verify a hole or impact site as bullet-caused. It may be desirable, however, to use both tests in certain cases where the bullet types are known and/or where the presence of copper would be useful in reconstructing certain ballistic events in a shooting incident (such as the hypothetical example of a bullet hole in a fence in Figures 4.2 and 4.9).

The following are the materials and reagents needed for testing:

- Small sprayer unit (two or more are recommended)

- Whatman BenchKote® (*Note:* Sheets of almost any smooth-surface filter paper can be used in lieu of BenchKote.)
- Dithiooxamide in ethanol (0.2% w/v solution) having a light orange color (*Note:* Dithiooxamide is a stable compound both as dry powder and as a 0.2% w/v reagent in ethanol; it can be stored at room temperature.)
- Ammonium hydroxide solution (2:5 dilution of concentrated ammonium hydroxide solution) (*Note:* This, too, is stable at room temperature for weeks to months when kept in airtight containers. If the solution does not have a distinct ammonia odor prior to use, a new solution should be prepared. The ammonium hydroxide concentration is not particularly critical, but the 2:5 dilution of concentrated NH_4OH solution (28–30% NH_3) is recommended. Solutions as strong as a 1:1 dilution have been used, but the strong ammonia odor is objectionable to many.)
- Sections (squares) of BenchKote (a plastic-backed form of filter paper manufactured by Whatman, Inc., of Clifton, New Jersey) for use as a lifting medium in concert with the ammonium hydroxide solution (*Note:* BenchKote is not mandatory, but it does offer several advantages over plain filter paper. It can be cut to various sizes and shapes as needed for the particular surface, and the analyst can write or draw on the plastic backing. This backing adds strength to the paper side and serves as a moisture barrier during the lifting process.)

Theory

Copper residues are soluble in both acidic and ammoniac solutions. Lead residues are *insoluble* in ammoniacal solutions (indeed, if otherwise water soluble, they would be *precipitated* in the presence of OH^- ions); however, they will be subsequently solubilized by acetic acid or tartrate buffer solutions used with the Modified Griess Test for nitrites and with the sodium rhodizonate reagent. If copper and lead residues are both present in bullet wipe or impact transfers, contact with the 2:5 ammonium hydroxide solution will preferentially transfer some of the copper residues and leave the lead residues in place. Once the residual NH_4OH solution has dried (evaporated) from the object or surface being tested, application of the pH 2.8 tartrate buffer solution used with the sodium rhodizonate test will solubilize some of the lead in the same residue and allow it to react with this reagent.

From the foregoing it should be apparent that if one wishes to test for *both* lead and copper, the DTO test for copper *must* precede the sodium rhodizonate test for lead. If carried out in the reverse order, the acidic nature of the lifting reagent for the sodium rhodizonate test will lift *both* metals. It would be a stroke of good luck that sufficient copper were left behind for subsequent detection with DTO or 2-NN if the lead test were carried out first.

Procedure

Follow the steps here for testing bullet holes in clothing.

Step 1. The section of clothing containing the possible copper-containing bullet wipe should be placed over a water-repellant substrate such as waxed paper or the plastic side of a separate piece of BenchKote.

Step 2. The filter paper side of a suitably sized section of BenchKote is moistened to a glossy sheen with 2:5 ammonium hydroxide solution from a small sprayer (allow adequate ventilation).

Step 3. The moistened side of the BenchKote paper is pressed firmly against the putative bullet hole and the adjacent area. Maintain firm contact for about 30 seconds but do *not* cause the filter paper to move or slide across the surfaces being tested.

The hole should be partially visible or detectable by feel through the translucent BenchKote paper so that the location of the hole and any other “landmarks” can be delineated on the plastic surface with a black marking pen. These marks are for subsequent orientation purposes after the processing of the test paper has been completed. We typically place a small dot on the plastic backing at the center of the hole being tested, and trace one or more landmarks such as seams, buttonholes, and the edges of a sleeve or collar.

Step 4. The BenchKote paper is inverted and visually inspected prior to any further treatment. Photography is highly recommended at this point for the following reasons:

- As previously stated, the color complex between DTO and copper ions, while specific for copper, is not particularly exciting and can look like the mere transference of dirt or grime. Verification that there has been no transference that might later be confused with a DTO–copper reaction is very important before proceeding to the next step.
- If there has been transference of some material that has a similar color to the DTO–copper response, the examiner should consider using 2-NN instead of DTO.

Another option with or without the presence of any potentially confusing color transference is simply to allow the ammonium solution to dry and carefully protect and package the “lift” for later processing in the laboratory. If copper residues have been transferred to the filter paper, they will still be there days, weeks, months, and even years later, and can be rendered visible with the DTO reagent.

Step 5. Following satisfactory completion of the previous step, the filter paper side is sprayed *lightly* with the 0.2%-alcohol DTO reagent after verifying that the DTO reagent are working with a known copper transfer or deposit in one or more corners of the BenchKote filter paper. A dark greenish-gray ring corresponding to the margin of the hole constitutes a positive test for copper-containing bullet wipe. Although this chemical complex between copper and DTO is typically stable over long periods of time, color photography of the results is strongly advised.

Note: If the filter paper side is still quite wet, it may be desirable to let it dry somewhat before overspraying with the alcohol DTO reagent. There is often a tendency to apply more DTO than necessary. The examiner should realize that there is vastly more reagent in each drop of this solution than there is likely to be on the transfer paper, so drenching the paper is clearly counterproductive. Partial drying prior to DTO application will improve sensitivity and contrast.

For bullet graze or ricochet marks, go directly to Steps 2, 3, 4, and 5 of the procedure just described.

Note: Prior microscopic examination of impact marks will often reveal flecks of copper-jacketing material lapped or piled up on raised or abrasive particles on the struck surface. This simple nonconsumptive examination, if available, should not be overlooked. If such flecks of metal are present, macrophotography is strongly encouraged.

Additional note: As pointed out previously, if the ammonia solution lift shows a transference of material that could be confused with the color of the DTO–copper complex (or that could obscure it), we recommend the alternative 2-NN reagent. Like DTO, 2-NN is made up as a 0.2% w/v solution in ethanol, in which it has a light yellow color. It is not as stable as DTO and should be stored in a refrigerator when not in use. Also, as with DTO, a known copper transfer should be tested first to verify the 2-NN's viability. This reagent can detect as little as 0.1 μg of copper in a 1-cm-diameter spot on smooth white filter paper.

Supplemental 2-NN Procedure for Copper Residues

The 2-NN reagent should be considered where the color of the ammonium hydroxide lift might be confused with, or obscure, the DTO–copper reaction.

The same technique described in Step 5 of the DTO procedure is employed here. The appearance of a pink color against the light yellow background of the reagent indicates the presence of copper. Pink is much easier to see against any dingy background color on the BenchKote or filter paper lift and should be photographed. It may be desirable to outline any positive pink reaction with a pencil because there is more to do in this procedure.

A few false positives have been observed with the 2-NN reagent (a pink result even though copper is not present); consequently, a follow-up treatment should be carried out, which involves allowing the 2-NN–treated lift to reach near-dryness and then lightly overspraying it with the DTO reagent. If the pink color developed with 2-NN is indeed due to the presence of copper, it will disappear and be replaced by the DTO–copper reaction.

Figure 5.6 shows a BenchKote lift (using the 2:5 ammonium hydroxide solution) of a ricochet mark produced by a copper-jacketed bullet. The copper-positive area has been cut lengthwise and one-half of it has been sprayed with DTO, the other half with 2-NN. Figure 5.7 shows the effect of overspraying the 2-NN–treated portion with the DTO reagent.

Note: The DTO and 2-NN tests are also capable of giving positive responses with impact marks and bullet holes produced by copper-plated, steel-jacketed bullets.

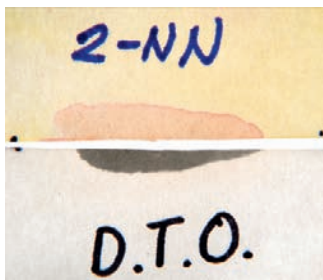


FIGURE 5.6 Comparison of the 2-NN test and the DTO reagent on a ricochet mark lifted with BenchKote and ammonium hydroxide solution.

The lift of the ricochet mark was produced by a copper-jacketed bullet. It has been sectioned lengthwise, then the halves treated separately with the 2-NN and DTO reagents for copper.

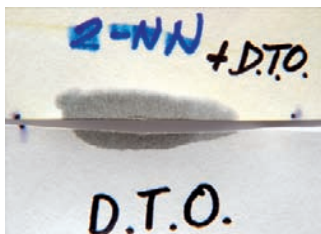


FIGURE 5.7 Results of overspraying a 2-NN test with the DTO reagent.

Shown is the copper-positive 2-NN response from Figure 5.6 after spraying with the DTO reagent. The DTO reagent replaces 2-NN and gives the dark gray-green color for copper.

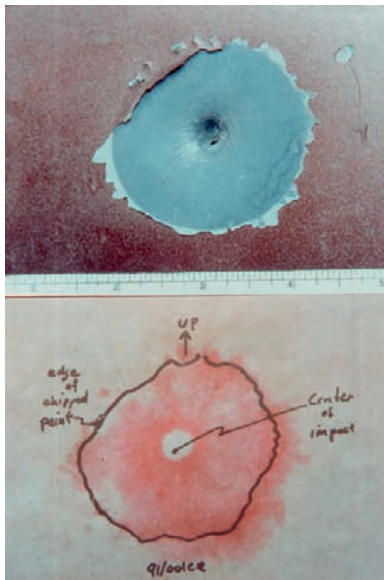


FIGURE 5.8 A suspected bullet impact site in a car door.

An area of deformed metal and missing paint is shown in the upper half of this image. The responsible object failed to perforate the sheet metal and was never found but the driver told investigators that a person in another car shot at him with a small caliber pistol. The lower half of the image shows the BenchKote–tartrate buffer “lift” shortly after being treated with sodium rhodizonate solution and mounted on a light box. The outline of the missing paint has been marked during the lifting process. This impact site was ultimately determined to be the consequence of a 40 gr, 22-caliber lead bullet that failed to perforate the car door because of its low velocity. Note that the lead splash developed covers the area of missing paint and even extends out onto the surviving paint. The small, unresponsive area in the center of the lift was a result of the inability of the lifting paper to make contact at the deepest point of the impact site. The pattern of lead splash and the deformation of the sheet metal show this to have been a near-orthogonal strike.

THE SODIUM RHODIZONATE TEST FOR LEAD RESIDUES

The sodium rhodizonate test allows lead-containing residues in bullet wipe and/or projectile impact sites to be made visible by a simple color-complexing reaction (shown in Figure 5.8). Depending on the nature of the object to be tested, such lead-containing traces may be visualized in situ (on the actual object) or lifted onto BenchKote or filter paper as in the tests for copper. The criterion for deciding to apply the reagents directly to an object or through a lifting technique will be described in the Procedure section.

The following are the materials and reagents needed for the sodium rhodizonate test.

- Small sprayer unit (two are recommended)
- pH 2.8 aqueous tartrate buffer, 3% w/v (1.9 grams of sodium bitartrate + 1.5 grams of tartaric acid per 100 ml of distilled or deionized water) (*Note:* For those with pH testing capabilities, a 3% w/v solution of tartaric acid in water can be adjusted to pH 2.8 with the addition of three or four reagent-grade sodium hydroxide pellets.) Add a small amount of preservative such as benzalkonium chloride and/or refrigerate if this reagent is to be stored for any length of time.
- Saturated aqueous sodium rhodizonate (rhodizonic acid, disodium derivative) solution (*Note:* This reagent is unstable once it is mixed with water and must be prepared just prior to use. Control tests (described later) are used to verify its reactivity after standing for any length of time, such as 15 minutes or more, after preparation. The concentration of the sodium rhodizonate reagent is not particularly critical. It can be prepared in the field simply by adding small amounts of the dark, powdery reagent to the chosen volume of water until a moderately strong orange-brown solution is formed (comparable to strong tea). A slight excess of undissolved reagent is acceptable and represents a saturated solution.)
- Whatman BenchKote (*Note:* Sheets of smooth filter paper can be used in place of BenchKote but this product offers the same distinct advantages as those described for the DTO test.)
- Dilute hydrochloric acid solution (5 ml 37% HCl + 95 ml distilled water). (*Note:* This reagent may be optional in the field and can be used later as a final step if deemed necessary, because it is stable over time and at room temperature unless the cap is left loose.) The solution is used either as an overspray or as a spot treatment after obtaining the positive pink color response with the tartrate buffer and sodium rhodizonate solution.

Procedure

The sodium rhodizonate procedure is based on a well-known colorimetric test for lead that is sensitive to microgram quantities of this metal in the form of particulate deposits from primer residues, vaporized bullet metal, bullet fragments, lead-containing bullet wipe, or other impactive transfers by lead-containing projectiles.

The pH 2.8 tartrate buffer solution solubilizes a portion of the lead in the direct-application method and allows it to react with the sodium rhodizonate reagent. Similarly, it causes a transference (lifting) of some of the lead deposits onto a more suitable medium and background (smooth white filter paper or BenchKote paper) in situations where direct application is not desirable or practical. The same technique as described for the DTO test applies: firm pressure without slippage or movement, marking landmarks, and placing orientation marks on the lift.

The tartrate buffer decolorizes the orange-brown color of the sodium rhodizonate and leaves the pink lead-rhodizonate color complex according to the chemical reaction shown earlier in Figure 5.3.

The 5% HCl reagent is optional and is used if there is any doubt or question that the pink color developed with the sodium rhodizonate reagent is due to lead: The addition of or overspraying with 5% HCl will turn the pink to a blue-purple. The reader is forewarned that the color intensity will be reduced and the blue color may fade with time. A color

photograph of the test results prior to 5% HCl addition is therefore strongly recommended. (Barium and strontium may give vaguely similar colors with the rhodizonate/tartrate reagents, but they are decolorized after 5% HCl overspraying.)

It should also be pointed out that the *entire* area of the pink response need *not* be sprayed with the 5% HCl solution. We frequently mask off the majority of the positive pink area and then spray a small representative site. Placing a drop of HCl on a small, selected area of the pink response is an alternative method for carrying out the confirmation test.

Verification of Reagents

Verification that the reagents are working correctly is accomplished by lightly marking a corner of the BenchKote or filter paper with the nose of a lead bullet, or by placing on it a drop of a known solution of soluble lead salt such as lead acetate containing approximately 0.02% soluble lead by weight. This area is misted with the tartrate buffer solution and then oversprayed with freshly prepared sodium rhodizonate solution. An immediate pink color should form where the known lead sample was used to mark the test paper, and the orange-brown color of the rhodizonate reagent should decolorize in a few minutes.

If the optional hydrochloric acid treatment is to be used, a subsequent overspray with this reagent should cause the pink to turn blue-purple, often with some loss of intensity if the lead concentration is low. A preferable method is to simply place one or two drops of the hydrochloric acid solution in selected areas and then observe and document the immediate pink-to-purple change for lead.

DIRECT-APPLICATION METHODS FOR TESTING

Where the substrate is white or light-colored and *absorbent*, the analyst may elect to treat the surface directly. Examples of such surfaces would be lightly colored cotton garments and a lightly colored pine board with a questionable bullet hole or graze mark in them. In such instances the approach described for the verification of reagents is employed; however, before applying *any* of the reagents described in this chapter, there must be careful thought and consideration of possible pretesting.

If, for example, it is deemed important to test for the presence of copper, there are multiple factors to be considered and evaluated. Although the DTO reagent is more sensitive than 2-NN, the development of the dark gray-green copper–DTO complex is not likely to be seen or distinguished in a ring of bullet wipe or in a sooty area. Furthermore, the object must be lightly moistened with the ammonium hydroxide solution to yield a good reaction. The treated object must be thoroughly dried (to remove the ammonium hydroxide) before application of the tartrate buffer and sodium rhodizonate solution; otherwise, the test for lead will fail. If the 2-NN reagent appears to be a better choice (because of background color problems for the DTO test), you are now confronted with the possibility of a pink color result (due to copper) to be followed by the sodium rhodizonate test, which also yields pink.

There are a couple of solutions to this quandary. One is to return to the lifting technique with filter paper or BenchKote treated with the ammonium hydroxide solution. Another is to divide or partition the object or material to be treated along some line of symmetry and

only treat half of it, leaving the other half for treatment with the tartrate buffer and sodium rhodizonate reagent. Pre- and post-treatment steps should be photographed with and without a scale and under the same lighting conditions. Some form of orientation mark(s) along with an item number or site identifier in the field of view is recommended. If a traditional film camera is used, a gray card to calculate proper exposure is very useful where bright or white objects are involved. Digital cameras have the advantage of immediate playback, allowing the adequacy of the exposure to be observed. An additional photograph would follow any treatment of a positive sodium rhodizonate response with the 5% HCl solution.

EXAMPLE

As stated elsewhere, the differences between the “rifle world” and the “pistol world” are great. This is true for long-distance trajectories, for wound ballistics, and for the behavior of lead-in cores on impact with objects in a terminal ballistic manner. Figure 5.9 shows a direct-application spray of tartaric acid buffer followed by sodium rhodizonate, allowing the visualization of *significant* amounts of vaporized lead on the jacket. While there were several shots from a .223 caliber rifle fired into this jacket, the large amount of lead in the armpit area is a telling sign that the bullet hit something else before this area. In this case, one or more bullets struck the decedent’s arm, exited, and entered the torso area. The quantity and pattern of lead shown is not what would be expected for common handgun bullets. Note the known positive reagent check in the lower right corner of the image.



FIGURE 5.9 A light-colored jacket or other garment is a good candidate for the direct-spray method of lead analysis. Rifle bullets in particular will create large amounts of “vaporous” lead as a result of impacts.

“LIFTING,” OR TRANSFER, METHODS FOR TESTING

The “lifting,” or transfer, method is useful with dark-colored, immovable, nonporous, mildly bloodstained, and/or difficult-to-reach objects or surfaces. Its success requires skill and sound judgment on the part of the examiner or investigator. Over- or underwetting with the tartrate buffer solution, incomplete contact, or movement of the lifting paper can cause problems. Heavily bloodstained objects may require special processing by the forensic laboratory prior to testing for lead residues.

Hydrophobic (water-repellant) substrates also present difficulties that may require some thought and evaluation prior to testing. Nylon garments, oil-based enamel finishes, plastics, and the like, fall in this category. We have found it useful to add a *small* amount of liquid detergent to the tartrate buffer solution or about 10 ml of reagent alcohol per 100 ml of buffer solution to act as a wetting agent. Experimentation on an area known to have *no* evidentiary value is highly desirable before the questioned area of an item or object is tested.

If the substrate to be tested can be wetted without the tartrate buffer beading or running, proceed as follows:

Step 1. Prepare a section of BenchKote or filter paper of sufficient size to cover the questioned site *and* some of the surrounding unaffected area to serve as a “blank.”

Step 2. Evenly moisten the evidence item to the extent that the tartrate buffer is *not* running off or forming puddles, but to the degree that the subsequent pressing of the BenchKote or filter paper against the item will cause blotting. Very porous surfaces such as cinderblock, bricks, and concrete surfaces may also necessitate a light premoistening of the transfer paper. These materials are especially troublesome because they are very alkaline and often neutralize the tartrate buffer, thereby preventing the transfer of any lead residues. The 15% acetic acid solution normally used with the Modified Griess Test may be preferable as a lifting agent. It may even be necessary to lightly mist such surfaces with 15% acetic acid and carry out a second lift.

Step 3. The transfer paper must be thoroughly pushed and pressed into the surface without allowing it to slip or slide.

Step 4. Orientation marks should be placed on the backside of the transfer paper (the side toward the examiner) *before* it is lifted from the surface.

Step 5. If dry areas are seen, careful lifting of one side of the transfer paper and respraying is appropriate.

Step 6. Once it is certain that the limits of the transfer paper’s contact with the substrate have been defined and documented, the paper may be turned over, placed on a suitable surface, and sprayed with fresh sodium rhodizonate solution to produce an even yellow-brown color. Any transferred lead residues will immediately appear pink. (Note that right-left reversal will be present when you view or photograph the contact side of the transfer paper.)

If the surface to be tested is hydrophobic or difficult to work with, or if it is deemed undesirable to spray the object itself, proceed as follows:

Step 1. Prepare a section of the transfer paper as described previously.

Step 2. Evenly moisten the transfer paper until it is shiny wet and translucent but not runny.

Step 3. Promptly press the transfer paper firmly against the substrate as previously described. If properly wetted, you should be able to partially see through the BenchKote.

Step 4. Make appropriate orientation marks on the transfer paper *before* lifting it from the surface.

Step 5. If the hydrochloric acid confirmatory step is determined to be necessary, the lift (or a selected portion of it) can be oversprayed with the 5% HCl to give the blue-purple color with lead. This color change should be promptly photographed.

Step 6. After the transfer paper has dried, it should be stored inside plastic protective sheets like those used for photographs. In the event there is some need or desire to carry out further testing on any lead-positive response, a scanning electron microscope (SEM) stub can be used to stub the lift or any area that has produced a positive response to the sodium rhodizonate reagent, and the stub examined with an SEM/EDS (energy-dispersive X-ray) system. This can not only confirm the presence of lead but also reveal other elements often associated with firearm-generated lead deposits (e.g., barium, antimony, tin).

Note: As previously mentioned, right-left reversal occurs with the lifting technique; therefore, you may wish to photograph the fresh, translucent lift on a light box or while taped to a window exposed to daylight. Alternatively, the photo lab can be instructed to reverse the negative when making a print. Digital photographs are easily reversed with a computer. These techniques will make it easier for nontechnical people to understand the spatial relationships for any lead deposits lifted from the evidence item.

EXAMPLE

Figure 5.9 showed a light-colored jacket that lent itself well to the direct-spray method of lead detection. Now examine Figure 5.10, which shows the T-shirt that was worn underneath that jacket. In this case, a direct spray would not be a good idea because a positive response for lead would be quite difficult to discern.



FIGURE 5.10 Shirt with a significant amount of damage to the right armpit area. Because of the darker color, and the presence of blood, a direct-spray method is not desirable.



FIGURE 5.11 Reverse image of a sodium rhodizonate lift of the T-shirt shown in Figure 5.10. One of the lift technique's best properties is its ability to show pattern information for lead deposits where they may not have otherwise been visible. Note the reference lines drawn from the T-shirt.

The corresponding lead lift on paper is shown in Figure 5.11. There are three things to note in this figure: (1) There are visible reference lines that look like the edges of the T-shirt to show the orientation and location of the positive result; (2) some blood has been absorbed by the test material, warranting proper handling of the paper; (3) the image has been flipped for ease of understanding by the audience. Remember, the lift paper will be a flipped image once it is pulled away from the area of interest. In this one case examination, it was appropriate to shift from the direct to the lift technique because of the different fabrics in the jacket and T-shirt.

THE DIMETHYLGLYOXIME TEST FOR NICKEL RESIDUES

Nickel is a silver-white metal with an atomic weight of 58.71. Its melting point is 1555°C and it has a calculated boiling point of 2837°C. Nickel is a hard metal (a Moh's hardness of 3.8 compared to lead, copper, and steel at 1.5, 2.5, and 4, respectively) belonging to the iron-cobalt group. It easily takes on a polish that is readily seen in nickel-plated bullets, buckshot, or cartridge cases, which have a shiny, almost mirror-like sheen to them. Nickel resists oxidation, and nickel-plated cartridge cases left at a scene for months and years look as shiny as they did when deposited there.

A number of brands and types of bullets have a shiny nickel coating over their gilding metal or mild steel jackets. Certain pistol bullets in the Winchester SilverTip line have a nickel plating over a copper alloy jacket. Pistol bullets and a few rifle bullets of foreign manufacture likewise come with a nickel plating, as do certain loadings of buckshot.

After an evaluation of the circumstances of a shooting incident, it may become apparent that one or more shooters discharged ammunition with nickel-plated bullets. In such cases it may be appropriate to consider the use of the dimethylglyoxime (DMG) test. Just as with

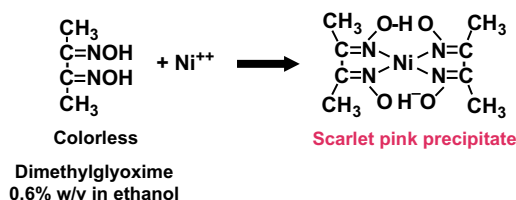


FIGURE 5.12 Dimethylglyoxime test for nickel.

the DTO test for copper, a DMG test for nickel could resolve some important questions in an shooting investigation. Another advantage of this reagent is that it is a clear colorless solution, making color development much more visible and more easily interpreted. The testing process is carried out by the transfer method using the same 2:5 dilution of concentrated ammonium hydroxide solution employed with the DTO and 2-NN reagents for copper. The DMG reagent is available either as a pure white to off-white powder or as a 1% w/v solution in ethyl alcohol, or it can be purchased in pure form and the appropriate-strength solution can be prepared in or by the laboratory.

Chemistry of the Nickel Dimethylglyoxime Reaction

According to Fiegl (1958), DMG forms a stable, bright red insoluble salt with nickel salts in neutral, acetic acid, or ammoniacal solutions. When placed in the same environment, two DMG molecules form a ring around a single metal nickel ion and bind to it in a chelating process (as shown in Figure 5.12). The resultant compound has been used as a sun-fast pigment in paints, lacquers, cellulose compounds, and cosmetics.

DMG Test Procedure

Some thought must be given to the incident under investigation. Just as you need to determine the reconstructive value of a test for copper, so it is when considering the DMG test for nickel. In fact, this test can be even more complicated than a test for copper if the examiner is faced with discrimination of bullet holes or impact marks produced by nickel-plated projectiles, copper-jacketed bullets, or plain lead bullets. At least two techniques are available to the examiner, as described in the following sections.

Technique A

Sections of BenchKote or filter paper that have been pretreated with an alcoholic solution of DMG and dried are used in this procedure. We have found no detectable difference in the performance of such pretreated papers using solutions of 0.2% w/v or 1% w/v. They are stable over long periods of time and can be kept in a manila envelope or folder.

A corner of the pretreated test panel previously cut to the appropriate size is lightly moistened with the same 2:5 ammonium hydroxide solution used with the DTO and 2-NN reagents. A drop of a standard nickel solution on the order of 0.005% soluble nickel is placed on the moistened area. A common U.S. 5-cent coin (the one with Jefferson on one side and Monticello on the other), which is composed of a 75% copper and 25% nickel alloy, can be

used as an alternate method for reagent verification; it is pressed firmly against the moistened area for about 30 seconds.

Once the positive response for nickel is noted, the remaining area of the transfer panel is lightly sprayed with the ammonium hydroxide solution, then firmly pressed against the suspected bullet hole or impact site along with an appropriate surrounding area. The lift is then removed, inverted, and inspected for the scarlet-pink response for nickel. If this response is the consequence of a nickel-plated bullet (as opposed to nickel-plated shot), copper is also likely to be present, and a subsequent overspray with the DTO reagent should reveal this since the DMG reagent does not interfere with the DTO–copper reaction. If the nickel-positive response is due to nickel-plated shot, there should be no copper present. Instead, a large amount of lead should be present when this same site is later tested using the tartrate buffer transfer technique and the sodium rhodizonate reagent.

The pre-impregnation of the test paper provides the advantage that the DMG reagent is evenly distributed across the test medium. Moreover, the color change that occurs will be more representative of the substance at its original location. Finally, as previously pointed out, the DTO test for copper can be carried out by lightly overspraying this same test paper.

There is at least one disadvantage to the pre-impregnated transfer papers, however. If the detection of copper is also important and the lift pulls up the same dingy color that was described in the DTO procedure, the use of 2-NN is severely, if not totally, compromised when a positive response for nickel has occurred. This is for the obvious reason that the analyst is now trying to see a pink color against an already strong pink background.

The previous example of a positive nickel response from nickel-plated lead shot compounds this potential problem in that the large amount of lead residue that stands to be present might result in a dingy area of transfer against which the DTO test (to show the *absence* of copper) is obscured. Such a quandary should be thought out in advance and if it is a clear possibility, then Technique B should be used.

Technique B

This technique goes back to a lift of the area with plain filter paper or straight BenchKote paper moistened with the 2:5 ammonium hydroxide solution. As before, judgments should be made about any need for a copper test and the presence or absence of a dingy transferred color that would mask the DTO test. If a copper test is deemed useful, then carefully cut the test paper in half through the area of special interest. After verifying the performance of the reagents with a known nickel and copper source as described in Technique A, lightly spray one half of the lift with the appropriate copper reagent and the other half with the DMG reagent. Document the results as before, and dry and retain the test papers.

Barrel Residues

Because the use of nickel-plated bullets is relatively uncommon and the presence or absence of nickel residues in the bore of a gun may have important reconstructive value, it is appropriate to add a method for the testing of gun barrels. One round of a nickel-plated bullet will typically leave nickel deposits that produce an unequivocal DMG response, whereas subsequent shots with common copper-jacketed or lead bullets will greatly reduce or even negate any positive response for nickel.

To test the bore of a firearm for nickel deposits, soft cotton gun-cleaning patches pre-impregnated with DMG are recommended. Alternatively, a patch moistened with 2:5 ammonium hydroxide can be used. A patch from the same supply should be moistened and tested for a positive response with a known nickel source before processing the bore of the submitted firearm. When the examiner is ready to test the bore, the pretreated DMG test patch is pushed through the bore just as would be done in normal cleaning, making certain that the patch fits tightly.

If an ammonia-only patch has been used, it is then oversprayed with the DMG in alcohol reagent. This patch also should be chosen to fit tightly in the bore. It is further suggested that the patch be worked back and forth to enhance the removal of any nickel residues.

Note: Nickel-plated firearms should not be tested for the obvious reason. Likewise, it is usually pointless to test the bore of a shotgun since nickel-plated shot is usually nested in a plastic shotcup and does not come in contact with the bore.

SUMMARY AND CONCLUDING COMMENTS

This chapter described two reagents, DTO and 2-NN, for the detection of traces of copper in bullet wipe and bullet impact sites, and for particular residues generated during the discharge of copper-containing frangible ammunition. One or both of these tests need be carried out only when the detection of copper stands to be of importance in the case at hand or until such time that totally lead-free ammunition is common.

The sodium rhodizonate test for lead will reveal both the presence and the pattern of lead deposits on clothing and other surfaces, around and in bullet holes, at bullet impact sites, and in the overall gunshot residue deposits associated with close-proximity discharges. These deposits can confirm a hole or damage site as bullet-caused. Lead-containing “lead-in” marks associated with low-incident-angle projectile strikes, and/or the location of “lead splash” at a bullet impact site, can also establish the directionality of the impacting bullet. These characteristic marks will be discussed further in Chapter 9, dealing with ricochet.

Whether the analyst employs the lifting technique or the direct-application technique, areas that extend beyond the site in question should also be treated with the DTO and 2-NN reagents. This both serves as a reagent blank (so that that the reagents themselves are not contaminated with the particular metal) and ensures that the surface being tested does not contain detectable levels of lead, copper, or nickel. The use of cotton swabs or commercial test sticks to test suspected bullet impact sites is discouraged because it is difficult to completely rule out the presence of lead or copper in the tested material or surface. Moreover, *no* pattern information is provided when using cotton swabs to test selected sites.

With rare exceptions, the DMG–nickel response, the DTO–copper response, and rhodizonate-developed lead deposits are stable over time when stored at room temperature and out of strong light. However, subsequent hydrochloric acid treatment with the sodium rhodizonate test reduces the sensitivity of the test approximately tenfold and may result in a gradual fading of the lead-specific blue-purple color. Color photography would be appropriate for the documentation of any color reactions that the examiner develops.

A DMG test for the nickel used in some ammunition, also described in this chapter, may, after a careful evaluation of what is known about the case, serve as a useful adjunct to the standard copper and lead tests.

It should be understood that any copper, lead, and nickel lifted by the transfer technique have *not* been destroyed or consumed. They have simply been rendered visible by a color-complexing reaction. This means that alternative procedures (e.g., instrumental methods such as SEM-EDX) could be employed to further test these color complexes if their chemical identities come to be in serious question. Testing can be done on small, representative areas that are both color-positive and color-negative by excising a small square or rectangle out of the lift with a scalpel which is mounted on a stub designed for SEM-EDX, appropriately carbon-coated, and then analyzed.

In those instances where the lifting method has been used for lead or copper, it is very unlikely that all of the lead or copper has been transferred to the lifting paper. Typically there will be additional lead and copper left behind on the substrate so that the test can either be repeated or evaluated by some other means at some later time.

It must also be understood that traces of these metals may not be transferred or solubilized in a sufficient amount to respond to the particular reagent. This is especially true in the case of nickel residues because this metal resists oxidation and solubilization by either ammonium hydroxide or tartrate buffer. Stated another way, positive responses for any of the tests described in this chapter are useful and potentially meaningful. The failure to detect lead, copper, or nickel in bullet wipe or at a bullet impact site does not necessarily rule out their presence in the bullet's composition or construction.

If at any time the examiner is unsure about the effectiveness of the planned protocol, a control test should be carried out on a nonevidentiary area of the substrate.

Finally, as with all chemicals, special precautions should *always* be taken to avoid reagent absorption or inhalation. Rubber gloves and a fume hood are appropriate when working in the laboratory. If the examiner is carrying out such tests in the field, rubber gloves are still a requirement, along with an open area free of bystanders and with the tester located upwind of the object being treated.

CHAPTER KNOWLEDGE

- Can you name all the reagents mentioned in this chapter? Can you name the appropriate reaction color changes for each metal of interest?
- If you had a cartridge for examination and wanted to know what the bullet jacket was made of, how might you use these reagents to make a determination?
- Do you thoroughly understand the difference between molecular compounds and the elemental nature of the metals of interest in this chapter?
- Make sure that you understand the definitions of the following terms: *known positive*, *background*, *chromophoric*, *colorimetric*, *reagent*, *solvent*.
- When a lift technique is used, is the investigator *destroying* anything?

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Distance and Orientation Derived from Gunshot Residue Patterns

INTRODUCTION

The term “gunshot residues” (GSRs) includes unconsumed powder particles, carbonaceous material from the incomplete combustion of propellant, primer constituents, and ablated bullet metal. In certain situations, this term also includes vaporized lead and/or bullet lubricants. It is important to differentiate “GSR” from “primer residue.” While primer residues are certainly a component of GSR, their detection, scale, and meanings are significantly different. All of these materials are expelled from the muzzle of a firearm during discharge and, at close range, will be deposited on nearly any surface. The dimensions of the pattern and the density of certain discharge products provide a means for estimating the distance between the muzzle of a gun and the surface bearing them.

A useful analogy that can be made in describing GSRs for a jury is this. An individual holds in his hand a golf ball, sand, and ash. He throws all of these materials at the same time with the same initial speed. The ash is the least dense and has the least mass. It represents the carbonaceous and lead residue component of GSR. This component is typically deposited at very close ranges. The sand represents the partially burned and unburned gunpowder particles. These have significantly more mass than the carbon/lead residue (the ash) and carry a greater distance from the muzzle. They create a pattern that increases in diameter and decreases in density the further away a surface or witness panel is. The golf ball represents the projectile, with significantly more mass than the ash or the sand; it continues down range to a much greater distance than the other materials do.

Realistically, one would not expect any sort of GSR at 30 yards or 500 yards from the muzzle, so beyond the GSR’s maximum deposition distance for a gun–ammunition combination, a range estimate based on these residues is not likely. Additionally, range determinations are most commonly bracketed. This means that a typical result is not “The range from muzzle to target was thirteen inches.” More likely and scientifically defensible

is wording such as “The range from muzzle to target was greater than six inches and less than twenty-four inches.” In this scenario, the known patterns created in the laboratory at 6 inches were likely too small in diameter and too dense as compared to the evidence pattern. The known patterns at 24 inches were too large in diameter and too sparse in density, yielding the aforementioned 6-to-24 bracketing.

Spacing and replicate testing are chosen depending on factors such as evidence pattern, target material, availability of ammunition, and pattern reproducibility during testing. A good standard is to carry out testing at contact, and then 3, 6, 12, 18, 24, and 30 inches, with a minimum of three shots per known distance. This spread of distances usually covers most of the major changes in GSR patterns. At the greater distances, pattern changes are typically less rapid than at the shorter distances. Replicate testing allows the investigator to get an empirical baseline for the consistency of the gun–ammunition combination.

Probably the most useful discharge products are partially burned and unburned propellant particles, and sooty residues. Besides soot, the residues may include vaporized lead and materials present in the bore of the firearm from previous firings. Vaporized lead normally arises from the discharge of lead bullets or full-metal-jacketed (FMJ) bullets with lead cores and exposed lead bases. The sooty material (sometimes called “smoke”) typically consists of carbonaceous material and primer constituents (either vaporous materials or very fine particulates). It may also include vaporous lead from the previously described sources. The firing of a jacketed bullet through a previously leaded bore (from shooting lead bullets) will produce large amounts of vaporous lead. This will diminish with the discharge of each subsequent round of jacketed ammunition.

All discharge products provide varying degrees of useful information relating to the range of fire when they are deposited on any surface, including the skin of gunshot victims.

Forensic pathologists often provide range-of-fire estimates in their reports based on sooty residue deposits and/or powder stippling or tattooing patterns around an entry wound. Their opinions are usually based on experience and general considerations. Any numerical distance conclusions presented by a pathologist or other investigator who has not conducted known distance tests with at least a similar gun–ammunition combination should be carefully evaluated and reviewed.

Most pathologists and scene personnel will correctly limit their findings to verbal descriptions such as “contact,” “close,” “intermediate,” and “distant,” because any critical assessment regarding range of fire will require the creation of known distance patterns on a suitable material. Then a conclusion regarding the evidence pattern can be made based on observable traits such as pattern diameter and density and the presence or absence of sooty residues. Powder particles expelled from the muzzle of a firearm have velocities comparable to that of the projectile and, since they are relatively hard, they may produce physical damage (stippling) to any surface they strike. Such surfaces include wood, painted metal, plastic, leather, and wallboard.

The stippling of skin is well known and arises from the same mechanism—namely, the impact of very energetic particles of unconsumed and partially consumed gunpowder. In this situation the powder particles produce small, hemorrhagic injuries in a living individual. When the mass and energy of these particles are sufficient to enter and embed themselves in the skin, the term “tattooing” may be applied by some medical examiners. Others make no distinction between stippling and tattooing and often use these terms interchangeably. However, “tattooing” would *not* be applied to powder patterns in inanimate objects.

Figure 6.1 and Figure 6.2 show powder stippling in painted wallboard and automotive sheet metal, respectively. Figure 6.3 shows a powder-stippling pattern in wood with an added feature of special reconstructive value.



FIGURE 6.1 Powder pattern in painted wallboard.

The path of this close-range shot from a 38 caliber revolver was from the lower right of the photograph. Multiple particles of gunpowder can be seen adhering to, and embedded in, the paint. The pattern formed by these powder particles is elongated because of the oblique angle of fire. Once documented as to location and photographed, the path of this bullet should be determined. Following these efforts, the entire area of powder-stippled wallboard should be cut out and impounded for any later comparisons of propellant morphology and/or muzzle standoff distance determinations.

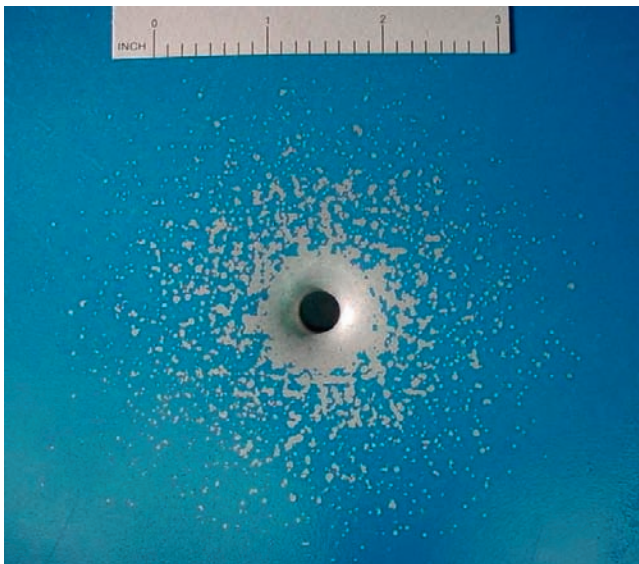


FIGURE 6.2 Powder stippling in painted sheet metal.

This shot was fired directly into a panel of painted sheet metal from a standoff distance of about 6 inches using a 357 Magnum revolver. The energy of the partially burned and unburned particles of gunpowder was sufficient to stipple and even remove small areas of paint at the individual impact sites.



FIGURE 6.3 Gunshot/residue/powder pattern on wood.

This shot was sufficiently close that soot and unburned powder particles were deposited around the entry bullet hole in the wooden gate. It was also discharged after a first shot was fired through this board from the opposite side. The sequence for the two shots was determined by the presence of powder particles embedded in the area of blown-out wood around the exit bullet hole on the right.

A portion of the powder pattern shown in Figure 6.3 involves an area of missing wood particles around an exit bullet hole. This figure is a recreation of a case where two armed individuals were on opposite sides of a gate. According to the surviving shooter he was standing very near the gate when the decedent fired a shot through it, barely missing him. He immediately returned fire, striking and killing the subject. This account is supported by the presence of powder embedded both in the interior surface of the gate (“I was standing very near the gate”) and in the blown-out areas of wood around the exit bullet hole (“I returned fire”).

In this example it is the mere presence and location of embedded powder particles that answers the critical question of shot sequence. It is the spatial distribution, composition, and density of GSRs and the patterns they create that often allow distance and/or orientation of the firearm to be determined. The expulsion of powder residues from the muzzle of a firearm follows a conical distribution with distance, much like a shotgun discharge in miniature. Depending on their size, density, and shape, these particles can easily produce powder patterns out to several feet. Spherical ball powder residue from centerfire ammunition will travel the farthest (powder patterns as far as four feet) because of this morphology’s superior exterior ballistic properties. Flattened ball powder comes in second. Flake powder residues travel the shortest distance, producing powder patterns at distances on the order of 18 to 24 inches. (See Chapter 3 for a review of the various physical forms of small arms propellants.)

With any and all physical forms of gunpowder, a distance will be reached with the particular gun–ammunition combination at which *no* discernable powder pattern is recognizable, although a few scattered powder particles may be found adhering to the surface of the “target.” These distances are on the order of 4 to as much as 15 feet. Figure 6.4 summarizes the effects of standoff distance and GSR deposition.

In addition to the physical form of the propellant, its burning rate, the weight of the powder charge, the efficiency of the particular load, and the gun’s barrel length all have a bearing on

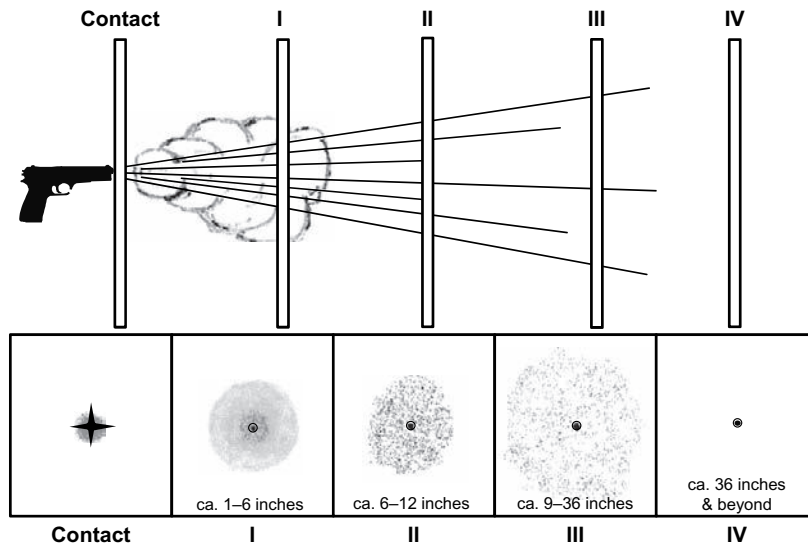


FIGURE 6.4 General characteristics and behavior of GSRs with range.

Typical characteristics include contact blast destruction, stellate tearing of skin or clothing, and very intense soot possible around the edges of the entry site but mostly on the inside of the garment or driven into the wound. The outline of certain contacting parts of the firearm (e.g., front sight, barrel bushing) may be imprinted on the skin adjacent to the entry hole. This phenomenon is referred to as *muzzle imprint*.

Zone I, shows intense, dark soot with dense deposits of unburned and partially burned powder particles around the bullet hole. Blast destruction is still possible in clothing, as are powder tattooing and stippling of the skin, as well as stippling of certain inanimate objects such as wood, drywall, painted surfaces, and plastics. Zone II shows no visible soot or only some faint sooting. A circular deposit of powder particles will be present around the bullet hole. Powder tattooing and stippling are likely, particularly with ball powder and poorly burning propellants.

Zone III shows no visible soot. A roughly circular deposit of widely dispersed powder particles is present around the bullet hole. Powder particles are often loosely adhering at the greater distances. The Modified Griess Test may raise nitrite-positive sites where powder particles struck but later were dislodged. Powder stippling of skin is still possible, particularly at the closer distances.

Zone IV shows no discernable pattern of firearms discharge products. A few scattered and loosely adhering powder particles may be found but lack any pattern. Bullet wipe will be present around the margin of the entry hole regardless of the distance from which the shot was fired.

any powder pattern that might be produced at some selected standoff distance from a recording medium. A long barrel will generally result in *decreasing* the unconsumed powder emerging from the muzzle but it can *increase* vaporous lead eroded from the bases of FMJ bullets containing exposed lead cores. Keeping all other factors the same, a shorter barrel produces more unconsumed powder at the muzzle, just as one would expect, but it also results in a greater dispersion of these particles because of the higher pressures at the muzzle. This in turn, increases the diameter of the powder pattern and reduces its density. *Density* here refers to the number of powder particles per unit area at some standard distance from the bullet hole.

Figures 6.5(a) and (b) show powder patterns on white filter paper (BenchKote®) at the same standoff distance of 6 inches with the same FMJ 357 Magnum ammunition fired from a 4-inch and an 18.5-inch barrel, respectively.

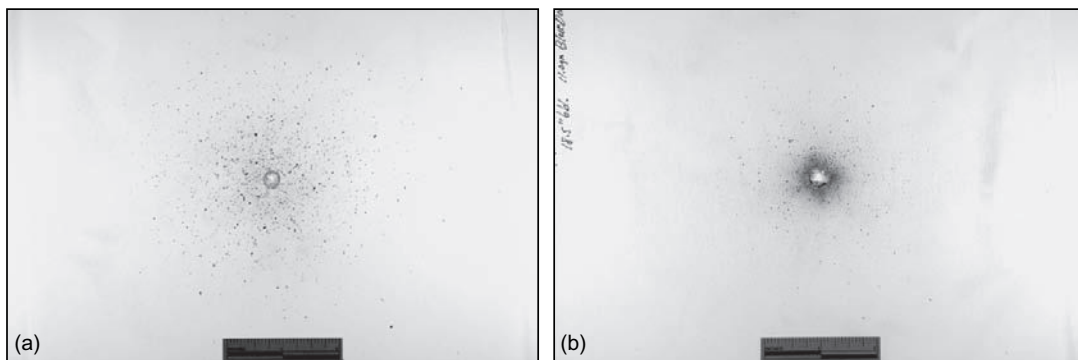


FIGURE 6.5 Powder pattern at a 6-inch standoff distance: (a) 357 Magnum cartridge fired from a 4-inch Smith & Wesson revolver; (b) 357 Magnum cartridge fired from a 18.5-inch Carbine.

Both 357 Magnum cartridges used to prepare these powder patterns were loaded with 11.0-gr charges of a medium-burning, unperforated disk-flake powder and 170-gr FMJ bullets. The much greater barrel length resulted in more of the propellant being consumed (reduced powder pattern (b)), but it also allowed more time for the hot powder gases to vaporize some lead from FMJ's base (dark gray deposits around the bullet hole).

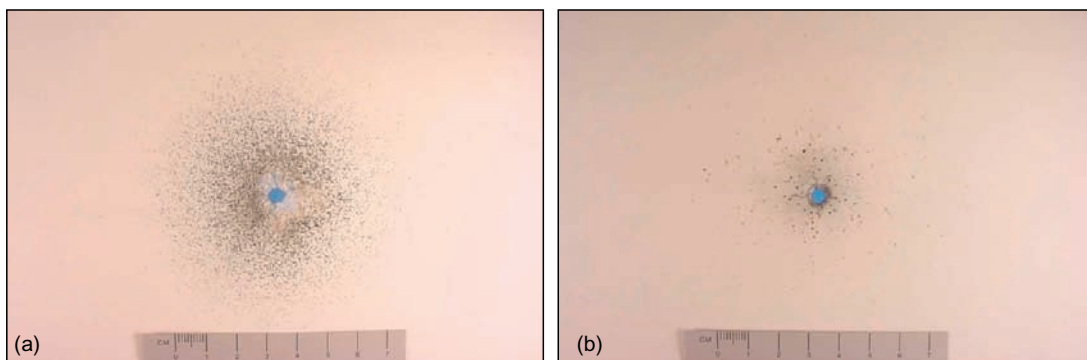


FIGURE 6.6 Powder pattern with factory .38 Special cartridge loaded with (a) ball powder and (b) disk/flake powder.

These powder patterns were produced with the same Colt revolver at the same standoff distance of 6 inches with two different lots of 125-gr JHP Remington 38 Spl. ammunition: one containing 18-gr charges of spherical ball powder and the other containing 5.5-gr charges of unperforated disk-flake powder. These cartridges produced comparable muzzle velocities but, as shown, produced very different powder patterns.

Finally, some propellant–bullet combinations are more efficient than others. This means that one can encounter cartridges of a particular brand, caliber, and bullet weight that are loaded to the same muzzle velocity and peak pressure but that produce very different amounts of gunshot and unconsumed propellant residues. Figures 6.6(a) and 6.6(b) show powder patterns produced with the same revolver at the same standoff distance, with two different lots of 125-gr JHP Remington 38 Special ammunition: one containing 18-gr charges of spherical ball powder and the other containing 5.5 grains of unperforated disk-flake

powder. These cartridges produced comparable muzzle velocities but, as can be seen, *very* different powder patterns.

The lesson to be learned here is that any test patterns must be produced with ammunition comparable to that discharged in the actual incident. Reliable numerical distance determinations can only be accomplished by empirical evaluation of the involved gun and ammunition types. Numerical range-of-fire estimates based on experience but without such testing leave firearm examiners, crime scene investigators, and pathologists on tenuous ground and open to legitimate attack.

The soot, or smoke, cloud generated during the discharge of a firearm rapidly expands and dissipates in a generally spherical form. These vaporous-to-fine aerosol particles travel much shorter distances than do partially burned and unburned powder particles. Visible soot/smoke deposits seldom extend more than 6 to 10 inches beyond the muzzle of the gun with modern ammunition. At very close standoff distances, they are very dark and localized around the bullet hole. As the muzzle-to-surface distance increases, these deposits often exhibit a gradient. With some gun–ammunition combinations, reproducible patterns or ringlike deposits may occur. Finally, there will come a distance at which the soot/smoke deposits are barely discernable, although chemical methods may render them visible.

TARGET MATERIALS

A variety of target materials have been used for the preparation of exemplar powder and GSR patterns with firearms submitted for examination. They include heavy white blotter paper, card stock, jean twill cloth, fresh pig skin, foamboard, and BenchKote. Initial test shots at selected distances are typically carried out and compared to the evidence pattern. When patterns are obtained that are close to it in diameter and density, some examiners carry out the final test shots with samples of the actual evidence material (garment, wall-board, etc.) taken from an area that does not affect or compromise the evidence. We support this approach because it can refine the examiner's estimate of range of fire by removing the variable created by the use of a target material other than the actual surface on which the powder–GSR pattern exists.

Patterns on human skin necessitate the use of some form of target material. As a result of multiple tests we and others have carried out, we generally prefer BenchKote for this purpose. Fresh white pig skin has been used but besides being difficult and messy to work with, it offers little advantage over BenchKote, heavy blotter paper, or jean twill cloth. Its only appeal is the fact that it *is* skin, but it still does not provide the vital reaction to stippling and tattooing that takes place on living human skin.

INTERPRETATION AND REPORTING OF RESULTS

It has been said that all measurements are estimates, and so it is with range-of-fire determinations based on powder–GSR patterns on both inanimate objects and gunshot victims. For other than contact shots, the examiner must carefully assess pattern diameter, the presence or absence of soot, the intensity and diameter of any soot deposits, the presence or

absence of stippling (or tattooing on skin), and powder pattern density. Each of these factors relates to range of fire for a particular gun—ammunition combination.

Close-range shots into curved or irregular surfaces and/or shots fired at nonorthogonal angles must also be thoughtfully dealt with and allowances made for in estimating the range-of-fire. In some cases range-of-fire estimates with uncertainty limits of plus or minus 2 inches are possible. In more typical to extreme cases, the examiner may set uncertainty limits of plus or minus 12 inches. The issue is usually not whether the gun was 4, 6, or 8 inches from the victim's shirt but whether the shot was fired at close range or from several feet away. In some cases where the question is self-inflicted versus inflicted by another, the critical issue may be whether the standoff distance is within or without arm's reach of the victim.

Take, for example, a powder pattern on a victim's shirt for which the examiner, after multiple test firings, reports the range of fire as "twelve to thirty-six inches with the twenty-four-inch pattern most closely representing the evidence pattern on the victim's shirt." If the responsible firearm is a rifle with a 26-inch barrel, the trigger was beyond the decedent's reach for all of these standoff distances. In the absence of a yardstick to depress the trigger, the use of a foot to fire the rifle, or an impactive discharge, a self-inflicted injury can be excluded.

The total absence of any powder or GSR deposits on a surface, on a gunshot victim, or on a victim's clothing presents a special problem. Some examiners are unwilling to say anything about range of fire in this case other than it is not a contact shot. Others have made statements to the effect that "The firearm was fired from a distance greater than _____," where the fill-in value is the distance beyond which no powder particles could be found on the target material. This is a perilous statement for several reasons.

First, the test firings are typically carried out under ideal conditions and into a near-ideal target material (some form of white, retentive material such as jean twill cloth). The evidence surface, whether it be the clothing of a gunshot victim, the victim's skin, or some inanimate object at a shooting scene, is likely to have experienced some loss or reduction of powder particles and/or GSR deposits through handling, bleeding, medical intervention, or exposure to the elements before collection. Therefore, the examiner is often looking at an understatement of the original pattern. At relatively close ranges (a few inches) this is not a problem, but if the shot was fired from several feet away, so that only a few powder particles arrived at the evidence surface, the loss of these few particles could result in no evidence being found on the victim or submitted object.

Second, the presence of an intervening object may be difficult to exclude. Most any intervening object, such as a pillow used as a silencer, a window, or a curtain through which a shot was fired, will filter out the powder particles and other GSRs. For those who wish to make some interpretive statement when no powder or GSR deposits are found on an evidence item or gunshot victim, the following is offered:

No powder particles or gunshot residue was detected around the bullet hole in the _____. Test firing of the submitted gun and ammunition deposited identifiable powder residues out to a distance of _____ feet. In the absence of an any intervening object(s) and because of the loss of any adhering powder particles, these findings would indicate that the shot was fired from a distance greater than _____ feet.

The foregoing is not presented as a recommendation but is given for the reason that negative findings invariably prompt one litigant or the other to request an interpretation of them.

GSR AND REVOLVERS

Because of their design, revolvers offer special reconstructive opportunities. The presence of the gap between the front of the cylinder and the barrel results in the escape of very hot, high-pressure gases containing all of the previously described GSR materials. This narrow gap between the face of the cylinder and the back of the barrel is typically on the order of 0.004 to 0.006 inches. The energetic gases emerge from each side of a revolver in a narrow, elliptical pattern, with the top strap and bottom of a revolver's frame effectively blocking them in the upward and downward directions.

Any surface immediately adjacent to the cylinder gap or within a few inches of the side of the revolver will receive GSR deposits and may even suffer physical damage or sustain very intense gunshot residue deposits. Such deposits are often found on the inside surface of one hand of a suicide victim as a result of grasping and supporting the revolver around the cylinder gap. They may also occur on the hand or hands of a gunshot victim who attempted to deflect a revolver fired by someone else. All revolver discharges occurring with the gun essentially tangential to any surface (clothing, a tabletop, a folded pillow used as a silencer, the interior of a holster) produce strong cylinder gap deposits as well as muzzle blast effects and GSR residues. These deposits provide not only positional information but also a close estimate of the revolver's barrel length, a useful parameter in a "no-gun" case. All of these concepts are illustrated in Figure 6.7.

The front face of the cylinder will typically possess a visible deposit of GSR around any chambers in which cartridges have been discharged. These circular deposits are called "flares" or "halos" and can be both conspicuous and diagnostic (see Figure 6.8). Flares are somewhat fragile and easily disturbed, so the presence of one or more of them on the face of the cylinder should be noted and documented before any processing of the firearm for fingerprints and certainly before any test firing. The presence of "fresh" (undisturbed,



FIGURE 6.7 Muzzle and cylinder gap deposits.

This 357 Magnum revolver was fired while held parallel to the wall and at a standoff distance of about 2 inches. The revolver was positioned just below the GSR patterns from the cylinder gap and the muzzle to illustrate the relationship between barrel length and GSR deposits. It should be noted that the cylinder gap discharge was so energetic that it removed some of the paint on this wall.



FIGURE 6.8 “Flares” on the face of a cylinder from a revolver.

The face of the cylinder removed from the revolver shown in Figure 6.7 shows two “flares” positioned at 11 o’clock and 1 o’clock. A careful inspection will also show that the 1-o’-clock flare overlaps the 11-o-clock flare. This is a consequence of the sequence of these shots.



FIGURE 6.9 Chamber A was under the hammer at the time of recovery. What is the minimum number of shots fired since the last thorough cleaning of this revolver?

powdery gray) flares on the face of a revolver’s cylinder allows the statement, “The revolver has been fired at least _____ times [number of flares] since its last thorough cleaning.” This language is recommended because multiple shots could conceivably be fired in one chamber, leaving the front margins of the remaining chambers free of any flares.

The position of flares at the time of recovery of a revolver can also be of critical importance. With a single shot from a revolver and no manipulation of the gun’s mechanism afterwards, the single “fresh” flare will be on the face of the chamber under the hammer. If it is *not* under the hammer, it can be reasonably concluded that the gun’s mechanism, particularly the cylinder, was manipulated or rotated in some way after the shot was fired. This can be a critical piece of information in suicide-versus-homicide determinations for obvious reasons when the fatal wound was immediately incapacitating.

Imagine that Figure 6.9 is the evidence presented for examination. A good first step is to evaluate what is known. For example, there are three distinct flares on the front face of the cylinder shown. As viewed, they are present around the top chamber and the two adjacent chambers to the right (A, B, and C). In examining the revolver, we would find that the cylinder rotates counterclockwise (from the shooter’s perspective). Remember, this means that the cylinder rotates clockwise as viewed in the image.

Now we should take time to review several alternate hypothetical case examples.

CASE EXAMPLES

Case 1

In the first case, assume that the chamber viewed at the top (A) in the figure was marked correctly, on examination by the crime scene investigator, as being under the fallen hammer. In this case, it makes logical sense that the gun was fired three times in a row, with a chronology of C, B, A, and that the hammer was *not* pulled to the rear an additional time. This is an expected circumstance when an individual practices with the firearm twice before committing suicide.

Case 2

In our next hypothetical case, we are given this revolver and the hammer is *down* over the chamber (marked F in Figure 6.9). After marking the cylinder orientation, it is often beneficial to gently try rotating it prior to opening the gun. This will give the investigator some idea of whether the rotation-locking mechanism is functioning properly. In this hypothetical, the cylinder is locked tightly. If the scene's initial appearance indicated a suicide, the condition of the gun should immediately set off alarm bells in the investigator's mind. Its condition in this case suggests that someone fired three shots, cocked the gun a fourth time, but let the hammer down on a live cartridge.

Case 3

For our last hypothetical case, let us assume that the hammer is down on chamber C, E, B, or D. What are some viable options? This can indeed be a strong clue that our suicide scene is staged; however, responding officers sometimes feel the need to "make the gun safe" when entering an unsecured scene. Obviously, if the safety of the public is at stake, moving a firearm may be the correct decision, but modern police training should include some concern for the physical evidence. In cases where the chamber under the hammer is in some completely unexpected orientation, intense questioning of responding officers may be in order. It is not unheard of for someone, including the individual who discovered the scene, to have opened the gun, realized his mistake, and then simply closed it without further comment.

THE MODIFIED GRIESS TEST FOR NITRITE RESIDUES

The primary constituent in all smokeless propellants is nitrated cellulose. During discharge of a firearm, particles of partially consumed and even unconsumed propellant that contain nitrite and nitrate compounds are violently expelled from the muzzle. The reconstructive value of the presence and pattern of these particles on skin, clothing, and other surfaces has been discussed. However, there are situations where the nitrite-bearing particles are masked by a dark background or have been dislodged, or their surviving morphology is so altered that they cannot be recognized.

Propellant particles and many of the sites where they have impacted a surface contain traces of nitrites ($-\text{NO}_2$) and nitrates ($-\text{NO}_3$). *Nitrates* are relatively common in nature and can be found in a number of materials *not* associated with small arms propellants. *Nitrites*,

on the other hand, are neither common nor particularly stable in the environment and *are* present in readily detectable amounts in nearly all smokeless and black powder residues following discharge.

It is these nitrite residues and the pattern they form around a bullet hole that are detected and rendered visible by the Modified Griess Test. The only exceptions we have encountered were several instances involving spherical ball powder that did not degrade sufficiently during the discharge process to produce a positive response for nitrites, even though numerous unconsumed particles of the propellant could be seen on the garment.

The current Griess (pronounced "grease") Test has evolved over the last 75 years: The reagents for nitrites in earlier formulations were found to be serious health hazards and have been replaced with less dangerous chemicals. The basic chemistry involved is the formation of an orange azo-dye between α -naphthol and a diazonium compound of sulfanilic acid. In cases involving clothing, this is accomplished by steaming (heating) the evidence garment with acetic acid vapors, which convert nitrites into nitrous acid (HNO_2), a volatile compound. A specially treated panel (desensitized photographic paper) containing sulfanilic acid and α -naphthol in the emulsion layer is then placed in direct contact with the gunshot residue-bearing surface of the garment. As with the transfer techniques used for lead and copper tests (see Chapter 5), multiple reference marks should be made on the transfer paper prior to its removal from the garment.

Next a layer of cheesecloth soaked in 15% acetic acid is placed on the opposite side of the garment and heat is applied with a common steam iron set on "cotton." This drives the hot acetic acid vapors through the garment, converting any nitrites to nitrous acid so they immediately volatilize and react with the reagents in the emulsion layer of the desensitized photographic paper. An alternative technique involves placing the acetic acid solution in the reservoir of the steam iron and omitting the cheesecloth. By either technique, nitrite-containing spots and particles will produce bright orange spots on the transfer paper.

The transfer technique just described requires the object being tested to be relatively thin and porous so that it can be steamed from the back side, with the reactive panel on the opposite side containing any nitrite residues. If this "sandwich" arrangement is not possible because of the nature of the object, alternatives will have to be considered. These include direct application of the reagents or a moistening of the emulsion side of the desensitized and treated photographic paper followed by firm and intimate contact between it and the evidence item for several minutes.

As long as adequate time has been allowed for the acetic acid fumes to liberate any nitrites as nitrous acid, we have found no need for steam-ironing objects other than garments. Readers who believe that the heat supplied by a steam iron is necessary or that it is an improvement in detecting nitrites should experiment with a test pattern by processing half of the powder pattern with prolonged physical contact and half with the steam iron technique. Smooth filter paper previously treated with the sulfanilic acid/ α -naphthol solution and then moistened with a light spray of 15% acetic acid can be substituted for the photographic paper, which is becoming less common in the average photo shop.

All of these procedures require some skill; consequently, any examiner who does not perform the Modified Griess Test on a regular basis should practice on some test powder patterns produced on comparable substrates prior to processing the evidence item(s). It should be recognized and remembered that the value of the Griess Test is in the development of a

pattern of nitrite-positive spots or sites around a bullet hole. The geometry, size, and density of this pattern become useful in at least two ways: one, establishing the shot as a close-range discharge and, two, they ultimately estimating the standoff distance for the shot that produced the associated bullet hole through subsequent test firings and test patterns from them.

If the sodium rhodizonate test for lead is contemplated, it can be carried out *after* the Modified Griess Test has been completed and documented. Color photography of any pattern or positive response both with and without a scale is recommended because these colors may fade or a background discoloration may develop over time. The reader should be reminded that acetic acid will solubilize and transfer some portion of any lead particulates or vaporous lead deposits on the object being tested. It is also important to note that the Griess Test, *unlike* the bullet metal tests described in Chapter 5, is carried out only once. Any nitrites present are converted into nitrous acid and rapidly react with the chemicals in the test paper to form colored spots. Prompt photo-documentation and/or a written description of the test results is a good idea if the test papers are not to be retained.

Materials Needed for the Modified Griess Test

The materials needed for the test are as follows:

- Acetic acid (15% w/v aqueous solution)
- α -naphthol (0.3% w/v in methanol)
- Sulfanilic acid (0.5% w/v in distilled water)
- Sodium nitrite (0.5% w/v aqueous solution)
- Distilled water
- Methanol
- Large sheets of photographic paper (smooth, quantitative-grade filter paper or selected brands of inkjet photographic paper may be substituted)
- Photographic “hypo” (fixer) solution (aqueous sodium thiosulfate solution)
- Cheese cloth or filter paper
- Steam iron

Preparation of Reagents and Materials

In the original method, desensitized photographic paper was used. Recently it has been discovered that certain brands of inkjet photographic paper can be substituted and give comparable and, in some instances, superior results. If traditional photographic paper is to be used, the silver salts must first be removed from the emulsion layer by soaking and rinsing large sheets of it in a tray containing fixer solution (obtained from a photography store). This step must be carried out in darkness. Once processed with the hypo, the sheets are allowed to dry before treatment with solutions of sulfanilic acid and α -naphthol. Examiners having access to a police photo lab have an advantage in that the lab should be able to prepare these sheets, thereby sparing them this somewhat awkward and unfamiliar step. No pretreatment is necessary if a suitable inkjet photographic paper is used.

Equal volumes of the sulfanilic acid solution and the α -naphthol solution (e.g., 100 ml and 100 ml) are mixed and placed in a clean photographic tray. Each sheet of the dry,

desensitized photographic paper (or inkjet photo paper) is momentarily dipped in this solution and then allowed to dry on a clean flat surface. Once dry, the sheets should be placed in a sealable envelope, dated, and stored in a refrigerator.

Cotton-tipped swabs are moistened with an aqueous solution of sodium nitrite, allowed to dry, and stored in an airtight container. They will be used to verify the efficacy of the test panels before application to the evidence item(s). Each swab is moistened with a drop of acetic acid and then touched to an edge or corner of the test paper.

Visual and microscopic examination with a stereomicroscope should first be carried out on the evidence items before any chemical testing. If the item or garment is dark or blood-stained, infrared viewers or photography can often render carbonaceous soot visible. Soft-X-ray films can often reveal powder particles underneath a coating of blood.

After these preliminary steps have been completed, the Modified Griess Test can be carried out with one of the described techniques depending on the nature of the object to be tested.

Note: Modification of the Griess Test amounted to substituting α -naphthol for N-(1-naphthyl)ethylenediamine dihydrochloride (a known carcinogen) to reduce health risks. However, the user must still consider *all* of these reagents as potential health hazards. The use of rubber gloves and a fume hood is required, as is scrupulous avoidance of inhalation of vapors and subsequent contact with these materials.

PRIMER RESIDUES

In the absence of visible GSRs on the hands of a suspected shooter, instrumental methods may be used to detect and identify very low levels of primer residues. Nearly all of these tests are directed toward the *inorganic* elements associated with firearms discharge products, although considerable research is being devoted to the numerous organic constituents present in primer and gunshot residues as well.

The organic constituents in GSRs include unconsumed nitrocellulose, stabilizers, plasticizers, flash inhibitors, and propellant modifiers. The research shows that these compounds provide very useful information to the forensic analyst and investigator, but their presence on the hands and clothing of shooters is not yet sought in average casework simply because a standard collection and analysis procedure has yet to be worked out and adopted.

Such procedures *have* been established for the inorganic constituents of GSRs. The collection of these constituents is by one of the following methods:

- Mild acid swabbing of selected areas of the hands followed by flameless atomic absorption spectroscopy analysis (FAAS) of the extracts of these swabs for elevated levels of metals (lead, barium, and antimony) associated with common primer formulations
- Sticky stub lifts of the hands, subsequently analyzed by scanning electron microscopy–energy dispersive X-ray (SEM/EDX) analysis

SEM/EDX has special advantages in that it provides high-resolution images of very small particles and allows their elemental composition to be determined without consuming or altering them. This is important because the very high temperatures and pressures associated with firearms discharges generate spheroid particles on the order of 1 to 10 microns (μm) in size, composed largely of lead, barium, and antimony when derived from common

primer formulations. For these reasons the SEM/EDX technique has become the predominant method for GSR/primer residue detection and identification on samples collected from hands. Microvacuuming and particle collection on special filter discs have also been developed for the processing of selected items of clothing from suspected shooters.

The use of SEM/EDX only stands to increase as new and varied primer formulations continue to be introduced by nearly every primer manufacturer. These “environmentally friendly” primers contain elements not previously associated with firearms discharge residue, including zinc, titanium, potassium, boron, strontium, silicon, calcium, zirconium, magnesium, aluminum, sulfur, and manganese. The morphology of these elements is only ascertainable with a scanning electron microscope, and since a number of them are relatively common in the environment, the combined analytical power of SEM and EDX is, and will continue to be, mandatory for their identification.

Some discussion regarding the current status and usefulness of GSR testing of the hands of suspected shooters is appropriate. The value of such testing has fallen short of the original hope of identifying a recent shooter and excluding nonshooters. This is not to say that such tests are of no value or that collecting samples is a futile exercise. The typical reporting language used in American crime laboratories when a positive result is obtained is something like “The subject either fired a gun, handled a gun, or was in close proximity to a firearm when it was discharged.” Given these choices for a positive result, many readers may regard the value of such evidence as very low and not worth the effort of taking samples from a suspect’s hands and the subsequent expense of analyzing them. But this negative reaction is not well thought-out.

The *circumstances* of each case must be considered when the sampling of one or more individuals’ hands for GSR–primer residue is contemplated. Consider a case in which three individuals admit to having been in a car where a gun was discharged, but all deny firing a gun. Testing these subjects is probably futile, as they are all likely to show positive for GSR–primer residue because of the relatively confined space in which the discharge occurred. Likewise, testing the hands of a suspected suicide victim with a loose-contact gunshot wound to the chest will probably show a positive result simply because the hands would have been in close proximity to the gun at the moment of discharge. This is also true if the victim was murdered, so a positive finding of GSR–primer residue does not distinguish a murder from a suicide.

Conversely, a negative finding, particularly in a living individual, does not exclude a subject as having fired a gun. The microscopic particulate residues associated with GSR may have never been deposited by chance, they can be removed by hand-washing, and they have been removed through normal activities with the passage of a few hours. This last fact is the reason that most, if not all, GSR collection procedures set a cutoff time after which no samples will be taken. Moreover, some firearm–ammunition combinations, the skin of some individuals, or both, do not consistently leave or retain detectable levels of primer residue on the hands.

So, after all of the foregoing negativism, when is the collection and analysis of such samples useful? They stand to be useful when the interval between the incident and the collection is short (minutes to an hour or two) *and* in situations where the individual denies owning a gun, shooting a gun, handling a gun, or being anywhere near the discharge of a gun or at the immediate scene of a shooting. In this situation a positive finding would be

very incriminating. However, what if the subject of interest was taken into custody by law enforcement officers and placed in the back of a patrol vehicle? Could there potentially be a transfer of primer residues from the officer's hands and or from his or her firearm? Could the back seat of the patrol vehicle already possess primer residues from previous subjects or from the officer's use of the back seat to transport firearms to and from the range for practice?

There are a number of other considerations that cannot be addressed within the limits of this chapter, but it suffices to say that there are instances when the collection and analysis of hand swabs or sticky tape lifts can provide useful and incriminating evidence. The desirability of sample collection simply needs to be well thought-out, as opposed to collecting such samples because they are available. Properly collected samples can be retained indefinitely and analyzed when such analysis is deemed useful.

It should be remembered, however, that a negative finding does not preclude the tested subject as having fired a gun. The absence of evidence is not necessarily evidence of absence. It has unfortunately become a common expectation of the legal system and of jurors that definitive results from investigators can be obtained, when the reality is that one of the most important skills of the competent investigator is knowing when to say, "I don't know," or when to give only an inconclusive result in the face of too many unknowns.

SUMMARY AND CONCLUDING COMMENTS

In this chapter, the various constituents of GSRs were described, along with their short-range exterior ballistic properties. The reconstructive value of visible and chemically detectable GSR deposits on various surfaces was also presented.

Additionally discussed were the reagents and general procedures for the application of the Modified Griess Test for nitrites. A detailed protocol is desirable for the routine use of this test with clothing. However, we urge examiners to consider a more thoughtful approach to nonstandard surfaces by carrying out some preliminary empirical testing to refine and select the best technique for its ultimate application to the evidence at hand.

The same recommendation holds with regard to the testing of suspected shooters' hands for trace amount of GSR/primer residue—namely, a thoughtful assessment of the suitability of the subject for sampling and the probative value of any positive result.

CHAPTER KNOWLEDGE

- Review the differences between gunshot residue and primer residue. What fundamental components are encompassed by the term *gunshot residue*?
- The shape of a lateral GSR pattern from a revolver was discussed in this chapter. What kind of lateral GSR pattern might you expect from a semiautomatic pistol?
- For those who work scenes, do you use primer residue collection kits? When do you use them and why?
- The concept, creation, and use of flares on the forward face of a revolver's cylinder was also discussed in this chapter. Is there a corresponding phenomenon with regard to semiautomatic pistols?

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Projectile Penetration and Perforation

INTRODUCTION

Common materials struck by projectiles include Sheetrock (wallboard), wood, sheet metal (e.g., filing cabinets, vehicles, road signs), asphalt, concrete, construction block/bricks, rubber (e.g., tires), plastic (e.g., truck bedliners, patio furniture), and clothing and other fabrics (e.g., upholstered furniture). Penetration of bodies will be discussed in Chapter 11; specific penetration issues relating to the three common types of glass, in Chapter 8.

With most of these materials, there are essentially three possible outcomes of orthogonal impacts and near-orthogonal (perpendicular in both planes) impacts:

- The projectile will be stopped without penetrating.
- The projectile will penetrate and may become lodged or may disintegrate, and the fragments may rebound from the material. A lead bullet fired into a wooden fence post is an example of the former; the same type of bullet fired into a marble wall exemplifies the latter.
- The projectile may perforate the material.

The changes that take place in the projectile and in the impacted material can be seen as occurring in a predictable and characteristic manner once the dynamics and properties of each are understood.

With low-incident-angle strikes to materials other than clothing, the projectile will ricochet from the object. Just what represents a low incident angle will be discussed in detail in Chapter 9, where the important matter of ricochet is presented.

The Locardian view of the likely exchange between projectile and impacted material is a good starting point for all of these encounters, followed by some thoughts about the relative hardness of the projectile and substrate and the nature of the yielding or failing process for the material impacted. Another useful concept is dividing target materials into *nonyielding* (concrete/heavy steel) and *yielding* (sheet metal/wood/glass) groups, with the latter further subdivided into malleable (sheet metal) and frangible (glass/Sheetrock).

Some of the more common characteristics of specific materials are discussed in the following sections.

SHEETROCK/WALLBOARD

Sheetrock/wallboard is a common material used in home and office construction. It is composed of gypsum (calcium sulfate) and coated with heavy paper on both sides. The surface normally seen (and usually first struck by gunfire) is frequently painted or wall-papered. Popular thicknesses in the United States are 1/2 inch and 5/8 inches.

Sheetrock is rather easily defeated and perforated by most common small arms projectiles. By way of example, the necessary approximate threshold velocity (V_T) for 38 caliber/9mm bullets to perforate 1/2-inch Sheetrock is about 100 to 150 fps (30 to 46 m/s) depending on the weight of the bullet and its orientation (angle of impact) at the moment of impact. These velocities are on the order of what can be achieved with a common slingshot. A reader who has a ballistic chronograph and wishes to conduct some empirical testing is urged to practice his or her marksmanship with a slingshot and some fired bullets of a caliber and weight of interest, launching them into a panel of Sheetrock positioned just beyond the chronograph.

A projectile failing to perforate Sheetrock will often leave a clear impression of itself, including its orientation on impact. This impression may also contain the outline of the rifling impressions on the responsible bullet (see Figure 7.1). The location of such an impact site should be measured and documented, after which the area containing the impact site should be excised and impounded as evidence. This can be accomplished with a common utility knife available in any hardware store. Nonperforating bullet imprints have occurred in cases where a bullet passed through a gunshot victim and exited in a destabilized manner and with a velocity on the order of 100 to 150 fps (30 to 46 m/s) as it struck an interior wall.

Once the threshold velocity necessary to perforate the particular thickness of Sheetrock is substantially exceeded, velocity *losses* for near-orthogonal impacts are on the order of 30 fps (9 m/s) for perforating bullets. This significant difference, between the impact velocity necessary to perforate a panel of Sheetrock and the velocity loss during perforation, is a recurring phenomenon for all thin materials struck by projectiles and will be discussed in detail in the section on sheet metal.



FIGURE 7.1 Bullet impression in painted Sheetrock.

A decelerated and destabilized 38 caliber, 158 gr semi-jacketed hollow-point bullet struck the painted surface of this wallboard, leaving a 3-dimensional outline of itself that includes faint rifling marks and a knurled cannellure. The type of unfired bullet that produced this impression can be seen fourth from left in Figure 3.1(a).

If there is an air space inside the Sheetrock wall free of insulation, the dislodged gypsum from the bullet's path will often be impactively deposited on any opposing nearby and down-range surface (e.g., the Sheetrock on the opposite side of an interior wall) or on any other supporting surface (e.g., an exterior wall). In nonorthogonal strikes, the location of this deposit has an unusual and somewhat counterintuitive relationship to the path of the projectile. As the bullet approaches its future exit site during perforation of the Sheetrock, a spall of gypsum will be propelled away from this site at an angle essentially orthogonal to the exit surface. It is important to recognize and understand this since one may mistakenly believe that these impactive deposits of dislodged gypsum on the opposing surface represent a point of reference for the projectile's flight path. This is incorrect except where the projectile entered and perforated the Sheetrock at an orthogonal angle.

An example of this interesting behavior is shown in Figure 7.2. We will also see it in other brittle or frangible materials such as panels of glass when struck by bullets at nonorthogonal angles. Here again, we urge any reader who actually processes shooting scenes to take the time to construct a mock wall out of Sheetrock and a few two-by-fours, and then fire a few shots through it at orthogonal and nonorthogonal angles. Such an exercise provides opportunities to practice calculating the angular measurements described in a later chapter as well to evaluate deflection issues.

The frangible nature of many paints on the entry surface of Sheetrock and the underlying Sheetrock itself may greatly reduce or even obviate the transference of bullet wipe. Differentiating entry from exit is easy, however. The entry, or impact, side of Sheetrock will

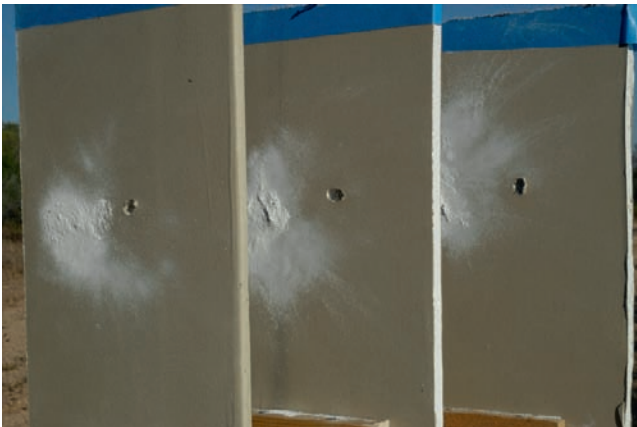


FIGURE 7.2 Down-range deposits of ejected gypsum from a nonorthogonal strike.

This illustration shows three of six panels of 5/8-in. Sheetrock set at a 45° intercept angle to the flight of a 9 mm FMJ-RN bullet. The bullet perforated a panel to the left (not shown). Its flight was from left to right. The bullet holes can be seen to the right of each spattered deposit of powdered gypsum. The deposits were propelled away from the exit surfaces at right angles to each surface. They then traversed the 6-inch space between the panels and were impactively deposited at the location visible in this photograph.

Although the bullet was noticeably destabilized, as evidenced by the out-of-round bullet holes, no detectable deflection occurred. *Note:* Figure 7.5 shows all six panels with a trajectory rod passing through the bullet holes.



FIGURE 7.3 Basically an orthogonal perforation of drywall by a stable pistol bullet. Note the bullet wipe around the circumference of the hole.

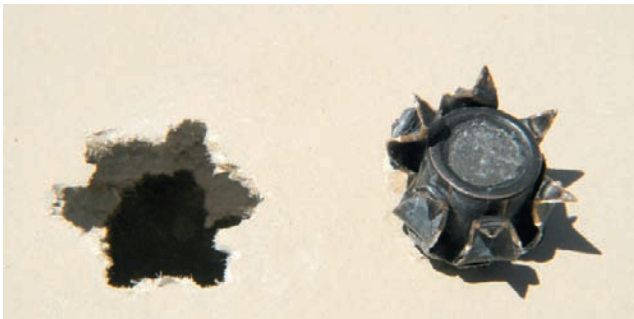


FIGURE 7.4 Entry bullet hole in Sheetrock produced by a previously expanded Black Talon bullet.

A 45-caliber Black Talon bullet was fired through 3 inches of tissue simulant mounted approximately 3 feet in front of a panel of painted wallboard. Passage through the tissue simulant caused the bullet to fully mushroom. It then struck and perforated the Sheetrock in a nose-forward orientation with its “talons” properly extended, leaving their characteristic outline around the margin of the hole.

faithfully record the orientation and morphology of the bullet that struck it. Figure 7.3 is a classic example of a stable bullet striking painted Sheetrock at a near-orthogonal angle.

Characteristics that should be documented and photographed include the round, regular perforation and the bullet wipe. In shallower-angle impacts the examiner should look carefully for parabolic shapes with bullet wipe, sometimes referred to as a lead-in marks for example, the profile of a destabilized or tumbling bullet and/or the extended “talons” of a Black Talon bullet that perforated a victim (Figure 7.4), the normal round or ovoid hole, or a direct strike.

Close-proximity discharges can produce stippling of the Sheetrock and can, of course, deposit gunshot residues on its surface. An example of this was shown in Figures 6.5 and 6.6.

Deflection of bullets that perforate common Sheetrock at angles significantly above the critical angle is essentially nil. Figure 7.5 shows a trajectory rod passed through a series of bullet holes produced by a destabilized bullet that perforated six panels of 1/2-inch Sheetrock mounted at 45-degree angles to the bullets’ flight paths. This nondeflecting behavior makes back-extrapolation of bullet holes through Sheetrock walls very reliable insofar as the values of the vertical and azimuth angles are concerned.



FIGURE 7.5 Bullet perforation of multiple panels of Sheetrock.

The 5/8-in.-thick panels of Sheetrock in this simple holder are approximately 6 inches apart and oriented at a 45° angle to the bullet's flight path. The bullet was a 124-gr 9 mm FMJ-RN bullet fired from a distance of approximately four feet with a Beretta Model 92FS pistol. Although the bullet was clearly destabilized by the second panel, passage of the trajectory rod through all six bullet holes shows that there was no measurable deflection.

Note: Figure 7.2 provides a close-up view of panels 2, 3, and 4 before the trajectory rod was passed through the bullet holes.



FIGURE 7.6 The lack of bullet wipe and regular smooth edges, as well as the "blasted-out" nature of frangible gypsum, characterize exits from this material.

Bullets themselves are little affected by passage through Sheetrock except that they will be destabilized in their subsequent flight. If they are of a hollow-point design, their hollow-point cavities will typically be plugged with gypsum as a consequence of a direct strike.

In drywall, exits are drastically different from entrances. The characteristics are exactly what would be expected intuitively. The edges of the exit hole are irregular, and the damaged areas are moved outward in the direction of the projectile's travel (see Figure 7.6). The exit sides of a drywall perforation from a stable versus an unstable bullet are usually indistinguishable.

WOOD

The appearance of entry and exit bullet holes in wood follows a commonsense model, with wood fibers forced inward around the margin of the entry hole and chips of wood frequently expelled or turned outward at the exit site. Most types of wood acquire detectable (often visible) deposits of bullet wipe around the margin of the entry hole. Both lead and copper (in the case of copper-alloy-jacketed bullets) can usually be detected in such bullet wipe by the lifting technique (see Chapter 5) even several months after the bullet hole was produced. Lead bullets and jacketed bullets with exposed lead noses typically leave strong deposits of lead throughout the bullet's track in wood.

This phenomenon can be exploited in very old bullet holes (e.g., years old) that no longer possess detectable copper or lead around the entry's exterior margin model, with wood fibers forced inward around the margin of the entry hole and chips of wood frequently expelled or turned outward at the exit site.

A jacketed bullet, on the other hand, will usually leave traces of lead at the entry point but not along the interior channel. In cases where lead fragments strike wood, significant amounts of visible lead may be seen and should not be confused with bullet wipe. Figures 7.7 and 7.8 give the reader some idea of what to expect in observing a stable angled entrance and exit through plywood.

The wood fibers along the channel of a bullet hole relax to varying degrees after the bullet's passage so that the resultant hole is usually smaller than the bullet that produced it. Care must be taken in choosing an appropriate probe, in both composition and diameter, for insertion through a bullet's path through any wooden object. Brass or copper rods should be avoided and, if tests for lead are contemplated, a probe free of lead residues on its surface is in order. Projectile nose shape, projectile hardness, impact velocity, and, of course, the nature of the particular wood all play a significant role in the properties of the final bullet hole and channel diameter.

Bullet deflection as a result of perforation of relatively thin specimens of wood (fence boards, small tree branches, gun stocks, etc.) is typically small (e.g., 1 to 2 degrees). Bullet destabilization, however, is common, as is the plugging of hollow-point cavities with wood particles. Soft-point and hollow-point bullets seldom expand as a consequence of wood perforation but often acquire embedded wood particles in their noses and hollow-point cavities.

Nonorthogonal impact to and penetration/perforation of wood will produce an elliptical entry hole. The arcsine of the ratio of the minimum diameter divided by the maximum



FIGURE 7.7 Oblique-angle perforation of wood.



FIGURE 7.8 Exit corresponding to the perforation shown in Figure 7.7.

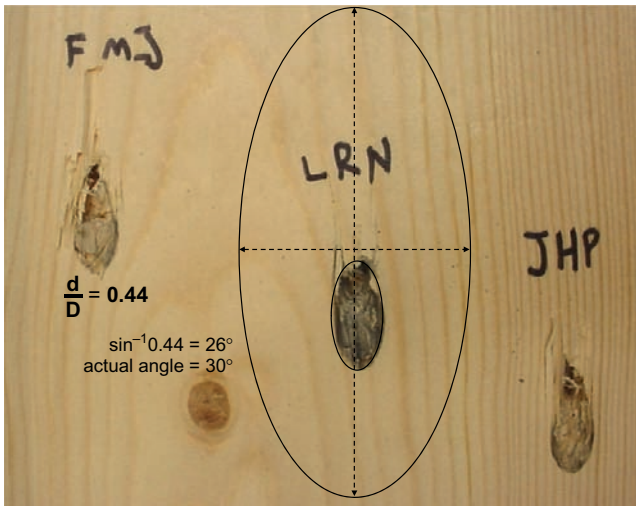


FIGURE 7.9 Nonorthogonal bullet holes in wood.

Bullet holes were produced by three types of 38 caliber bullets fired into this thin board at the same nominal incident angle of 30 degrees. This photograph was taken from a position orthogonal to the three bullet holes. A computer drawing tool was used to draw the best-fitting ellipse around the margin of the entry hole produced by the LRN bullet. This ellipse has been copied and enlarged after locking the aspect ratio. The arcsine function was used to derive the approximate intercept angle from the ratio of the width to the length of the ellipse. The calculated value and the true value are shown in the figure.

diameter of the best ellipse representing the outline of the hole can often provide a reasonable *estimate* of the incident angle of this strike. The best ellipse formed by the margin of the entry hole (or the bullet wipe around it) can most easily be constructed from a good straight-on photograph of the bullet hole and the use of a drawing tool on a computer. Once the ellipse is constructed, it can be enlarged proportionally to facilitate a measurement of the minimum and maximum diameters.

The actual dimensions of the bullet hole are unimportant. It is the *ratio* of any faithful representation of an elliptical (nonorthogonal) bullet hole that matters (see Figure 7.9). The

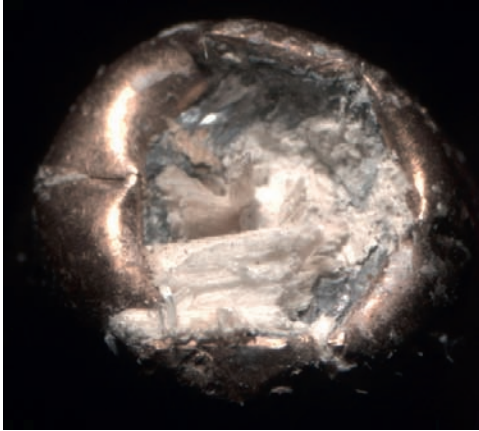


FIGURE 7.10 Wood trapped in the hollow-point cavity of a 40 Smith & Wesson caliber bullet.

arcsine (reciprocal sine) function on a pocket calculator with scientific functions is used to derive the equivalent incident angle.

Note: As with many techniques and calculations described in this book, the reader is urged to carry out some empirical tests with the type of ammunition and wood involved in a specific case so as to establish accuracy and confidence limits.

This is a useful adjunct to the traditional probe method for bullet path determination, particularly where the perforated board is relatively thin (1/2 inch or less), because the uncertainty in path measurements *increases* with *decreasing* thickness.

Spotting traces of wood on bullets that have perforated it can be either easy or impossible. In the case of full-metal-jacketed (FMJ) bullets, do not expect to see *any* traces. In the case of stable hollow-point bullets, however, wood may be present in great quantity. Figure 7.10 shows large quantities of wood fibers embedded in the nose of a 40 caliber hollow-point bullet. Unstable hollow points should not be expected to retain traces of the wood they have perforated. Bullets that have ricocheted from wood may display a burnished side only.

SHEET METAL

A lengthy discussion of bullet perforation in sheet metal is given by Nernstiel (see References). We have integrated the essential parameters from his work with a number of our own observations and measurements in the following.

The most common form of sheet metal encountered in shooting reconstruction cases is that found in motor vehicles. This is customarily 22-gauge steel measuring about 0.031 to 0.032 inches (0.79–0.82 millimeters) in thickness. Other commonly encountered forms in shooting incidents are office furniture (e.g., metal filing cabinets), certain home appliances (e.g., washing machines, refrigerators, ovens, dishwashers), and road signs.



FIGURE 7.11 Orthogonal perforation of a piece of sheet metal.



FIGURE 7.12 The corresponding exit side of Figure 7.11.

Determination of direction of travel in sheet metal is usually easy except in cases of very shallow angle. Because it is malleable, this thin metal will bend in the direction of travel of the passing projectile. Conversely, on the exit sides it will bend toward the observer (see Figures 7.11 and 7.12).

Sheet metal can be perforated by virtually all small arms projectiles, given sufficient impact velocity. For any particular bullet there is a *threshold velocity* that must be exceeded for the bullet to perforate a particular sheet metal thickness. Obviously, the angle of incidence enters into the determination of *threshold velocity* (V_T), but V_T values are ordinarily measured only for orthogonal impacts. At any velocity *less than* the threshold velocity for the bullet–sheet metal combination, the metal will undergo an amount of deformation (because of its malleability) that can be related to the impact velocity of the projectile. Most projectiles will likewise suffer some deformation that can also be related to impact velocity through subsequent empirical testing.

Figure 7.13 shows a lineup of lead round-nose bullets that struck sheet metal with ever-increasing impact velocities, nearly all of which were less than the threshold velocity for this 125-gr 9 mm bullet–0.032-in. sheet metal combination.

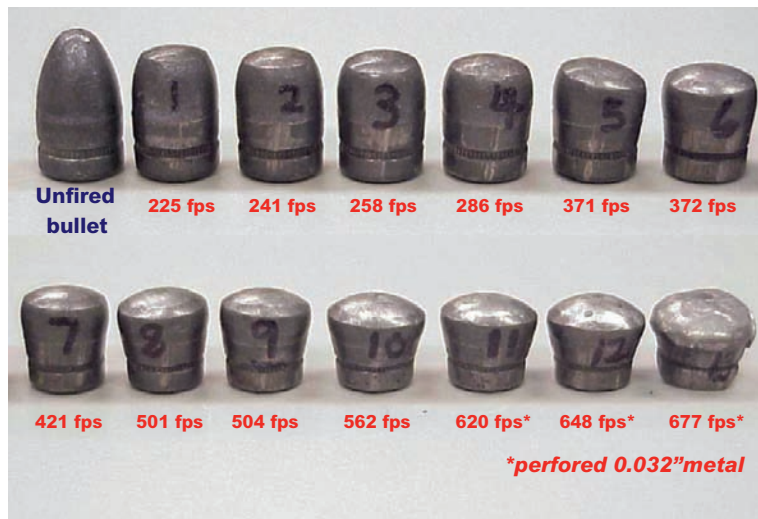


FIGURE 7.13 Bullets deformed by impact with sheet metal. 125-gr 9mm bullets in increasing order of impact velocity.

Shown is a lineup of LRN bullets that struck automotive sheet metal with ever-increasing impact velocities. (An unfired bullet appears at the far upper left.) The regular progression of the flattening of these bullets, along with the attendant thickening of their diameters with increasing impact velocity, has obvious forensic implications and reconstructive value. (The listed impact velocities are in feet per second (fps) and can easily be converted to meters per second by dividing each value by 3.2808.)

The two interrelated phenomena (bullet deformation and sheet metal deformation) have obvious reconstructive implications. Consider bullet #6 in Figure 7.13, which was found below a lead-positive indentation in a car door. Inspection of the interior of the door reveals that there were no supporting structures at the impact site. The fact that the bullet did not perforate the sheet metal is an immediate indication that this 9mm/38 caliber bullet was traveling at a relatively low velocity.

Some subsequent empirical testing in the laboratory shows comparable deformation in a bullet shot into automotive sheet metal at impact velocities of 350 to 400 fps (107–122 m/s). Given the normal muzzle velocity for this bullet type of approximately 1000 fps (305 m/s), a long-range shot or deceleration by an intervening object should immediately come to mind. The fact that the bullet struck nose first would offer greater support to the long-range shot than to passage through an intervening object, but the latter should not be ruled out simply because of the nose-first impact. The reader should revisit Figure 5.8, which depicted a strike by a 22 lead round-nose (LRN) bullet fired from an adjacent car that failed to perforate the driver's door. This failure is a statement about impact velocity.

Another concept in this discussion of thin-metal "targets" is that a striking projectile either will be defeated (stopped) or will perforate the target and have considerable remaining velocity. This applies to other thin targets such as skin, rubber, glass, thin boards, and clothing.

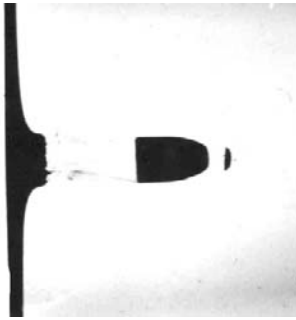


FIGURE 7.14 Plug formation as a result of bullet perforation of sheet metal.

This high-speed photograph shows the ejection of a circular plug of sheet metal immediately in front of a 124-gr 9 mm FMJ-RN bullet that has just perforated a panel of 0.030-in. sheet metal, losing approximately 70 fps of its impact velocity in the process.

At very close range this sheet metal plug can produce a satellite injury to a gunshot victim or can be found in the wound track. It can produce small defects or impact sites in inanimate objects when the distances from the bullet hole are short (inches to a few feet).

Within a few more inches of flight, the bullet will overtake and pass the sheet metal plug, which decelerates much more rapidly than the bullet that produced it. Sheet metal plugs may, in certain circumstances, remain attached to the nose of the causative bullet.

Photograph courtesy of Ruprecht Nennstiel of the German BKA Laboratory.

Sheet Metal Plugs and Tabs

The perforation process will frequently involve the production of a small sheet metal plug punched out by a bullet. This plug may become welded to the nose of the bullet (particularly if the metal is unpainted and the bullet is jacketed) or, more often, it will be ejected in front of the bullet and then quickly overtaken and passed by it. Figure 7.14 is a profile view of the ejection of a circular plug of sheet metal immediately in front of the 9 mm FMJ bullet that produced it.

If a perforating bullet strikes sheet metal at some angle other than orthogonal, the resulting plug will be ovoid in shape (an *ovoid plug*). In the case of a tumbling or destabilized bullet striking the sheet metal in yaw, a *tab* will be punched out. At close range (a few feet) these plugs and tabs are injurious missiles in their own right and may be found in close proximity to (or in) the gunshot wound produced by the responsible bullet. The circular or ovoid shape of a recovered plug tells much about the intercept angle of the bullet that produced it, just as a tab is the consequence of a destabilized bullet.

Occasionally the characteristic outline of the margins of a hollow-point cavity in a pistol bullet can be seen in the concave side of a plug, and the image of a knurled cannellure can be seen in a tab produced by a cannellured bullet. Transfers of bullet metal (including copper in the case of jacketed bullets) will be present on the concave side of plugs and tabs. In one high-profile case one of us was able to demonstrate a physical match between a sheet metal tab and the fatal bullet that produced it. These two items struck the victim within an inch of each other and allowed the critical issue of the fatal bullet's entry path into the vehicle to be established.

The next concept of importance is that once the threshold velocity necessary to achieve perforation is exceeded, the velocity loss (V_{Loss}) experienced by the perforating bullet is

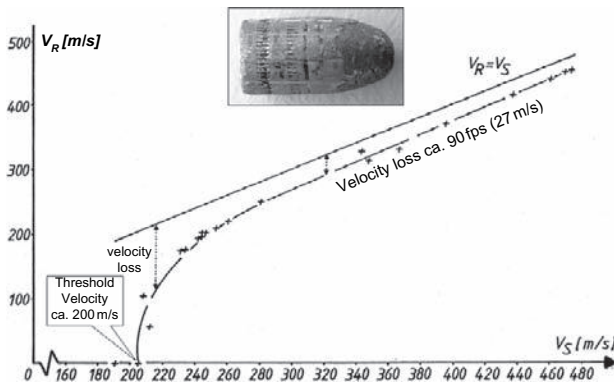


FIGURE 7.15 Threshold velocity and velocity loss for a 38 caliber, 158-gr LRN bullet striking 0.32-in.-thick sheet metal.

The horizontal x -axis represents the striking velocity (V_S) before perforation of the sheet metal. The vertical y -axis represents remaining velocity (V_R) after perforation. The straight, diagonal line in this graph represents no velocity loss (i.e., the absence of any intervening material). The curved line was constructed from exit velocity values (1) for these bullets at various impact velocities. At threshold velocities of about 660 fps (200 m/s) and lower, the bullets fail to perforate the sheet metal. A further inspection of the exit velocity line shows that as the impact velocities exceed approximately 900 fps, the velocity loss becomes nearly constant at about 90 fps. It should also be noted that velocity loss is not the same as threshold velocity; it is substantially less than the threshold velocity necessary to perforate the material.

much less than the threshold velocity (V_T) (e.g., $V_{Loss} \ll V_T$). Additionally, the velocity loss becomes essentially constant regardless of impact velocity once the impact velocity (V_{IMP}) becomes well in excess of the threshold velocity necessary for perforation. This can be more easily understood by studying Figure 7.15.

The threshold velocity for the standard 158-gr 38 Spl. bullet shown in the figure was approximately 675 fps (206 m/s); the nominal velocity loss, about 80 fps (24 m/s) after producing a hole of about 0.45 inches in diameter. V_T values for orthogonal strikes to 0.032-in. sheet metal for a few other common bullets are 540 fps (165 m/s) for the 50-gr FMJ 25 Automatic bullet, 425 fps (130 m/s) for the 73-gr FMJ 32 Automatic bullet, and 360 fps (110 m/s) for the 124-gr FMJ 9mm Luger bullet. The velocity loss experienced by the FMJ 9mm bullet, for example, is about 65 fps (20 m/s).

Table 7.1 provides some supplemental data regarding velocity losses for representative bullets perforating sheet metal. The phenomenon of velocity loss as being much less than the *threshold velocity for perforation* was noted without special discussion in the previous section on Sheetrock. It also holds true for all “thin” targets whether brittle, frangible, elastic (e.g., skin), or malleable (e.g., sheet metal).

The near-constancy of velocity loss once the threshold velocity is substantially exceeded is important for several reasons. For example, if we can make some reasonable estimates of the bullet’s impact velocity in an object or victim down range of a perforated panel of sheet metal, we can simply add the nominal value of velocity loss due to the sheet metal perforation to estimate the impact velocity of the bullet when it struck the panel. This, in turn, can often be related to range-of-fire estimates in which the gun and ammunition are known and the initial strike to the sheet metal was a direct one.

TABLE 7.1 Average Velocity Loss (V_{Loss}) Values for Common Bullets after Perforating Standard 22-gauge (~ 0.032 -in./0.8 mm) Sheet Metal

32 Automatic 73 gr. FMJ-RN	116 fps / 35 m/s
9 mm L 115 gr. FMJ-RN	74 fps / 23 m/s
9 mm L 115 gr. Winchester S.T.-JHP	85 fps / 26 m/s
9 mm L 124 gr. FMJ-RN	66 fps / 20 m/s
9 mm L 124 gr. LRN	74 fps / 23 m/s
9 mm L 147 gr. FMJ-TC	52 fps / 16 m/s
38 Special 158 gr. LRN	94 fps / 29 m/s
40 S&W 180 gr. FMJ-TC	55 fps / 17 m/s
45 Automatic 230 gr. FMJ-RN	65 fps / 20 m/s
7.62 x 39 mm 123 gr. M43 FMJ	56 fps / 17 m/s
5.56 x 45 mm 55 gr. M193 FMJ	72 fps / 22 m/s
5.56 x 45 mm 62 gr. M855 FMJ	60 fps / 18 m/s

Deflection as a consequence of sheet metal perforation is typically small, for example, 0.5 degrees to 1.5 degrees for various 9 mm bullets fired through sheet metal 0.032-in. (0.82-mm) thick at an incident angle of 45 degrees and at impact velocities on the order of 1000 to 1200 fps (330–370 m/s).

Bullet Hole Size in Sheet Metal

The *size* (diameter) of the bullet hole in sheet metal relative to the bullet that caused it makes an interesting study. Most FMJ bullets, for example, will typically leave a hole slightly *smaller* than their own diameter at “low” impact velocities. With higher velocities the hole diameter will increase and ultimately become slightly larger than that of the causative bullet. Just what constitutes “low” and “high” velocity associated with bullet hole diameter will have to be worked out by actual testing for the particular bullet–sheet metal combination.

This velocity-related phenomenon is believed due to the slightly elastic nature of the perforated sheet metal, which at lower impact velocities relaxes slightly after the bullet’s passage, resulting in a slight reduction of hole diameter. At higher impact velocities the acceleration of the sheet metal away from the margins of the bullet hole is such that it exceeds and overcomes the slight relaxation of the metal, so that the final bullet hole is slightly larger than the causative bullet.

The amount of final deformation of the sheet metal surrounding the bullet hole also bears a relationship to impact velocity, with less and less deformation as velocity increases. At relatively low impact velocities the metal surrounding the impact site has more time to stretch and deform as the bullet acts on the metal. Much of this deformation is retained after the bullet breaches and perforates. At much higher impact velocities, the surrounding sheet metal has much less time to stretch and deform during perforation. The limits (diameter) of this deformation can be measured by placing a straight edge across the deformed area

TABLE 7.2 Bullet Hole Diameter and Metal Deformation for 223 caliber, 55-gr M193 Bullets Fired into 0.028-in. Thick Sheet Metal from an AR15 Rifle

Impact Velocity (fps)	Bullet Hole Diameter (in.)	Sheet-Metal Deformation Width (in.)
1693	0.215	1.10
1850	0.216	1.05
2227	0.221	1.00
2279	0.223	0.93
2425	0.228	0.96
2692	0.228	0.95
2819	0.233	0.99
3051	0.228	0.75
3220	0.230	0.75

and over the center of the bullet hole and then carefully marking the two points where the straight edge loses contact with the impacted surface. Table 7.2 provides a comparison of bullet hole diameter and static metal deformation for a series of orthogonal shots into 0.028-in. (0.7-mm) sheet metal with an AR15 rifle and 55-gr M193 FMJ-BT bullets.

Lead and lead-alloy bullets typically produce holes that are larger than the bullet itself. This is due to some flattening of the bullet and to an increase in its diameter during impact and prior to perforation of the sheet metal. For example, the diameters of bullet holes in 22-gauge sheet metal produced by common 38 caliber (358-in. diameter) 158-gr LRN bullets, at impact velocities on the order of 1000 fps, measure 0.43 to 0.46 inches.

RUBBER AND ELASTICS

Rubber and elastic materials behave much like skin in that something similar to an abrasion rim can often be seen around the margin of a bullet hole that roughly relates to the caliber of the projectile. The actual bullet hole will typically be smaller (in some situations *much* smaller) than the bullet that produced it. Automobile tires are the most common example of rubber struck by gunfire.

Note: The reader should bear in mind the correct terminology: The *tire* is the rubber portion; the *wheel* is the inner metal portion.

Typically, handgun bullets should not be expected to perforate the wheel, while rifle bullets can usually easily defeat it. A tire’s black color makes locating the pseudo-abrasion rim very difficult. The holes produced by stable FMJ bullets and lead buckshot pellets are so small that they can easily be confused with a nail puncture. The DTO and/or the sodium rhodizonate test may resolve the question, but we have encountered situations where these tests failed to reveal traces of copper or lead around the margin of known bullet holes.



FIGURE 7.16 Two perforations of a rubber tire. While both are the result of a 9 mm Luger caliber bullet, the top hole was created by a hollow-point bullet; the lower, by an FMJ bullet.

Hollow-point pistol bullets, such as those commonly used by American law enforcement, produce a more easily recognized bullet hole as a result of the “cookie-cutter” effect (see Figure 7.16).

Stable hollow-point bullets punch out a plug of rubber that, in some instances, may be recovered from the bullet’s cavity; they may also be found on the ground at scenes or inside the tire’s air space. The result is a relatively conspicuous hole in the tire. In some instances it is possible to physically fit this plug from the hollow-point cavity of a bullet back into the area of missing rubber in the struck tire.

The following case example has two primary areas of interest. Of original value in this event was that one group of law enforcement shooters was using 45 caliber hollow-point bullets while another group of shooters was using plain FMJ bullets. Both were shooting at a vehicle repeatedly, striking the tires numerous times. It was rapidly apparent at the scene exactly which group scored which hits on the tires based on the presence of a cookie-cutter holes or the lack thereof. What became interesting later in the investigation, when projectiles were being examined, was that two of the rubber plugs recovered had pattern information on the former exterior surface. The images in Figures 7.17(a) through 7.17(c) show two recovered rubber plugs. One was found on the ground at a scene; the other was trapped in the hollow-point cavity of a damaged bullet.

Some of the perforations of the tire sidewalls went directly through patterned areas of the rubber as can be seen in Figure 7.18(a). Comparison of these areas with the patterns observed on the rubber plugs visible in Figures 7.18(b) and 7.18(c) showed that each individual plug could be associated with a specific perforation.

If the shooting scene reconstructionist was lucky enough to have these plugs trapped in the nose of the bullet, a specific bullet could be linked to a specific hole in the tire. An ancillary to that would be that if a plug were found on the roadway of a lengthy running gun battle, some conclusion could be made about where along the path a specific shot through the tire was made.

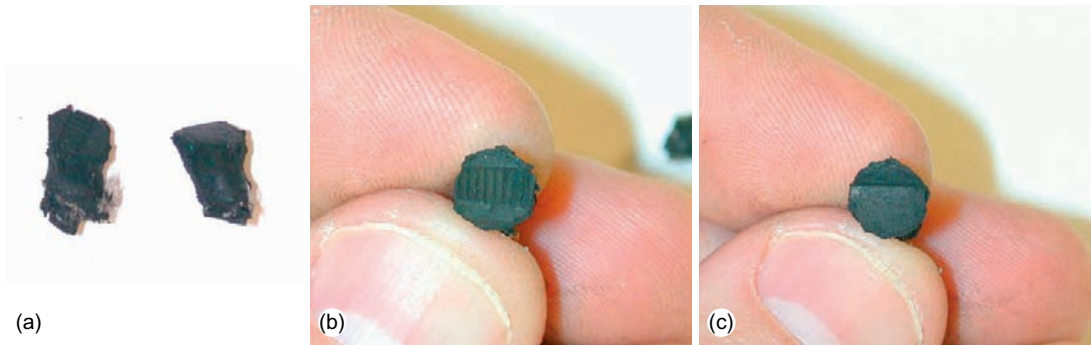


FIGURE 7.17 (a) Side view of two rubber plugs created by the cookie-cutter effect of hollow-point pistol bullets. (b) View of one plug with a distinctive pattern. (c) Second plug, also with a distinctive pattern.

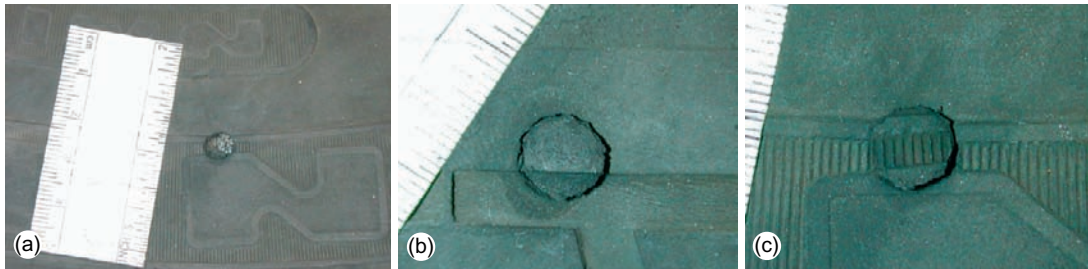


FIGURE 7.18 (a) One of several perforations in the sidewall of a tire. (b) One of the recovered plugs properly seated and oriented in the hole from which it originated. (c) Another of the recovered plugs in place, also showing the alignment of the original sidewall pattern.

Empirical testing has revealed that there is no discernable difference in bullet holes produced in the sidewalls or tread area of a demounted tire versus the same tire inflated and mounted on a wheel. This is good news if one wishes to carry out ballistic tests on tire rubber to demonstrate the appearance of bullet holes fired from different angles or produced by different types of bullets.

Note: The reader should note that when dealing with rifle bullets this differentiation can no longer be made. The size of a typical rifle bullet's hollow-point cavity compared to the nose profile of an FMJ bullet, or even that of a soft-point bullet, is almost indistinguishable, and makes no difference in the perforations of the elastic material. All of pointed-nose bullets will create holes closely reminiscent of holes produced by FMJ pistol bullets.

Deflation tests carried out on typical tubeless automobile tires perforated by FMJ and hollow-point pistol bullets of 9mm to 45 caliber resulted in very slow deflation (up to several minutes) for the former. Deflation times on the order of 20 to 30 seconds were obtained for the latter. Bullets that have been ricocheted into tires will usually produce an irregular entry hole due to their deformed shape and the likelihood that they will strike the tire in a yawed orientation.

Projectiles striking and perforating a tire will either hit some interior location on the metal wheel or will perforate and exit the opposite sidewall. These exit sites can be just as

difficult to locate as entrance holes, if not more so. Since tires rotate and, in the case of front tires, can turn as well, the position and location of the wheels of a shot vehicle should be marked and documented *before* the vehicle is moved. This can be done with a bright colored spray paint by making a stripe on the wheel and sidewall which extends onto the surface on which the tire is resting.

Documentation should include one or more close-up photographs that allow one to see the various markings on the tire and their relationship to the ground and the immediate features of the vehicle itself. It is also important to mark the relationship between the tire and the wheel on which it is mounted. If any suspected bullet holes can be seen prior to moving the vehicle, these should be marked in some way and documented through photography.

Bullets that perforate a tire but then strike the wheel often break up or ricochet inside the tire without exiting. This means that both the recovery of any bullet or bullet fragments and the reconstruction of the bullet's flight path will necessitate the tire's demounting. Without the orientation marks just described, the examiner will not be able to properly align the entry hole in the rubber with the subsequent impact mark on the metal wheel.

The fact that tires revolve when a vehicle is in motion presents complications as well as interesting reconstructive opportunities. In some cases it may be possible to determine whether the wheel was turning or stationary when one or more bullets struck and perforated a tire. Down-range fixed features of the vehicle, such as the frame, shock absorbers, and springs, that were either struck or missed by the exiting bullet provide reference points for evaluating the issue of a moving or stationary vehicle at the time of the shooting. Such endeavors must integrate the path(s) of the bullet(s) through the tire, any down-range impact points in the vehicle itself, and the location of the shooter at the time the shots were fired.

Finally, there may be some positions where a struck area on a tire is not ballistically accessible; that is, a bullet cannot be fired into the tire along the path taken through the tire without first perforating some portion of the vehicle, such as the fender. This is especially important with front tires since the turning of the steering wheel to various positions will significantly alter the ballistic accessibility of certain areas on them. This concept of ruling out certain bullet routes to the struck tire should be considered early on. It is one of the fundamental concepts of the *scientific method* (see Chapter 1). A bullet path through a fender that extends to the tire creates an alternative means of assessing whether the tire was in motion. The ideal case is one in which a bullet perforates a fender and then the exterior sidewall of the tire, exits from the interior sidewall, and comes to rest in the frame or wheel well.

Mild Steel Wheel Impacts by Rifle Bullets

One special case is the interaction of a rifle bullet with the rather thick but mild steel of common car wheels. Now that we have addressed interactions of bullets with thin sheet metal and tire rubber, the reader should have an idea of how complex the evaluation of entrance and exit can become simply by slightly changing location on a car or changing from handgun calibers to rifle calibers. Common handgun calibers with standard lead- and copper-construction bullets do not perforate steel wheels. Higher-speed projectiles such as 357 Magnum bullets may leave dents and *significant* deposits of lead, but will fail to defeat the thick steel of a wheel.

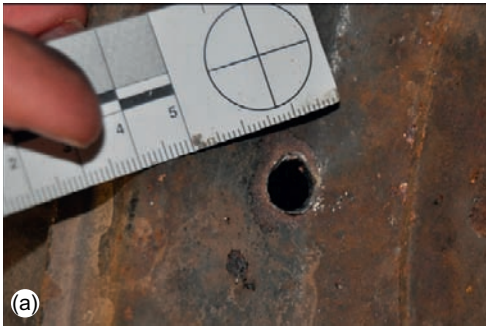


FIGURE 7.19(A) While this hole may intuitively look more like an entrance than the one pictured in (b), this is actually the *exit* of a 223 caliber rifle projectile.



FIGURE 7.19(B) “Crown” effect at the *entrance* of a 223 caliber rifle bullet at a relatively thick, mild steel wheel. Intuitively, the image in (a) seems more like an exit than does the image in (b).

When we move a scenario into the rifle world, impact dynamics become significantly different. The difference in speed, combined with a much smaller surface area at impact, yield a completely different outcome from that when pistol bullets are employed; resulting perforations may surprise many readers. Consider Figures 7.19(a) and (b), and decide which of the two is an entrance and which is an exit. This example was created with a standard lead-core copper-jacketed, 55 gr, soft-point 223 Remington caliber bullet from approximately 50 feet.

Some may be amazed to find that the image displaying the almost crownlike protruding circle is the entrance. The exit possesses no such characteristic and is less impressive. Through high-speed photography, we can see that this phenomenon occurs in the same manner that a “crown” rises around a drop of liquid that has just landed in a pool of water. The only difference is that the mild steel of the wheel cools rapidly, freezing the shape in place for us to observe. This should give some pause when evaluating new bullet–material interactions, because many uninitiated investigators may have gotten this question of directionality entirely wrong the first time they ran across it. A common theme in a good forensics course should be that an “Inconclusive” or “I don’t know” answer is *not wrong* when there is insufficient evidence to sway a conclusion one way or the other.

Because deflation times were mentioned previously for perforations of tire material only, it seems appropriate to address them in cases where the wheel itself has been compromised in the area retaining the tire’s air pressure. The result of shooting through the wheel in these locations is *not* as is commonly depicted on television shows and movies, no “explosive” forces are released that flip cars over in the air. However, when a bullet defeats the wheel,

deflation is almost immediate. In cases where the vehicle is in a dirty area, a large cloud of dust may be created by the rapid release of air.

PLASTICS

The term “plastics” includes a wide variety of materials, ranging from relatively hard and brittle Plexiglas and polycarbonate windows and patio covers, to polyvinyl shower curtains and bright orange hunting vests and polypropylene bedliners for pickup trucks. The former respond to gunfire much like glass, bone, and ceramic materials. This behavior includes cone fracturing, propagation of radial fractures, and adherence to the crack rule regarding shot sequence. For these reasons no further discussion would seem necessary for this category of plastics.

“Soft” plastics, on the other hand, display several properties and responses to bullet impact that differ from those of other materials. The thick polypropylene bedliners popularly used in pickup trucks are particularly interesting, as bullet holes produced in them shrink somewhat after the bullet’s passage. The result is that the inside diameter of such a hole is an understatement of the responsible bullet’s caliber. However, the interior of this channel often possesses a negative image of the bullet’s rifling characteristics, which can usually be seen by close inspection of the entry or exit site under strong light and low-power magnification. These important features can be “recovered” by casting the bullet’s channel with a suitable silicon rubber product (e.g., Mikrosil®). Although the dimensions of the rifling impressions on this casting are undersized, the general rifling characteristics of the responsible bullet (number of lands and grooves, direction of twist, and the *ratio* of land widths to groove widths) can be determined.

Ricochet marks on this thick plastic material will also record the rifling characteristics of the responsible bullet. The only caveat is that one is looking at an impression of the *underside* of the bullet rather than the top where the direction of twist determination is normally made. This means that rifling impressions visible in a ricochet mark in a truck bedliner (or similar material) that cant to the left are the consequence of right-twist rifling.

SUMMARY AND CONCLUDING COMMENTS

Much is to be learned from the appearance, shape, and dimensions of bullet holes in various materials. In some situations these factors may relate to impact velocity, bullet shape, bullet hardness, bullet stability, and, of course, the material struck and the angle of intercept with it. Other events useful in reconstruction arise out of the nature of the fracturing process in brittle materials, the ejection of the broken and pulverized material by the perforating bullet, the damage and deformation suffered by the bullet, and the transference of trace evidence between the projectile and the struck surface.

The deformation process associated with malleable materials such as sheet metal has special attributes that are quite different from that seen with frangible materials such as Sheetrock.

Many examples were presented in this chapter, but they are merely a beginning point for anyone who is directly involved in the reconstruction of shooting incidents. They provide some insight, some concepts, and some expectations, along with a basis for further study involving case-specific materials, firearms, and ammunition.

CHAPTER KNOWLEDGE

- What is the difference between penetration and perforation?
- Besides the materials mentioned in this chapter, with what other substrates have you observed terminal ballistic interactions? What would you *expect* to see happen when these objects are struck?
- When was the last time you conducted live-fire testing to resolve some penetration or perforation question? Did you publish your work?
- Are there circumstances in which it would be difficult to determine an entrance from an exit?

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Projectiles and Glass

INTRODUCTION

The study of bullet interaction with glass deserves special attention because of the frequency with which it occurs in investigations. Whether a shooting takes place in conjunction with a vehicle or with a structure, glass will be present. This chapter will familiarize the reader with some of the basic types of glass as well as some extremely useful forensic aspects of putting bullets through glass.

Since bullets that perforate any type of glass will frequently sustain characteristic damage and contain embedded glass particles, a brief review of the basic chemistry of glass and its special properties is a useful starting point for this chapter. The optical, physical, and chemical properties of glass particles embedded in recovered bullets allow glass to be discriminated from other silica-containing minerals such as sand and quartz.

The common glass used to manufacture windows and most containers is known as soda-lime glass because substantial amounts of sodium carbonate and calcium oxide are mixed with pure silica sand (SiO_2), often along with smaller amounts of other inorganic materials. The materials are heated until a relatively viscous molten mass is created. Colors are produced by the addition of small amounts of metallic ions (e.g., Fe^{++} for green; Fe^{+++} , for brown). The molten mass may be injected into forms or molds to make containers such as jars and bottles or headlight lenses, or it can be formed into sheets of uniform thickness to make windows and other plate glass structures.

EVIDENCE OF GLASS IMPACT ON BULLETS

The initial engagement between a typical pistol bullet and an unbroken panel of glass will create a flat spot on the bullet the size and orientation of which is related to a number of things. One is the intercept angle between the bullet and the glass. This smooth, flat spot may not survive subsequent impactive events, but when it does, it can be useful in answering certain questions, for example, *Did the bullet that perforated the driver's side window and then struck and killed the driver come from a rooftop shooter or from a shooter standing on the street adjacent to the victim's vehicle?* At this particular crime scene, the rooftop in question and the

location of the victim's vehicle form a vertical angle of approximately 45 degrees. If the fatal bullet shows an essentially orthogonal flat spot from its impact with the tempered-glass side window, the rooftop hypothesis can be effectively excluded. Figure 8.1 shows a series of 9mm full-metal-jacketed (FMJ) bullets that struck panels of glass at the approximate angles indicated by the lines drawn across the flattened areas.

The passage of any bullet through any of the three glass types will also result in abrasive pitting and checking of the bullet's nose and ogive (see Figure 8.2). Even the bearing surface of the bullet may acquire some of this abrasive damage from its violent journey through the pulverized glass. Areas showing this abrasive damage will typically survive subsequent impactful events. The reader should become familiar with the appearance of such damage, which is most noticeable when bullets are examined under the stereomicroscope. It is relatively easy to prepare some "training" specimens. Simply fire representative bullets through typical panels of glass placed in a cardboard box positioned over or against the entry port of an appropriate bullet recovery device (e.g., water recovery tank). A panel or layer of rubber

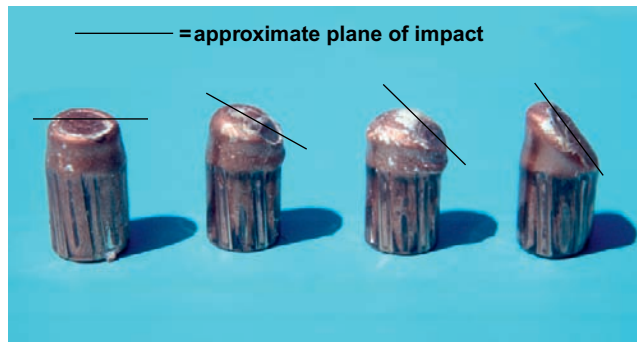


FIGURE 8.1 Intercept-angle estimates from bullet deformation during impact with glass. These four FMJ-RN 9mm bullets were fired through flat panels of glass at varying intercept angles. The approximate relationship between each bullet and the surface of the glass it struck is represented by the black line.



FIGURE 8.2 The effects of glass on a perforating bullet.

A fired, but undamaged, 7.62 NATO rifle bullet appears on the left; on the right is the same type of bullet after perforation of a 0.087-in. (2.2mm) panel of plate glass at 2372 fps. Note the sand-blasted appearance of the ogive of this bullet due to the abrasive effects of the pulverized glass through which the bullet passed.

cut from old inner tubes on the back side of the glass will prevent glass fragments from going into the device.

Along with the abrasive effects, microscopic examination will typically reveal sparkly inclusions of powdered glass. These may be so numerous and obvious in bullets from actual casework that a few particles can be dislodged and mounted on a microscope slide, where inspection under the polarizing microscope will reveal that they are sharp, angular, and isotropic. This is quite different from soil and sand grains, most of which show weathering effects and are anisotropic.

A more sophisticated analytical approach to characterizing the inclusions in the surface of recovered bullets is scanning electron microscopy–energy-dispersive spectroscopy (SEM/EDX), a nondestructive technique that does *not* require the removal of any particles and allows their morphology, method of deposition, and elemental composition to be ascertained in situ. Like the polarizing microscope, SEM/EDX will reveal glass particles to have sharp angles and edges; soil grains will typically show evidence of weathering.

The elemental compositions of the two types of particles will also be revealing. A typical soda-lime glass spectrum, in addition to silicon and oxygen, will show the presence of sodium, magnesium, and calcium whereas a silica (quartz) sand grain (the closest contender to glass) will usually appear rounded and yield a spectrum showing only silicon and oxygen (because of its chemical composition, SiO_2). Other soil minerals are radically different in elemental composition.

Visually, a bullet with traces of drywall or gypsum adhering to it may, on the surface, appear similar to a bullet with adhering perforated glass. The similarity lies in the fact that both bullets may have significant amounts of white, powdery material on them. However, a closer examination will show that the drywall will be loosely clinging to the bullet and may even be removed with water; glass will be embedded and not likely to be easily removed. Also, drywall tends not to create its own damage to a bullet whereas glass provides enough resistance to the passage of the projectile that flat spots or fragmentation may occur. Figure 8.3 is a split image allowing the reader to see a bullet with impacted glass on the left and a pristine bullet of the same type fired into water on the right.

For comparison, Figure 8.4 shows drywall adhering to the sides of a bullet that passed through a wall while unstable. Once the investigator has seen the differences, identifying this crucial evidence at a scene or under a microscope can be easy. The bullet shown is a particularly nice example, however, because the primary impact was a pane of glass. Note the

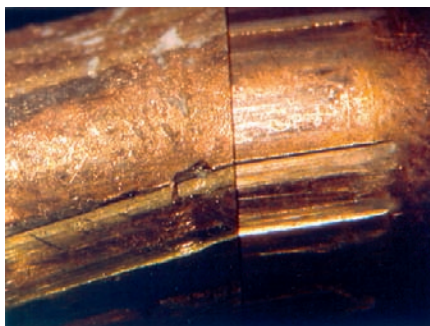


FIGURE 8.3 A split-field view of a pristine bullet on the right and a bullet displaying checking and embedded glass on the left.



FIGURE 8.4 A fired bullet with adhering gypsum/drywall on the underside as viewed. The primary impact was to glass, as demonstrated by the checking of the ogive.

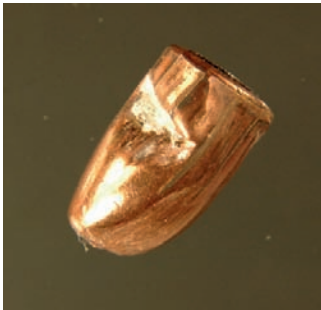


FIGURE 8.5 An unstable bullet that impacted a glass window pane. The location of the glass in the bearing surface and the size of the trace evidence tell us about the impact conditions.

ogive on the right and the visible embedded glass and checking. These would be washed away with difficulty while the gypsum would come away relatively easily.

Another observation involving the common attributes of a bullet's passage through glass involves the size of the glass fragments and the amount of damage to the bullet from the glass-related impact. Compare Figure 8.5 to previous figures that show bullets that have perforated glass.

Readers familiar with ricochet and stability (see Chapter 9) should immediately be thinking that the damage to the side of this bullet that holds a large crystal-like cube of glass did not result from a primary impact. In fact, the bullet was ricocheted from a yielding surface (note the damage to the ogive on the underside and the fact that it has striae running nose to base) before it struck the glass. It was recovered a short distance from the window and had just enough momentum to defeat the pane. The presence of the large piece of glass would not be expected if this had been a full-speed impact.

As a corollary to this observation, the amount of powdery white material around a bullet hole in glass can be related to the speed at impact. The more powdering, the higher the bullet's velocity. Even though the composition is different, this can be observed by contrasting a perforation created by a 223 Remington bullet with that created by a 22 long rifle (LR) caliber bullet.

TYPES OF GLASS

Three types of glass are commonly encountered in shooting incidents: plate/float, laminated, and tempered. In shooting incidents, *plate* glass is most frequently encountered in windows in residences and many businesses; *tempered* glass, in vehicle side and rear windows; and *laminated* glass, in windshields. Because they display some unique properties and effects when struck by projectiles, the types will be treated separately.

Plate/Single-Strength Glass

The most common contemporary means of manufacturing sheets of plate glass is to float the molten glass on a bed of molten tin. The “float” method produces a very smooth panel of uniform thickness that lacks “ream” lines. These are associated with much older methods of glass manufacture and are of no particular importance to the criminalist or firearms examiner involved in the evaluation of bullet holes in glass.

The tin float method results in a unique and useful property of glass. The side that was in contact with the tin will fluoresce a dull yellow-green color when examined in the dark under shortwave ultraviolet light, whereas the internal composition and opposite surface will not. This seeming bit of trivia can be useful in certain cases for the reconstruction of shattered windows and can ultimately determine the direction of bullet impact. Sheets of such glass may be as thin as several millimeters and would typically be found in small picture frames. Thicker forms, as thick as 6 millimeters, would be used in common windows in homes and some commercial buildings. The name *plate glass* or *single-strength glass* is used for this basic form.

Cone Fractures and Direction of Fire into Plate Glass

The first property of interest regarding the effect of projectile impact is the *cone fracture*. A classic example is the displaced cone of glass in a plate glass window struck by a steel BB. The cone-shaped area of missing and ejected glass is on the side *opposite* the side against which the impact occurred. A hole is frequently present that is usually smaller than the steel 0.175 caliber BB that produced it. Given their generally low velocity and the thickness of typical plate glass windows in stores and commercial buildings, BBs seldom perforate such glass. If a careful search is made, they can usually be found on the ground near the impact site. Figure 8.6 illustrates classic BB gun cone fracturing.

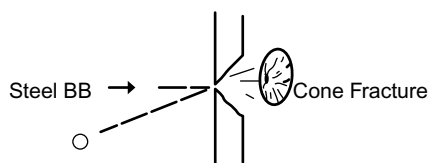


FIGURE 8.6 A steel BB strike to plate glass with cone fracturing.

Most shot fired from BB guns and air rifles does not perforate the glass in windows and doors, even though there is often a hole at the center of the impact site, because of its relatively low velocity. With or without perforation, a cone-shaped area of glass will be ejected from the side opposite the side of impact. Cone fracturing occurs in plate and laminated glass. It also occurs in tempered glass for the first bullet or projectile strike that defeats it.

The real value of the cone fracture, exemplified in its simplest form in the BB impact site, is that it establishes the *direction of fire*. This is one of the primary questions put to investigators and laboratory analysts. Beyond the simple BB strike, cone fracturing occurs with much more substantial and energetic projectiles that perforate panels of plate glass. Careful examination of the margin of the bullet hole will reveal a somewhat stair-stepped or tapered flaking away of the glass around the hole's *exit* side. The glass will be flat and smooth right up to the edge of the hole on the *entrance* side. It is interesting to note that the same effect is found in other brittle and/or ceramic materials, including bone. Forensic pathologists often use this phenomenon in determining direction of fire in perforating gunshot wounds to the skull.

The glass that is flaked away from the margin of the exit bullet hole becomes a part of the glass propelled down range and, combined with the pulverized glass that was immediately in front of the bullet, becomes a source of injury-producing evidence with reconstructive value. A useful example is the pseudostippling of the skin of gunshot victims located near the exit side of a window through which a bullet passed.

Radial and Concentric Fractures and Direction of Fire into Plate Glass

During the initial interaction between a projectile and a panel of single-strength glass, the bullet undergoes some considerable flattening at the contact point and the glass begins to yield somewhat without any breakage or fracturing; this is illustrated in Figure 8.7(a). The amount of projectile flattening will depend on a number of factors, to include bullet

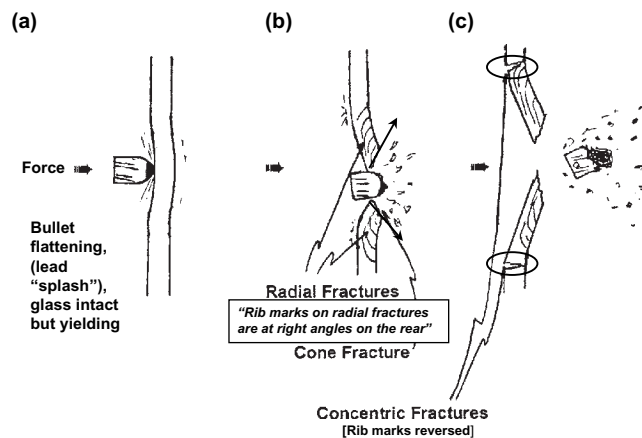


FIGURE 8.7 The perforation of plate glass: (a) Pre-failure yielding of the glass to a bullet's advance. (b) Initiation of radial fractures on the back side. (c) Rib marks on the edges of radial fractures.

The three phases of glass breakage and perforation by a projectile are illustrated in these drawings. (a) Prior to failure, the glass actually yields slightly to the bullet's advance. Flattening of the bullet's nose also occurs during this first phase. (b) If the projectile is made of lead or has an exposed lead nose, lead splash begins, with some of the vaporized lead ejected back toward the source of the projectile. (c) Radial cracks open up on the back side of the glass and propagate outward. The rib marks on them are formed during this process. Pulverized glass and cone fracturing also occur on the back side. The continued bending causes concentric cracks and fractures to open up on the entry side of the glass. The damaged and destabilized bullet continues its flight amid a shower of pulverized glass particles.

design and hardness (lead round-nose versus steel-jacketed spitzer point), impact velocity, intercept angle, and glass thickness, as well as how large an area the panel of glass occupies before reaching support structures.

For example, a 1/4-inch-thick panel of glass 4 inches square and firmly mounted in a 4-sided frame will yield less to a bullet's initial impact than a 3-foot-square panel similarly mounted. Lead splash may occur with lead and jacketed bullets with exposed lead noses, as these encounter the glass with increasing likelihood as impact velocity increases.

As the projectile continues to deform and bend the pane of glass, the glass will begin to fail (open up) on the back side by means of crack formation. The cracks, called radial fractures, radiate out or away from the point of the application of force—see Figure 8.7(b)—because glass can withstand compressive forces (on the entry side) more than it can endure stretching forces (on the back side). As the fractures propagate outward from the developing bullet hole, they create pie-shaped shards. Because of the momentum transfer to these developing shards, stretching of the glass now occurs on the impact side and in a concentric pattern, resulting in *concentric fractures*, with the glass opening up on the impact side.

An appreciation of these events is important because examination of the edges of radial fractures can allow the direction of fire to be established independently of the cone fracture method. This is useful because the area of cone fracturing is relatively small and may not survive to be identifiable in the static aftermath. Pieces of glass with surviving radial fractures are frequently present and allow for the determination of direction of fire based on *rib marks*. These features form as the glass opens up on the back side (the side opposite the application of force) and as the radial fractures propagate outward from the bullet impact point. They start at right angles to the back-side surface of the glass and turn toward the source of breaking force as shown in Figure 8.7(c). Conversely, rib marks that occur on concentric fractures will be at right angles to the *entry* side rather than the exit side. Unlike rib marks on radial fractures, the direction in which rib marks on concentric fractures turn has no diagnostic value. This does not present a problem so long as the examiner can locate the radial fractures.

Figure 8.8 provides an example of a pie-shaped shard with rib marks on all three edges. The 4-R memory aid shown in Figure 8.7(b) should be useful in sorting out which edges are concentric and which are radial fractures, and at which corner the breaking force was applied. The more difficult matter may be knowing which side of a piece of submitted glass was on the exterior or interior of the building. If such glass is going to be collected by someone other than the laboratory analyst, it is critical that field investigators or crime scene technicians mark the exterior or interior side of any glass pieces removed from a projectile-struck window. In situations where submitted pieces of glass have not been so labeled, it may be possible to resolve this through careful inspection of the two surfaces for such things as adhering putty from the mounted edges of the glass, rain spots, weathering effects, and paint overspray. This may require the collection and submission of an additional piece of glass from the struck window whose exterior or interior surface *has* been marked.

In the absence of a physical match between the documented piece and one of the evidence pieces, the previously described features on the reference piece and on the evidence pieces can be compared. One final method offers an additional means for resolving the dilemma, and that is an examination under ultraviolet light. If the glass was manufactured by the tin float method, one side will fluoresce a dull greenish-yellow color. Compare the

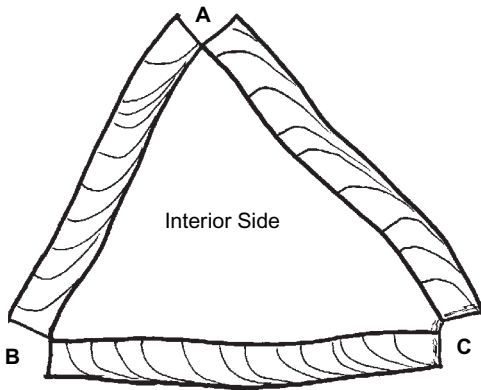


FIGURE 8.8 Sketch of arrangement and interpretation of rib marks on a pie-shaped piece of plate glass with the edges opened out.

This is a typical situation where a section of glass from a shattered window is submitted to the examiner. The scene investigator has marked the surface that faced the interior of the residence, from which the sample was collected. No obvious cone fractures are present on this specimen from which the direction of force can be determined. Two edges must be radial fractures and the third a concentric fracture. Applying the 4-R test ("Rib marks on radial fractures are at right angles on the rear") leads to only one solution: Edges AC and BC are radial fractures. The rib marks turn and point to C, where the breaking force was applied. The 4-R test also shows that the force came from the exterior side of the glass. The selection of corner A or B as a possibility for the focal point of the breaking force is quickly excluded by this test.

fluorescent properties of the evidence piece(s) with a piece of known orientation in the bullet-struck window.

A preferable alternative to the foregoing would be to thoroughly tape the remaining glass in the window and submit the entire window; however, this is not always possible or feasible. Properly marking the pieces collected at the scene will save much time in trying to distinguish interior from exterior surfaces.

In summary, the rib marks on radial fractures can be used to determine the direction of fire. The examiner may find the "4-R" memory aid useful: Rib marks on **R**adial fractures are at **R**ight angles on the **R**ear. The location of the point of initial breakage (or application of force) is shown by the *direction* of the rib marks on the radial fractures in that they turn and point to this site. (In Figure 8.8 edges AC and BC are radial fractures, the force was applied at corner C, and the projectile came from outside to inside.)

As a general statement, the length and density of the radial fractures can indicate the impact velocity of the projectile. For a high-velocity bullet (e.g., 2000+ fps), compared to a low-velocity bullet (<1000 fps), radial fractures will typically be more numerous and much shorter for the same thickness of single-strength glass. Figure 8.9 illustrates these effects in a panel of common window glass perforated by a high-velocity rifle bullet and a low-velocity pistol bullet. It should be apparent from the figure and from examples of the bullets fired through this panel of glass that hole size bears little or no relevance to bullet caliber other than to say that the responsible bullet is likely to be smaller than the hole's minimum diameter.

Rib marks can be somewhat difficult to photograph, but careful manipulation of the light source or fogging of the broken edges with burning magnesium ribbon will allow these

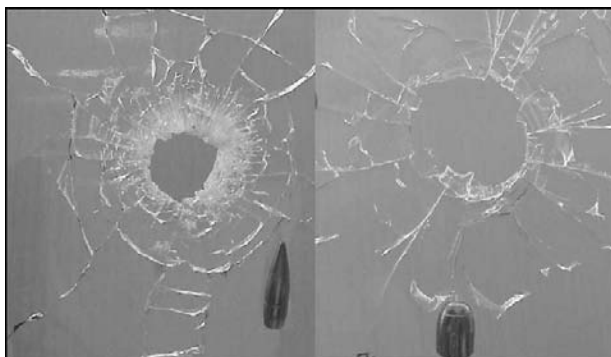


FIGURE 8.9 High-and low-velocity bullet holes in a pane of plate glass.

On the *left*, a bullet hole in common window glass produced by a 147-gr, 7.62 mm NATO bullet with an impact velocity of approximately 2800 fps. On the *right*, bullet hole in the same pane of single-strength glass created by a 230-gr, 45 Automatic bullet with an impact velocity of approximately 850 fps. Examples of each bullet serve as a scale.

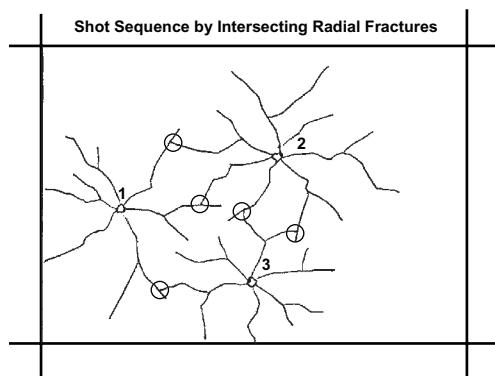


FIGURE 8.10 Sequence of three shots into a plate glass window: the “crack” rule.

This sketch depicts three shots through a glass window. The determination of sequence is made on the basis of the circled T intersections. Radial fractures are stopped when they reach a preexisting crack in the glass. In this idealized example, the sequence of all three shots can be established. Cone fracturing around the bullet holes or subsequent examination of the rib marks on the radial fractures allow the direction of fire to be determined.

marks to be recorded. Or a sketch can be drawn similar to Figure 8.10. Tracing an outline of the actual piece of glass can also be useful in this regard.

Sequence of Shots into Plate Glass—the “Crack” Rule or “T” Test

In cases where two or more shots strike plate glass, a radial fracture will not cross a pre-existing fracture. As with cone fracturing, this phenomenon also occurs in various plastic substitutes for window glass and in other brittle materials such as skull bone. Locating these “T” intersections will permit the examiner to determine the *sequence* of shots. Figure 8.10 provides a stylized example of sequence determination based on intersecting radial fractures. The rib marks and/or cone fractures will establish the *direction* of fire. Combined with the directional determination, one can ascertain who fired first and from which side of the glass the first and subsequent shots came.

Significant caution should be exercised when attempting to use the T test. If there is a chance that other forces have propagated the cracks after the shots were fired, the test does not apply. If the perforations are distant from each other, the number of intersections of cracks may be few and far between. If tactical teams have made entry after the initial shooting events, if doors were slammed, flash bangs deployed, and so forth, erroneous results are possible. The best-case scenario for this test is that the bullet holes are close to each other, with numerous intersections, and that the scene has been relatively undisturbed since the event.

Tempered/Double-Strength Glass

Tempered, or double strength, glass is used in many applications because of its greater resistance to breakage and the reduced likelihood of its causing serious injuries if it is broken. It is our experience that the term “safety” is applied by various groups to both laminated and tempered glass. For this reason, and to avoid ambiguity, we suggest that it not be used.

Manufacture and Properties of Tempered Glass

Tempered glass starts out as a hot panel of single-strength glass, the flat surfaces of which are quickly cooled by blasts of air. “Tempering” results in a piece of glass that is generally much more resistant to breakage than its untempered counterpart; consequently, it is sometimes referred to as *double-strength*. It is employed in vehicle side and rear windows and in a number of other applications such as commercial store and doorway windows, glass-enclosed shower stalls, and some Arcadia door windows.

Although it is much stronger than the same thickness of plate glass, when tempered glass does fail it instantaneously breaks into many small pieces that are generally cubic to rectangular in shape. This has been called “dicing” by glass manufacturers, and although it is a desirable feature from an enhanced safety standpoint, it creates some serious problems from a shooting reconstruction standpoint. Foremost is the fact that once broken, the pane of tempered glass is *very* fragile and, in fact, often falls out of the framework that was supporting it. Pressure differentials between the inside and the outside of a vehicle with the windows up and doors closed may cause it to fail completely and fall out. Close-range blast effects from the responsible firearm may also lead to this result.

Even when the failed tempered glass in a vehicle survives the shot and remains in place, it may fall out shortly thereafter because of vibration, bumps, curbs, potholes in the roadway, high “G” loadings in turns or spin-outs, or subsequent impacts with other vehicles or objects.

Post-shooting events as just described may give the false impression that the shot that broke a window occurred where the shattered glass is located. From the foregoing it should be apparent that this is not necessarily the case. Also, this fragile evidence is at risk of being lost during towing or loading of the vehicle onto a flatbed truck. Careless or inattentive post-event manipulation of the shattered window (e.g., opening and closing the door) is likewise potentially disruptive. All of these potentially disruptive endeavors should be undertaken only after the projectile-struck window has been adequately photographed, documented, and reinforced with clear tape or plastic film. The last effort *may* prevent the glass from falling out but provides no guarantee of its survival.



FIGURE 8.11 Shot sequence in tempered glass.

This remarkable photograph shows a tempered-glass rear window of a vehicle that was struck by a group of 00-buckshot pellets at an incident angle of about 45 degrees (left to right and slightly upward). The first pellet to break the glass created the leftmost hole, from which numerous radial fractures extend in all directions. The other pellets, arriving fractions of a second later, created holes that lack radial fractures because they struck failed glass.

The first projectile to break a pane of tempered glass possesses radial fractures. All subsequent projectile strikes merely knock out previous shattered glass.

Sequence of Perforations in Tempered Glass

When a panel of tempered glass *does* survive sufficiently for the bullet hole(s) to be located, the *first* strike will have intense but relatively short radial fractures around it. After a few inches these radial fractures will begin to wander and quickly result in the usual miniature jigsaw puzzle of square and rectangular pieces of glass. Any subsequent shots through this “diced” glass will simply dislodge areas of previously broken glass, leaving somewhat irregular holes with *no* radial fractures. These facts allow the *first* shot into the glass to be identified (see Figure 8.11).

Cone fracturing is much more subtle in tempered glass than in normal plate glass and, in fact, may not be identifiable in some cases. Also, rib marks are lacking on the edges of the radial fractures in tempered glass.

It is interesting that the velocity *loss* experienced by a particular weight and design of a bullet perforating an unbroken panel of tempered glass is only slightly greater than that suffered by subsequent bullets of the same type fired through the failed or “diced” glass. This may, at first, seem counterintuitive but the reason for it is that the kinetic energy used to produce the initial failure of the intact tempered glass is relatively low. The bulk of the bullet’s velocity loss is the result of the momentum transfer associated with the down-range acceleration and ejection of the dislodged glass. An inspection of bullet holes in tempered glass will reveal that the amount of glass dislodged in subsequent shots is similar to the amount dislodged by the first shot; consequently, the velocity loss experienced by subsequent bullets is quite similar to that of the bullet associated with the first strike.

By way of example, for a panel of 0.19-in. (4.8-mm) tempered glass struck orthogonally by 230-gr, FMJ-RN 45 Automatic bullets with impact velocities on the order of 825 fps, the velocity loss for the first strike was 52 fps. The second and third shots through the shattered pane produced velocity loss values of 55 fps and 50 fps. Another panel of the

same 0.19-in. thickness, when shot with two rounds of 115-gr, FMJ-RN 9 mm ammunition having nominal impact velocities of 1100 fps yielded velocity loss values of 184 fps and 136 fps, respectively. Tempered glass of 0.13-in. (3.3 mm) thickness shot orthogonally with two 147-gr, JHP 9 mm bullets having impact velocities of 949 fps and 923 fps experienced velocity losses of 74 fps (first strike) and 70 fps (second strike). From these data it should be apparent that there is no substantial difference in velocity loss for shots into intact versus shattered tempered glass.

Sequencing of Projectiles through Tempered Glass by Examining Recovered Bullets

The *first* bullet to impact an intact panel of tempered glass will acquire a smooth, flat spot at the contact point. The previously described dicing of the glass can produce an interesting and useful effect on the nose of *subsequent* bullets that strike it. Although a diced panel of tempered glass may seem fragile and easily displaced when pushed with a finger, to a bullet traveling 800 to several thousand feet per second, a collision with it is a major event. This, in part, is evidenced by the comparable velocity losses for the same type and weight of bullet fired through unbroken and broken (diced) tempered glass.

As a typical pistol bullet encounters a pane of diced tempered glass, the individual small squares and rectangles of glass struck and shattered by its nose produce “facets” in the bullet rather than a single, smooth flat spot. *If* they survive subsequent terminal ballistic events, these facets *identify* the bullet as a shot through a previously broken (diced) section of tempered glass. Examples are shown in Figures 8.12(a) and 8.12(b).

In Figure 8.13(a), readers can test their deductive skills. Two of the three holes for these bullets are shown in Figure 8.13(b). A quick look by the now educated investigator should yield some results.

Which bullet was the first one through the pane of tempered glass? Can the other two be sequenced? If not, do the faceting patterns tell of a location in the glass that was perforated?

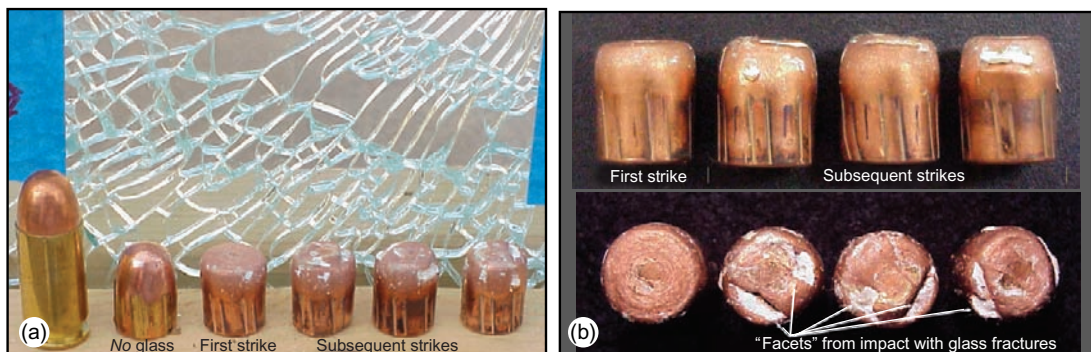


FIGURE 8.12 (a) Shot sequence of and (b) facet formation on bullets through tempered glass.

Shown are three views of four 45 Automatic bullets fired through tempered glass. A live round and an unfired bullet were shown at far left in this figure, along with a section of failed tempered glass. Note the smooth, even impact damage to the “first-strike” bullet and the facets on the bullets that struck the failed and diced glass. The white powder is pulverized glass.

This is a common, enjoyable exercise that we have used in live-fire shooting incident reconstruction classes. The correct answer is that the middle bullet was the first through the glass and that the side bullets were subsequent perforations. However, an added bit of useful information is that the almost parallel lines present on the nose of the bullet at the left can be associated with the radial cracks coming from the primary perforation. In other words, while the two bullets on the sides cannot be sequenced chronologically, they can be connected to their respective holes in the pane. The examiner must still be vigilant that the damage being interpreted is from a glass perforation and not from some subsequent terminal ballistic event.

The presence of pulverized and embedded glass in a recovered bullet is usually apparent when the bullet is examined under the stereomicroscope. On occasion it may be desirable or necessary to examine bullets suspected of perforating glass under the scanning electron microscope. When coupled with an EDX system, SEM allows the *direction of deposition* and the basic elemental composition of the embedded particles to be determined. Glass particles exhibit a characteristic sharp, angular appearance under SEM/EDX (see Figure 8.14). Their elemental composition is typically a very large silicon peak with sodium, magnesium, and calcium present (soda-lime glass), whereas sand, silica, and/or quartz grains are nearly pure silicon dioxide and have weather-worn, rounded shapes.

Direction of travel can usually be determined for the first shot through tempered glass through the usual examination of any conical-fracturing. This of course depends on the amount of glass remaining at the time of examination.

The example in Figure 8.15 is from the outside of a vehicle's tempered-glass window. The angle of the photograph shows that the beveling extends outward; in other words, the larger side of the perforation is visible. If one were to run a finger along the glass as viewed, the texture would become rough and the finger would descend into the hole. The correct conclusion is that the bullet traveled from the inside of the car to the outside. Unfortunately, this technique is not as reliable for subsequent perforations: Because the glass is already diced, beveling is not as prominent.

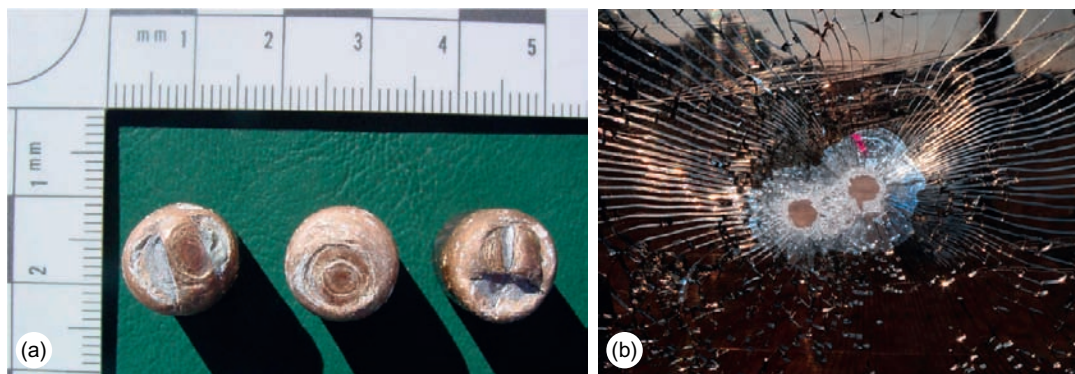


FIGURE 8.13 (a) A nose view of three bullets that perforated tempered glass. (b) Two perforations in tempered glass created by two of the bullets shown in Figure 8.14.

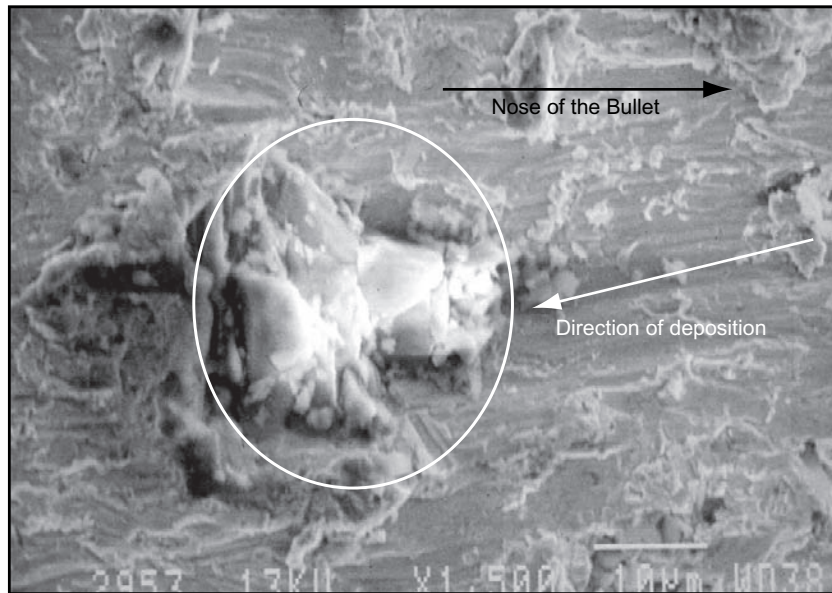


FIGURE 8.14 SEM view of glass particles in a jacketed bullet.

A 15003x SEM view of characteristic glass particles (circled) in a bullet jacket. Note their very angular appearance



FIGURE 8.15 Beveled, primary defeat of a pane of tempered glass as viewed from outside the vehicle.

Because of the fragile nature of tempered glass once it has diced, the presence of any remaining cubes in the weather stripping on moveable windows can be a conclusive indicator of the window's position at the time it was broken. Figure 8.16 is a rather egregious example showing that the pane *must* have been all the way up when it was shot out. In other cases, one must pry apart the groove in the weather stripping to see if there are any small bits of glass remaining.



FIGURE 8.16 Diced or broken tempered glass is very fragile; it cannot be driven into the weather stripping if it was previously broken.

Laminated/Windshield Glass

Another type of glass is created using two sheets of plate glass with a plastic layer sandwiched between them. This is so-called *laminated glass* and it is the standard for automobile windshields. These panels of glass and the thin polyvinyl plastic layer between them are typically molded to have the curvature seen in modern automobiles. Some more expensive cars may have numerous alternating layers of plastic and glass. As just pointed out, laminated glass is simply two preshaped pieces of normal plate glass (each typically about 0.10 to 0.12 inches thick) with a thin layer of clear plastic resin in between. This unique arrangement provides a significant measure of occupant protection from inward-ejected glass fragments when a windshield is struck by a hard object such as stone thrown up by another vehicle. It also reduces the seriousness of injuries to front-seat occupants who strike and fracture the windshield during the high decelerative forces of a frontal collision.

These desirable attributes and the increased thickness of laminated glass have some very *undesirable* effects on bullet behavior and subsequent reconstructive efforts in shooting incidents where projectiles have struck and broken (or perforated) vehicle windshields:

- Frequent separation of bullet jackets from their lead cores (particularly with jacketed hollow-point or soft-point pistol bullets)
- The *unreliability* of the T test as a means of determining shot sequence
- Substantial deflection of perforating bullets

Regarding the last item, bullet deflection for common handgun bullets as the result of windshield perforation can be substantial—10 to 15 degrees in some extreme cases. With shots fired from close range (in front of the vehicle), deflection often occurs in a direction that is counterintuitive; empirical testing may be necessary to properly assess the nature and degree of deflection for specific projectile/glass/incident angle and impact velocity combinations.

Common pistol bullets fired into typical automotive windshields from positions in front of the vehicle frequently show a consistent *downward* deflection of 1 to 5 degrees. Failure to recognize and consider this phenomenon will result in back-extrapolations that place

the shooter *closer* to the vehicle than he actually was as a result of an elevated pre-impact flight path. (At reduced impact velocities the direction of bullet deflection may reverse itself. Bullet deflection as a result of glass *perforation* is discussed further Chapter 9.)

Although the glass in laminated windshields is plate, the bonding of two or more pieces of glass together and mounting them in a framework frequently results in subsequent crack propagation with the passage of time, much like that often seen after a small rock strikes a windshield. Stress and/or thermal changes as well as subsequent movement of the vehicle may result in the formation of one or more “T” points between the cracks emanating from two or more shots, but the configuration of this junction is *not* necessarily the consequence of shot sequence. Rather, it may merely be the result of continued crack growth. In an actual shooting incident, it would seem *very* unlikely that someone would have the opportunity to document the arrangement of the radial and concentric fracture lines in both layers of glass in a windshield *immediately* after shots were fired. Only then might one be justified in using the T test for sequence determination. Otherwise, our advice is “Don’t try it on laminated-glass windshields.”

All is not lost or hopeless, however. The direction of fire in windshields can usually be determined on the basis of cone fracturing, just as with single panes of plate glass. However, when assessing conical fracturing in windshields, if the investigator does not actually feel *both* sides of the hole, the plastic laminate in the middle can be misleading as to the direction of travel. This is because it will give the impression of looking at an exit side from *both* sides. Nevertheless, as long as the examiner feels both sides, one will still be bigger than the other.



FIGURE 8.17 Azimuth-angle estimates for shots into laminated windshields.

Two techniques for identifying the vertical axis for this bullet hole in a laminated windshield have been employed. A plumb bob and line were passed through the bullet hole after the vehicle was leveled in the examination bay. Two rectangles of white paper were placed above and below the hole, after which a projecting laser level was used to project a vertical line across its center. Black lines were drawn across these pieces of paper and out onto the surface of the windshield. The right-to-left path of the bullet is represented by the long axis of this relatively symmetrical bullet hole.

The clock orientation of the customary oval holes in common windshields provides some indication of the *azimuth angle* of the shot. An oval hole oriented at 12 o'clock by 6 o'clock was fired from an essentially straight-on position (from in front of the vehicle), whereas an orientation of 8 o'clock by 2 o'clock came from a decided left-to-right direction as one stands in front of the struck vehicle and views it. Conversely, a 4-o'clock to 10-o'clock orientation of the long axis of a bullet hole indicates a right-to-left flight path.

The approximate azimuth angle relative to the windshield glass at the point of impact can be refined somewhat by marking or establishing the vertical axis line through the bullet hole and then the line through the best estimate of the hole's long axis. An example of this is shown in Figure 8.17 on the previous page. The most accuracy that can be expected from this technique is on the order of 5 degrees of the true value where a symmetrical, oval bullet hole is present. A fixed down-range impact point within the vehicle is of considerable assistance so long as some evaluation or consideration of deflection is included in the back-extrapolation of the responsible bullet's path.

SUMMARY AND CONCLUDING COMMENTS

One of the most interesting and informative aspects of interaction in a shooting incident reconstruction is a bullet's behavior with glass. Simply determining that a bullet or fragment has gone through glass can be a field observation with important ramifications for the immediate investigation's direction as well as for the end result of the entire reconstruction. The presence of checking or of an embedded glittering, powdery white material can indicate that a bullet perforated any of the three major types of glass.

Each of type of glass—plate/float, tempered, and laminate—allows a wide variety of conclusions. When dealing with plate glass, direction of travel can be established from conical fracturing, and shot order *may* be determined via the T test. Tempered glass can show where the first defeat of the pane took place, and examination of the bullets themselves may show which was first through. Conical fracturing can tell direction of travel, particularly when dealing with the primary defeat. Laminate or windshield glass can also give direction of travel as long as the examiner is careful with the evaluation of the beveling, considering the plastic layer in the middle. The T test should not be employed with windshield glass.

Because of the frequency with which a shooting reconstructionist will deal with glass, knowledge of this material should be extensive.

CHAPTER KNOWLEDGE

- Name the three most common types of glass encountered in shooting investigations.
- Can you describe the manufacturing process for each type of glass, and do you understand why they are used in different capacities?
- The faceting phenomenon is directly related to the concept of inertia of rest. Can you describe this effectively to an audience?
- Residential windows are commonly made with two panes of single-strength glass. If a rifle bullet with an exposed lead nose were fired through one of these windows, what might you expect to see between the panes?

References and Further Reading

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Projectile Ricochet and Deflection

INTRODUCTION

Numerous articles have appeared over the last 30 years on the subject of projectile ricochet. They are listed in the References and Further Reading section at the end of this chapter. These articles largely contain the results for specific target materials and a few specific bullets or projectile types. Most of them make little effort at setting forth any general properties or behavior for projectiles undergoing ricochet, largely because of the substantial variety in bullet types and surfaces struck, the varying responses of struck surfaces, and variations in post-impact behavior of such projectiles. Moreover, many of these articles arose out of specific case situations and therefore do not have general applicability to the overall subject of projectile ricochet.

This chapter provides the reader with some useful definitions as well as some general expectations for the behavior of projectiles on impact with a variety of surface types and the sort of damage ricocheted bullets acquire during different ricochet events. The importance and reconstructive value of the appearance of ricochet damage on recovered bullets, as well as that of the impact sites associated with these events, are presented.

Most of us have seen depictions of bullet ricochet in film and on television. A few of these have been good representations of the real world and certain laws of physics. Most, however, range from fanciful to farcical. Erroneous statements about bullet ricochet have been found printed in law enforcement training manuals, medical examiner's reports, and most certainly in crime investigation television shows.

One of the most common errors is to assume that projectiles behave like light striking a mirror. In physics, the angle of incidence is equal to the angle of departure. As we will see, this is not at all a proper model for terminal ballistic interactions. What is most surprising is that some firearms examiners have seriously flawed notions about the behavior of projectiles when they strike various surfaces at a low incident angle. In one recent report involving an injury sustained by a ricocheted bullet, an examiner of long experience included the following statement in his report on the matter: "After impact with the ground this bullet

could have gone anywhere.” This is, of course, simply incorrect and falls into the same category as “Anything is possible.” The range of possibilities may be large, but anything is not possible. For example, it is not possible to be 40 years old without first being 20 years old.

Through empirical testing and observation, we can learn to predict the general behavior of projectiles after shallow-angle impacts and ricochets from specific surfaces. This chapter describes the ricochet process and offers some insight into what one can expect to see at the impact site and on the bullet, and how the bullet will behave during its post-impact flight.

DEFINITIONS

The following definitions are used in this chapter:

Ricochet: The continued flight of a rebounded projectile and/or major projectile fragments after a low-angle impact with a surface or object. Another way of describing ricochet is that it is the occurrence of deflection without penetration or perforation. It is typically a *surface* phenomenon.

Deflection (as differentiated from ricochet): A deviation in a projectile’s normal path through the atmosphere as a consequence of an impact with some object. *While it may be said that deflection always occurs with ricochet, the term deflection is further refined for two types of impactive events that occur during a projectile’s normal flight path.* Figures 9.1(a) and 9.1(b) provide simplified profile views of projectile ricochet from two general types of surfaces:

Deflection as a consequence of ricochet describes any lateral component of the ricocheted projectile’s departure path relative to the plane of the impacted surface as viewed from the shooter’s position and with the plane of the surface normalized to a horizontal attitude. The angle formed is between the path of the departing projectile subsequent to impact and the pre-impact plane of the projectile’s path (see Figure 9.2).

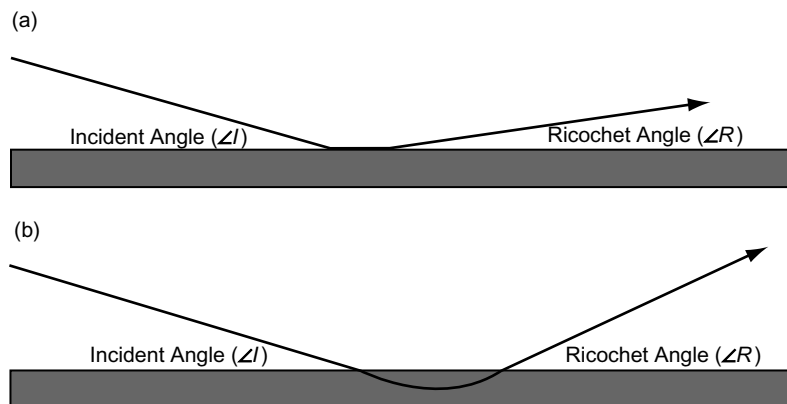


FIGURE 9.1 Simplified profile view of projectile ricochet from (a) a hard, unyielding surface; and (b) a yielding surface.

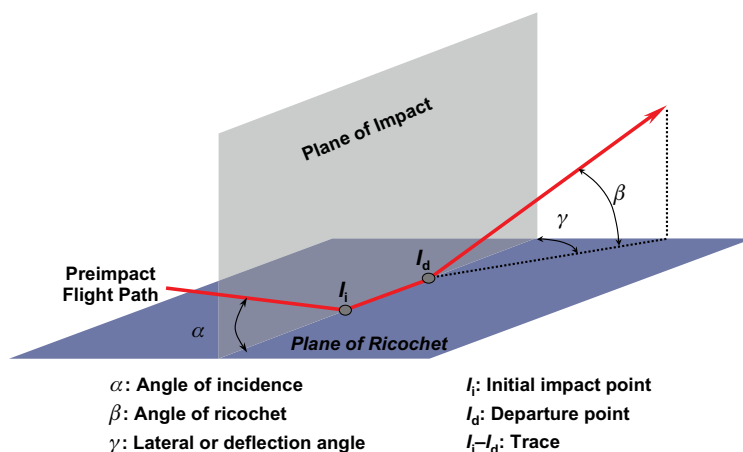


FIGURE 9.2 Detailed diagram of projectile approach, impact, ricochet, and deflection.

Source: Adapted from the work of Dr. Beat Kneubuehl.

Deflection as a consequence of *perforating, penetrating, or striking an object* describes deviations in *any* direction from the projectile's normal flight path as a consequence of perforating or striking an object rather than rebounding off its surfaces. For example, a bullet may be *deflected* by passage *through* a tree branch, a windshield, or a panel of sheet metal, but this does not represent an instance of ricochet. Since such deflection can occur in any direction in the examples cited (up, down, right, or left), its clock position is used to describe it. As viewed from the shooter's position (or the position directly behind the projectile at impact), 12 o'clock is taken as straight up relative to the horizontal plane at the location of the event; 3 o'clock is directly to the right; 9 o'clock is directly to the left, and so forth.

Incident Angle ($\angle I$): The intercept angle described by the pre-impact path of the projectile and the plane of the impact surface at the impact site when viewed in profile (refer to Figure 9.1). The angle formed between the path of the projectile prior to impact and the plane of the impacted surface (refer to Figure 9.2). Note that this definition differs from the NATO definition. For those who wish to convert from the forensic definition used here to the corresponding NATO angle, use the equation [90 degree-F.A.] = NATO $\angle$.

Ricochet Angle ($\angle R$): In the same coordinate system used for incident angle, the angle defined by the path taken by the ricocheted projectile (or major projectile fragments) as it departs the impacted surface, with one additional qualification—the reference plane of the impact site is the one *prior* to bullet impact even though in some situations the bullet is departing a much modified surface (e.g., water, sheet metal, soil); refer to Figures 9.1(a) and (b). The angle formed between the path of the departing projectile subsequent to impact and the plane of the impacted surface (refer to Figure 9.2).

Critical Angle: The incident (intercept) angle above which the particular projectile at a given impact velocity no longer ricochets from the impacted surface. Above the critical angle a projectile will significantly fragment when interacting with unyielding surfaces, and will penetrate when interacting with a yielding surface.

Pinch Point: The small area of surviving paint that was pinched between the initial contact point of a low incident angle projectile and a painted sheet metal surface. The pinch point establishes the entry side of the ricochet mark. This phenomenon may, on occasion, also be seen on painted wood.

Bow Effect: The flow pattern of abrasive materials in soil, sod, and/or sand around the nose, ogive, and/or bearing surface of a bullet generated during penetration into and ricochet from such materials. This characteristic pattern is uniquely associated with ricochets from soil, sand, or sod where the bullet has entered the substrate to some depth before departing it. It is most noticeable on the ogive of the bullet, but may extend back along the bearing surface as well. This type of marking takes its name from its similarity to the flow pattern of water off the bow of a boat.

Lead-In Mark: The dark, elliptical transfer of material from a bullet as it makes its initial contact with a surface at a low incident angle. The lead-in mark establishes the entry side of the ricochet mark. This phenomenon is a form of bullet wipe, but is transferred from only a portion of the bearing surface because of the shallow angle of intercept.

“Chisum” Trail: So named for Criminalist Jerry Chisum, who first described it in the United States. This unique ricochet mark occurs on a flat, unyielding surface as the bullet departs it. It is caused by the right or left edge of a flattened bullet remaining in contact with the surface after the main body has lifted off. The asymmetrical extension of the ricochet mark will be on the left side if the bullet was fired from a firearm having left-twist rifling and on the right side in the case of right-twist rifling.

Lead Splash: The impactive spatter and vaporization of lead with its subsequent downrange deposition in the case of nonorthogonal impact angles. This is typically associated with lead and semijacketed bullets possessing exposed lead points. The geometry of lead splash deposition can provide information on the direction of fire. The amount of lead splash is a function of impact velocity.

EXAMINING RICOCHETED BULLETS

There is much to be learned from a careful examination of a ricocheted bullet as well as any suspected impact sites. Certain laws of physics must be obeyed during the ricochet process and the projectile’s subsequent flight. For example, the steeper the incident angle, the greater the forces acting on the bullet during impact and the greater the “work” performed on the bullet throughout impact and ricochet. This, in turn, results in greater velocity loss and greater deformation to the bullet than would occur if the same bullet had struck the same surface at the same impact velocity but at a shallower angle.

With increasing incident angle there will be a corresponding increase in evidence transfer and effects at the impact site. If the impacted surface is one that yields to the bullet’s advance, the greater will be the deformation of or disruption to it as the incident angle increases. Ultimately, with an increasing incident angle the projectile will no longer ricochet. Rather, it will either fragment into numerous pieces or penetrate/perforate the substrate. This important angle is known as the *critical angle*. For any ricochet to take place, the incident angle *must* be less than the critical angle for the particular bullet and substrate.

If one isolates the parameter of impact velocity and continually increases it while holding all other parameters constant (i.e., incident angle, bullet, substrate), the same previously described general effects will be seen. These effects are quite logical and have a strong commonsense quality to them.

Our everyday observations of the damage sustained by vehicles that graze a concrete divider at highway speeds versus vehicles that strike such barriers at comparable speeds but at much more acute angles (e.g., 45 degrees) provide simple examples of ricochet to which juries can relate. The vehicle represents a projectile; the concrete divider, an impacted surface. At a shallow grazing angle a vehicle loses very little speed, sustains minimal damage, and undergoes only a slight directional change as it “ricochets” off the divider. Likewise, the concrete suffers very little damage. Consider now the consequences of a 45-degree impact at typical highway speeds. Substantial damage will occur to both the vehicle and the concrete divider, and velocity losses will be much greater.

Still, bullets are small and travel much faster than automobiles. For example, the relatively low velocity of 900 feet per second (fps) for a common pistol bullet translates to over 600 miles per hour for a car. Moreover, bullets can impact a much greater variety of materials than the concrete dividers and barricades used in the vehicle-as-a-projectile analogy. As a consequence, some examiners confronted with ricochet questions tend to give up with claims of “It’s too complicated” or “There are too many variables.” The illustrations and data presented in this chapter will refute such statements and provide the reader with a sound basis for understanding and evaluating possible ricochet issues.

Some General Principals, Observations, and Comments

The reflection of light from a first-surface mirror can be viewed as the ideal, and yet incorrect, model for ricochet. In this situation, the incident angle equals the ricochet angle; there is no lateral deflection and no loss of velocity.

The behavior of a ball rebounding from the edges of a pool table comes close to this ideal ricochet model. As before, the incident angle is, for all practical purposes, equal to the ricochet angle; very little velocity is lost during the ricochet process; and neither the impacted surface (the edge of the pool table) nor the projectile (the billiard ball) sustains any damage during impact. Unfortunately, bullets seldom behave this way when they ricochet, yet laypersons (from whom juries are chosen) and possibly lawyers and judges may have the billiard ball model in mind when the subject of ricochet arises.

The closest real-world example of such a ricochet would be a steel BB or steel shot impacting a smooth, marble or steel surface at a low incident angle. These projectiles are much harder than most bullets and have a much higher coefficient of restitution than spheres composed of lead and of the same weight or diameter. By way of example, standard 0.173-in., 5.25-gr steel BBs ricocheting from smooth, *unyielding* stone, at a fixed incident angle of 12.5 degrees and an average impact velocity of 276 feet per second, depart with an average velocity of 256 fps and a ricochet angle of 8.9 degrees $\pm$ 0.5 degrees for 10 shots. No visible damage is sustained by the smooth stone and only a faint blemish is noted on the recovered BBs.

In actual experience, one or more of the following events will take place with the ricochet of common projectiles from a surface:

- The projectile will lose some of its velocity as a consequence of the impact and ricochet.
- The projectile will usually depart at some angle other than the incident angle. This ricochet angle is usually less than the incident angle for most, but not all, hard surfaces.
- The projectile will usually, but not always, undergo deformation and/or damage and possibly breakup or fragmentation during impact. An exception to this is low-angle impact and ricochet from water, which often results in destabilization of the bullet but not deformation.
- The impacted surface may undergo deformation (malleable surfaces such as sheet metal) or breakup at the impact site (frangible surfaces such as cinderblocks).
- Mutual trace evidence transfers will often take place between the projectile and the impacted surface, with matter from the impacted surface becoming embedded in the ricocheted bullet and traces of the bullet left at the impact site.

Impact surfaces can be categorized into several types that are useful in making some very general predictions regarding projectile ricochet. These substrate categories are as follows:

- *Unyielding* surfaces (e.g., concrete, stone tile, steel plate)
- *Yielding* surfaces, homogeneous and nonhomogeneous (e.g., sand, sod, wood, sheet metal, Sheetrock, asphalt)
- *Frangible*, yielding surfaces, homogeneous and nonhomogeneous (e.g., cinderblock, bricks, concrete)
- *Liquid* surfaces (e.g., water—a special case of a homogeneous, yielding surface)

The nature of the damage to a ricocheted projectile and to the impacted surface is diagnostic in a variety of ways, some of which may require empirical testing to be properly evaluated and interpreted.

Factors Controlling or Affecting Projectile Ricochet

For incident angles sufficiently low to permit a projectile to ricochet from a particular surface, the ricochet angle may be affected by

- Incident angle
- Impact velocity
- Bullet shape (e.g., round nose versus wadcutter versus hollow point versus truncated cone)
- Bullet weight
- Bullet hardness
- Bullet center of gravity
- Impact surface hardness
- Response of the surface to the bullet's impact (the substrate either yields or does not yield)

This last parameter (surface response to impact) has a very important effect on ricochet angle. For example, a bullet impacting smooth, *unyielding* concrete versus yielding concrete



FIGURE 9.3 Example of a pane of tempered glass acting as an unyielding material. Note the parabolic shape on the right side, where the bullet first made contact with the glass.

(i.e., that fractures and leaves a crater) will typically result in significantly different ricochet angles, keeping all other variables the same. In this example, the bullet departing from the cratered concrete will do so at a higher angle than a bullet that ricochets *without* making a crater. This is also true with materials that behave in a similar manner—that is, low ricochet angles for unyielding surfaces and high ricochet angles when the surface yields to the bullet's advance.

Because each of the variables just listed can change the terminal ballistic dynamics of a particular interaction, the examiner must evaluate the particular circumstances he or she is dealing with. For example, a 158-gr, 38 Special, plain lead round-nose bullet traveling at 850fps and striking a windshield at an incident angle of 5 degrees will potentially fail to deform or crater the glass. The departure angle, as will be discussed in detail later, is expected to be low, and the glass behaves as an unyielding surface.

A good example of a bullet having ricocheted from a tempered-glass side window in a car is shown in Figure 9.3. In this case we would not expect to find glass on the bullet, but we clearly have bullet metal transferred to the window's surface. (Refer to the section in this chapter on determining the direction of rifling twist from unyielding surface impacts to see how it can be concluded that this impact is from a left-twist firearm.)

Now let us change the parameters of our experiment in some ways. We leave the material (glass) and angle of incidence the same (5 degrees), but switch to an 147-gr, 9mm Luger (still nominally 38 caliber), copper full-metal-jacketed (FMJ) bullet traveling at approximately 1000fps. The likelihood is that we may now crater the glass, leaving large amounts of powdered glass all over the windshield. More interesting, however, is that we might be dealing with a yielding surface interaction. The key is to evaluate the impact surface's features and potential deformation, not just the bullet's characteristics, to determine what kinds of departure properties we should expect.

Factors Controlling or Affecting Lateral Projectile Deflection During Ricochet

Lateral or side deflection (as a consequence of ricochet from a homogeneous material) depends largely on the direction of twist of the gun that fired the bullet, with the



FIGURE 9.4 Over-the-shoulder view of a ricochet from an *unyielding* stone.

magnitude of any deflection controlled by the length of contact with the substrate and the gun's twist rate. A bullet striking a smooth marble floor in a bank will experience very little deflection because its contact with the marble is very brief and the distance is short (typically about 1 inch).

Examine Figure 9.4. In this over-the-shoulder view, we can see the tracer leave the muzzle of a right-twist barrel, strike smooth stone, and continue downrange at a low departure angle with little lateral deflection. The same bullet fired at the same shallow incident angle into still water or smooth sand will remain in contact with the water or sand for a greater distance and be deflected significantly (e.g., 5–10 degrees and possibly more) in accordance with the direction of twist of the rifling of the gun.

Now examine Figure 9.5 and observe that simply by changing the struck surface to yielding sand, and alternating left- and right-twist barrels, the bullet's ricochet angle increases, as does the amount of lateral deflection.

Another way of thinking about these parameters is to visualize a monster truck tire traveling sideways while spinning. The rotation of the tire mirrors the rotation of a bullet. If it momentarily comes in contact with a surface with little friction, the tire does not experience a significant amount of force away from its path. However, if the tire is allowed to churn into something such as sand or gravel for a longer period of time, the amount of lateral force is significantly greater and in the direction of rotation.

Exceptions to this arise from inhomogeneities or nonuniformity in the substrate at the impact site. A representative example of such a substrate is the asphalt used in roadways and parking lots. Asphalt is composed of relatively soft bituminous material containing stones or aggregate of various sizes and shapes. Bullets striking it show much more variation in ricochet angle than they do with more homogeneous materials. For example, a bullet encountering a substantial stone on the right side of its nose as it enters otherwise soft asphalt is likely to result in a left deflection regardless of rifling twist direction. Any significant bullet yaw at the moment of impact also stands to play a role in deflection, particularly with yielding substrates.

In summary, lateral deflection during ricochet will be quite small or inconsequential for hard, unyielding surfaces and can be significant for yielding surfaces.



FIGURE 9.5 (a) Over-the-shoulder view of a ricochet from *yielding* sand, with a *right-twist* barrel. (b) Over-the-shoulder view of a ricochet from *yielding* sand, with a *left-twist* barrel.

PROJECTILE IMPACTS

The following subsections describe what happens with a variety of projectile impacts.

To Hard, Unyielding Surfaces

Figure 9.1(a) (page 144) provides the operative model for impact with a hard, unyielding surface. During contact and interaction with smooth marble, granite, concrete, thick steel, and the like, the softer bullet sustains a conspicuous flattening on its bearing surface that will extend out onto the ogive as the incident angle increases. The flattened area will be quite smooth when the struck surface is smooth (e.g., polished marble) and heavily striated when the surface is abrasive (e.g., concrete).

Characteristic mineral grain inclusions, particularly with concrete and comparable substrates, can easily be seen and characterized by SEM/EDX analysis, which also allows the direction of deposition of such mineral inclusions to be seen in excellent detail. With a normally spin-stabilized bullet, this pattern of deposition will be from front to back and aligned



FIGURE 9.6 Bullets ricocheted from smooth concrete and polished granite.

Three 124-gr, 9 mm bullets are shown in this figure. The bullet on the left was taken from a water recovery tank and is in pristine condition. The other two bullets struck smooth, flat slabs of concrete and polished granite with an incident angle of 210 degrees and with a nominal impact velocity of 1000 fps. The impact with the polished granite (middle) has flattened one side of the bullet and essentially “ironed out” the rifling impressions. The impact with the more abrasive concrete has obliterated the rifling impressions and heavily striated the area of flattening.

with the long axis of the bullet. A bullet that has struck some intervening object prior to impact and ricochet will usually do so in a yawed or destabilized orientation. In this situation the pattern of impact striae and mineral inclusions will be at some angle other than the bullet’s longitudinal axis.

Figure 9.6 shows three bullets. The one on the left was recovered from a water recovery tank without ricochet. The middle bullet struck polished granite, and the bullet on the right struck common concrete. The second and third bullets struck at an incident angle of ≈ 10 degrees while in normal, nose-first flight. Note that the impact-created striae travel longitudinally down the bullets’ long axes. If no significant, subsequent deformation occurs from post-ricochet impacts, the plane of the flattened area relative to the long axis of each bullet can provide a rough index of the incident angle (see Figure 9.7).

The corresponding impact marks can be difficult to locate on smooth, shiny surfaces such as polished marble or granite. Examination of such surfaces with oblique light in a near-dark condition may be necessary. Ricochet marks on concrete, flagstone, and thick steel are more readily discernable. Examples of such marks showing the “Chisum trail” are illustrated in Figure 9.8.

If the struck object or surface cannot be collected, confirmation of the mark as bullet-caused can be accomplished through the copper and/or lead test carried out by the transfer method described in Chapter 5.

The ricochet angles from hard, unyielding surfaces remain low (on the order of 1 to 2 degrees) and close to the plane of the struck surface for all incident angles up to the critical angle. This fact is of considerable importance in searching for a bullet that has ricocheted from such surfaces and for any effort to reconstruct the bullet’s pre-impact flight path. For example, locating an embedded bullet in a vertical wall 1 foot above the surface of a floor at a distance of 50 feet from the ricochet site allows the ricochet angle to be calculated from the tangent relationship (1 foot of height after 50 feet of post-impact flight), yielding a result of 1.1 degrees. But this angle tells us very little about the incident angle (other than that it was less than the critical angle), and shots with this particular ammunition at incident angles of 2, 4, 6, 8, and 10 degrees are later found to produce similar ricochet angles. (See Tables 9.1 through 9.3.) The important and useful parameters in this situation are these:

- The appearance and dimensions of the impact mark.
- The deformation suffered by the bullet during impact and ricochet.

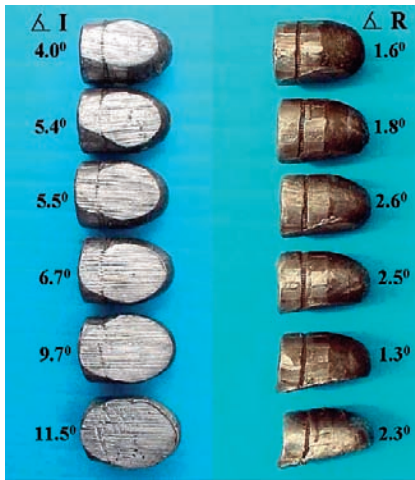


FIGURE 9.7 Relationship between incident angle and deformation of ricocheted bullets: profile view of a series of bullets ricocheted from a hard, unyielding surface.

These six LRN bullets were fired into smooth flagstone. Their flattened, impact sides are shown on the *left* with their associated incident angles. Their profile views appear on the *right* with their associated ricochet angles.

It should be noted that the ricochet angles are all around 2 degrees, even though there has been a nearly threefold change in incident angle (4 to nearly 12 degrees). This is typical behavior for bullets ricocheting from hard, unyielding surfaces. An estimate of the incident angle can be made by drawing lines through the bullet's longitudinal axis and along the plane of impact damage, with the bullet oriented in profile.



FIGURE 9.8 Diagnostic ricochet marks on hard, unyielding surfaces showing twist direction.

The five impact sites here were all created by 45 Automatic bullets that struck this smooth stone at about -15 degrees. The direction of travel was from below; the departure is shown at the top of the figure. Four of the bullets were FMJ-RN. The fifth (*lower right* impact site) was a JHP. All weighed 230 grains and had impact velocities on the order of 850 fps. The two impact sites at the *top* of this figure were fired at from a left-twist barrel, as evidenced by the asymmetrical extension of the bullet transfers on the *left side* of the mark. The remaining three were fired at from a right-twist barrel and display the same effect at the *upper right* of each impact mark.

TABLE 9.1 Ricochet of 9 mm Luger Bullets from Smooth Concrete

Ammunition	Incident Angle = -5°	Incident Angle = -10°
Winchester 115-gr FMJ-RN	$\angle R = 1.5^\circ / 1.6^\circ / 1.5^\circ = \text{Ave. } 1.5^\circ$	$\angle R = 1.6^\circ / 1.2^\circ / 1.4^\circ = \text{Ave. } 1.4^\circ$
Federal 124-gr FMJ-RN	$\angle R = 1.1^\circ / 1.8^\circ / 1.6^\circ = \text{Ave. } 1.5^\circ$	$\angle R = 2.4^\circ / 1.6^\circ / 1.2^\circ = \text{Ave. } 1.7^\circ$
Winchester 147-gr JHP	$\angle R = 1.5^\circ / 1.6^\circ / 1.5^\circ = \text{Ave. } 1.5^\circ$	$\angle R = 1.6^\circ / 1.2^\circ / 1.4^\circ = \text{Ave. } 1.4^\circ$

Note: A Ruger P-85 9 mmP pistol was mounted in a Ransom Rest and positioned so as to create incident angles of -5° and -10° into smooth concrete for multiple shots for each of three weights of 9 mm bullets. Downrange witness panels were used to measure the ricochet angles.

TABLE 9.2 Ricochet of 9 mm Luger Bullets from Smooth Steel (incident angle = -10°)

Winchester 115-gr FMJ-RN (pdt. Q4172)
Average $\angle R = .4^\circ \pm 0.1$ ($n = 12$)
Average velocity loss = 47 fps (4.4% of average impact velocity of 1061 fps)
Russian 115-gr FMJ-RN (steel jacket, lead core)
Average $\angle R = 1.4^\circ \pm 0.1$ ($n = 7$)
Average velocity loss = 71 fps (5.9% of average impact velocity of 1207 fps)
Federal 124-gr FMJ-RN (M882)
Average $\angle R = 1.4^\circ \pm 0.1$ ($n = 10$)
Average velocity loss = 73 fps (6.3% of average impact velocity of 1156 fps)
Winchester 147-gr JHP (pdt. XSUB9MM)
Average $\angle R = 0.9^\circ \pm 0.1$ ($n = 55$)
Average velocity loss = 52 fps (5.1% of average impact velocity of 1020 fps)

Note: A Ruger P-85 9 mmP pistol was mounted in a Ransom Rest and a heavy steel plate was positioned downrange to create an incident angle of 210° for multiple shots with each type shown and three weights of 9 mm bullets. Downrange cardstock witness panels at measured distances from the impact sites were used to calculate the ricochet angles of each shot. The Oehler M43 PBL system and Doppler radar were used to obtain the various impact and post-impact velocity values.

Both of these parameters will vary in a noticeable and reproducible way with incident angle, but it will once again require empirical testing to establish their relationships with incident angle as well as the uncertainty limits associated with them. This was illustrated earlier in Figure 9.7.

Tables 9.1 and 9.2 provide the results of ricochet tests with a number of common 9 mm bullets on impact with smooth steel and concrete at selected incident angles. A brief study of these tables reveals several very interesting things. The ricochet angles are all very low and very reproducible. The velocity lost by the bullets during ricochet is also low. There is little difference in the ricochet angles for these bullets fired into smooth concrete at substantially different incident angles (5 degrees versus 10 degrees).

The example of a bullet ricocheting from a smooth marble or concrete floor illustrates another point, and that concerns the geometric constraints imposed by projectile ricochet and by the scene. With consistently low ricochet angles, a victim struck in the head or upper body would have to have been at some considerable distance from the impact site if he had

TABLE 9.3 Ricochet of 0.173 in. Diameter, 5.25-gr Steel BBs from Smooth Stone (incident angle fixed at -12.5° impact velocity as shown)

Group 1 (low velocity)	Average $V_{\text{Impact}} = 276 \pm 4 \text{ fps } (n = 10)$ Average $V_{\text{Ricochet}} = 256 \pm 4 \text{ fps } (n = 5)$ Velocity loss = 7.2% Average $\angle R = 8.9^\circ \pm 0.5^\circ$ (5.6% C.V.)
Group 2 (medium velocity)	Average $V_{\text{Impact}} = 400 \pm 3 \text{ fps } (n = 10)$ Average $V_{\text{Ricochet}} = 374 \pm 6 \text{ fps } (n = 5)$ Velocity loss = 6.5% Average $\angle R = 9.1^\circ \pm 0.7^\circ$ (7.7% C.V.)
Group 3 (high velocity)	Average $V_{\text{Impact}} = 528 \pm 3 \text{ fps } (n = 12)$ Average $V_{\text{Ricochet}} = 487 \pm 2 \text{ fps } (n = 5)$ Velocity loss* = 22% Average $\angle R^* = 6.9^\circ \pm 0.2^\circ$ (2.9% C.V.)

*Some cratering of the stone was evident with these impacts.

Note: A Daisy Model 880 Powerline air rifle was mounted in a machine rest and positioned to create a fixed incident angle of -12.5° with a section of smooth stone. Selected impact velocity levels were achieved with a specific number of pumps. An Oehler M43 PBL chronograph system was used to measure the pre- and post-impact velocities of these standard steel BBs. A downrange cardstock witness panel was used to calculate the ricochet angle based on the tangent function from the height of the BB hole and its distance from the impact site.

been standing at the time he was struck and if he had been on the same plane as that of the impact site. Likewise, the approximate incident angle derived from the impact site's appearance and the ricochet damage to the bullet, together with the constraints of the scene, often allow certain scenarios to be excluded and others included.

Consider the interior of an airport hangar that is 100 feet in length with a smooth concrete floor. The ricochet mark is found at the 50-foot midpoint of the floor, and a gunshot victim with an irregular entry wound to the forehead produced by the ricocheted bullet is found next to the wall downrange of the ricochet site. The shooter claims that he thought the decedent was a burglar and that the wrench later observed in the decedent's hand was a gun. The shooter goes on to claim that he fired a warning shot into the floor immediately in front of his position while his presumed adversary was standing near the distant wall. The downward angle demonstrated by the shooter for this warning shot is on the order of 30 to 45 degrees.

This account is easily refuted with a little thought and a few test shots. Given the previously described ricochet behavior of bullets striking hard, unyielding surfaces, the victim could not have been standing when struck. The height of his entry wound when standing would have required ricochet angles of 6 degrees or more. Rather, the victim had to have been down and nearly prone on the floor at the time of his fatal injury. The critical angle for this gun-ammunition-substrate combination is found to have been 15 degrees, where the bullet fragmented into many pieces and produced a small crater in the concrete. The recovered bullet and the shape of the impact site show an incident angle on the order of

8 degrees $\pm$ 3 degrees—a value that is also at odds with the shooter’s account and that can be used to estimate his shooting position for selected gun heights.

CASE EXAMPLE

A shooting incident occurred in which multiple shots were fired in a house. The shooter was not immediately taken into custody, no firearms were recovered at the time of the investigation, and no cartridge casings were found at the scene. The victim suffered a gunshot wound to the thigh. The wound path is only a few inches in length.

The different bullets shown in Figures 9.9 and 9.10 were collected from the only two impacts at the scene. These impacts are long tears in the carpet with underlying marks on concrete. Both bullets are of the same caliber and hollow-point style, with the same general rifling characteristics.

Take a moment, without reading on, to formulate some ideas about what the physical evidence is telling you as the investigator. Key observations include the following:

- One bullet has carpet fibers trapped in its hollow-point cavity; the other does not.
- One bullet is *slightly* mushroomed; the other is not.

Both bullets possess flat areas on their ogives, indicative of ricochet from an unyielding surface.

Now examine the angles of the striae in the unyielding surface impact sites, and notice that for the bullet in Figure 9.9 the damage striae travel down its long axis. These indicate that the bullet was stable when it struck the concrete. An additional check of this conclusion is that there are carpet fibers trapped in the nose. As the bullet traveled into the carpet, the fibers entered the cavity. As the hollow point was crushed closed at impact with the underlying concrete, the fibers were trapped in place. If the bullet had been in yaw, the carpet fibers would not have been trapped in the cavity.

Figure 9.10 shows the opposite of many of these observations. There are no fibers in the cavity, and the striae are off axis. This bullet was unstable when it struck the floor. Combine this conclusion with the slight amount of soft tissue deformation (mushrooming), and the only logical conclusion is that the bullet in Figure 9.10 was the one that struck the victim. The other bullet was a miss.

To Frangible Materials

The most common examples of frangible material are cinderblocks used in home and building construction, stepping stones cast from mortar, and poorly fired bricks. These materials are more homogeneous than properly formulated and cured concrete. Up to a certain point, they are relatively hard and unyielding to bullet impacts, responding in the same manner as hard, unyielding surfaces—recording an impact mark composed of ablated bullet metal and producing low ricochet angles. When the failure point for a particular bullet/incident angle/impact velocity is reached, the material will shatter immediately below the initial impact site, where the force is concentrated and at its greatest.

If the incident angle is essentially orthogonal, the resultant crater will be symmetrical with its deepest point in the center, just as one would expect. Little, if any, identifiable bullet

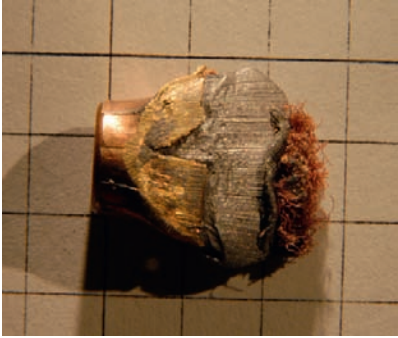


FIGURE 9.9 Important features include unyielding material impact damage, impact striae that traverse the bullet along the long axis, and trace carpet fibers in the nose.



FIGURE 9.10 Important features include unyielding material impact damage, impact striae that traverse the bullet *off angle* from the long axis, a lack of trace carpet fibers in the nose, and a minimal amount of expansion.

metal will be found in this crater because the shattered substrate containing any such transfers is dislodged and expelled from the final crater. In nonorthogonal impacts the projectile continues on into the crumbled substrate, knocking and flaking additional material out of its departure path. So long as the material is essentially homogeneous in the struck area, the effect is often a crater with its deepest point displaced toward the *approach* or *entry* side, as shown in Figure 9.11.

This phenomenon is at first counterintuitive until one considers the behavior of frangible materials and the forces involved. Ricochet angles are typically less than incident angles but higher than they would have been had the substrate not shattered under the bullet's initial impact. These are otherwise hard and abrasive materials, in which the bullet has suffered rapid deceleration and so usually experiences considerable deformation and even fragmentation. If located, the bullet or fragments thereof will show heavy damage and numerous mineral inclusions associated with the struck object.

An example of how inconspicuous, and how subtle, a bullet impact in concrete block can be is provided in Figure 9.12.

To Semi-Hard or Semi-Yielding Materials

Some materials fall between the hard, unyielding and yielding categories. Asphalt is a common example. It is also the most perplexing example of a shooting scene surface from which a bullet is believed to have ricocheted. There are multiple reasons for this.

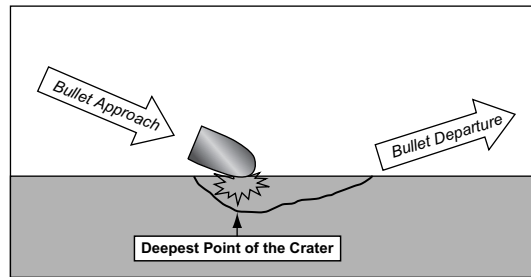


FIGURE 9.11 Diagram of a projectile impact crater in a frangible material—in this case, a concrete (cinder) block.

This drawing depicts the sudden impact of a bullet striking a relatively homogeneous frangible material as it approaches at a nonorthogonal angle. The shattering of the substrate extends the deepest immediately below the point of initial contact. The continued advance and ricochet of the bullet flake away more of the material toward the departure side of the crater but not to the depth of the initial disruption.



FIGURE 9.12 Two suspected impacts in a concrete block.

Bullet impact sites to asphalt are seldom conspicuous, and an area of asphalt often has an assortment of small craters and gouges in it from other sources (see Figure 9.13). Asphalt roadways and parking lots may continue to be used after a shooting incident and before a detailed search for a bullet impact site can be carried out. This can quickly modify the appearance of the impact site, as can rain and street-sweeping equipment.

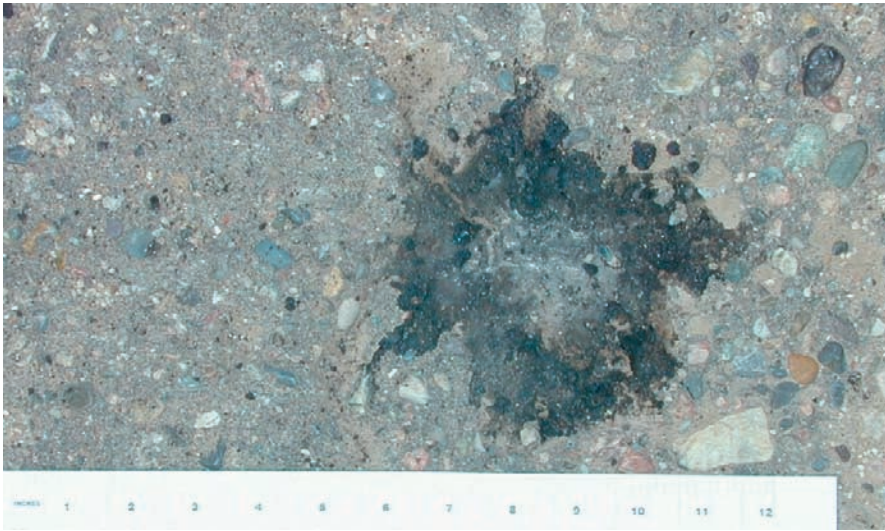


FIGURE 9.13 Classic impact in asphalt displaying the “fresh” look that can disappear in days for a variety of reasons.

Chemical tests for lead or copper may fail on bullet impact sites in asphalt because of the dislodgement of the lead- or copper-containing areas. Lead-in marks, lead splash, pinch points, and Chisum trails are not to be found in asphalt ricochet sites. The combination of all of these missing phenomena produce a rather gloomy forecast for success in locating a ricochet site in asphalt, but there are several features that can be pointed out.

The edges of a crater produced by a recent ricochet event will be sharp and fragile. They are quickly worn away with traffic and weathering effects. The newly exposed asphalt will look “fresh” compared to the undisturbed asphalt that surrounds it. Most noteworthy will often be powdery deposits from one or more struck and fractured stones in the aggregate. These will usually be downrange of the struck or cracked stone and can therefore provide directional information. Powder is a very good indicator of recent damage because it is quickly removed and lost with traffic passing over the site, street sweepers, rain, and so forth. Should one be so lucky as to see it, it should be photographed along with the inclusion of some form of orientation (direction).

The authors have, on occasion, observed small particles of bullet metal adhering to one or more struck stones in a ricochet mark in asphalt. These too should be photographed in place and then collected. Particles of dislodged asphalt may be found predominantly downrange of the impact site. The ejected asphalt possesses another useful reconstructive property, and that is its ability to produce pseudostippling of the skin. This occurs when the entry wound is close to the impact site.

Consider a gunshot victim found in a parking lot with a head wound surrounded by intense pseudostippling composed of asphalt particles. He had to have been down at the moment he was shot given the ejected asphalt’s very short-range ballistic properties. This can be easily demonstrated with witness panels of suitable materials such as fresh pig skin mounted at selected distances downrange of test shots fired into asphalt at the incident



FIGURE 9.14 “Bad” sides of bullets ricocheted from asphalt. The opposite sides are virtually pristine.

angle needed to produce a comparable crater and comparable damage to the ricocheted bullet.

Bullets associated with ricochets from asphalt show characteristic damage consisting of coarse front-to-back gouges and striae with both mineral inclusions and tar-like smears from the asphalt’s organic constituents. Such material is soluble in a variety of organic solvents, which can be demonstrated with a cotton-tipped applicator moistened with toluene. Impacts of jacketed bullets with the small stone aggregate in asphalt often produce tears in the jacket. The overall coarseness and irregularity of the ricochet damage produced by asphalt distinguishes impacts with it from impacts with hard, unyielding surfaces such as concrete.

Because of asphalt’s dual/nonhomogeneous composition of soft, yielding organic and hard mineral materials, ricochet angles vary widely and can even exceed the incident angle. By way of an example, five rounds of 124-gr, 9mm FMJ ammunition were fired into moderately weathered asphalt at an incident angle of -5.0 degrees and resulted in ricochet angles of 2.1, 4.5, 5.3, 5.7, and 7.1 degrees. As can be seen in Figure 9.14, these results show a wide dispersion, with values above and below that of the incident angle. Table 9.4 provides some additional results for shots into asphalt at three selected incident angles.

To Yielding Surfaces

Figure 9.1(b) provides the operative model for impacts to yielding surfaces. With these surfaces the ricochet angle is often *greater* than the incident angle, which is the complete opposite of the effect of ricochets from hard, unyielding surfaces. The results for some ricochet tests with a 147-gr, 7.62 NATO bullet fired from an FAL rifle at a fixed incident angle of 4 degrees provide a useful illustration. These FMJ-BT bullets impacted smooth dry sand and smooth concrete at approximately 2600 fps. They ricocheted intact but destabilized, as evidenced by the yawed bullet holes in multiple downrange witness panels. The average ricochet angle from sand was 12.3 ± 1.3 degrees for six shots; for concrete, the average ricochet angle was 1.9 ± 0.5 .

The most dramatic examples of ricochet angles substantially exceeding the incident angle are achieved with water and fine sand, but such elevated angles can also occur with soil, sod, Sheetrock, wood, and sheet metal. This, at first, defies logic, but it occurs because the

TABLE 9.4 Ricochet of 9mmP Bullets from Asphalt at Three Incident Angles

Incident Angle = -5°
 $2.1^\circ/4.5^\circ/5.3^\circ/5.7^\circ/7.1^\circ = \text{Average } 4.9^\circ \pm 1.8^\circ$

Incident Angle = -10°
 $3.8^\circ/4.5^\circ/5.6^\circ/7.3^\circ/7.7^\circ = \text{Average } 5.8^\circ \pm 1.7^\circ$

Incident Angle = -15°
 $5.4^\circ/7.2^\circ/9.5^\circ/14^\circ/14^\circ = \text{Average } 10.0^\circ \pm 3.9^\circ$

Note: A Ruger P-85 9mmP pistol was mounted in a Ransom Rest and incident angles of -5° , -10° , and -15° were used to fire Federal brand 124-gr FMJ-RN bullets into moderately weathered parking lot asphalt. Five rounds at each of the three incident angles were fired. The temperature of the asphalt was approximately 75°F . The average impact velocity for the bullets was $1041\text{ fps} \pm 10\text{ fps}$. All 15 strikes created visible craters in the asphalt, although several of the -5° impacts were quite subtle. The wide range of ricochet angles shown in the table is a common phenomenon with asphalt. It should be noted that one of the -5° shots departed with an angle of 7.1° .

bullet is pushing or forming a departure ramp at its front underside because of its ogival shape and the even, yielding nature of these substrates. The result is the bullet departing from a very different surface from the one it first encountered. Because bullets spend considerably more time and distance interacting with yielding surfaces as compared to unyielding surfaces, the velocity losses are much greater.

On occasion we have found bullets ricocheted from soil and sand a few feet beyond the impact site. As with hard surfaces, the ricocheted bullets are destabilized and rapidly lose their remaining velocity because of their yawing or tumbling flight. They do *not* acquire the flattened areas of low-angle impacts with hard, unyielding surfaces for the simple reason that the struck surface *yields* to the bullet's advance. With various materials (e.g., wood, sheet metal, Sheetrock, or asphaltic tile flooring) the bullet may retain its basic shape and only show a slight scuffing or burnishing in the contacting area, with the possible transference of some of the struck substrate. The deepest point of the indented ricochet mark is usually displaced toward the departure end of the mark. However, in some materials, and with certain incident angles, the indentation may be so symmetrical (with the deepest point at its mid-point) that the direction of fire is not obvious from the geometry of the ricochet mark itself.

Several phenomena can establish the direction of fire in such ricochet marks. At low incident angles the initial contact between the bullet and the surface results in the production of a dark, elongated, elliptical transfer of material. When present, this *lead-in* mark establishes the direction of travel for the causative bullet. Three examples of lead-in marks are shown in Figure 9.15.

With painted sheet metal another mark is often produced, called the *pinch point*. This takes the form of a small area of surviving paint that was pinched between the bullet's initial contact point and the painted sheet metal surface. As with the lead-in mark, the pinch point is at the beginning of the ricochet mark. Figure 9.16 provides an illustration of a pinch point in sheet metal. Pinch points tend to occur more often with round-nosed bullets and less often with truncated-cone bullets.

There is yet another phenomenon that sometimes occurs in painted sheet metal. For reasons that are unclear, some paints fracture in a characteristic and reproducible way as the metal yields to the bullet's advance. These fracture lines may not be readily visible on

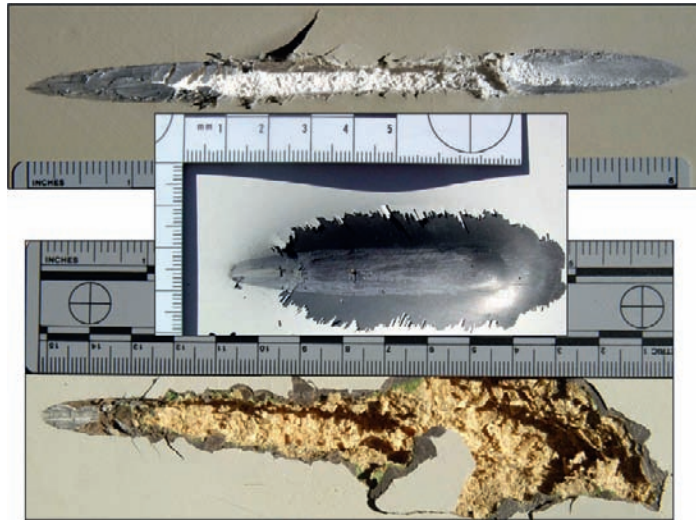


FIGURE 9.15 Lead-in marks for three ricochet sites.

This assemblage shows low incident angle strikes and ricochet damage to painted drywall (*top*), automotive sheet metal (*middle*), and painted particle board (*bottom*). The dark gray lead-in marks produced by 38 caliber LRN bullets are at the left edge of each mark, showing the direction of travel for each as left to right. All three photographs are printed to the same scale.

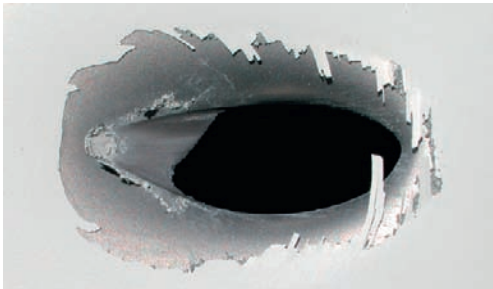


FIGURE 9.16 Pinch point in a painted metal surface.

The pinch point is the small, circular area of surviving paint to the *left* of this elongated bullet hole in automotive sheet metal. It represents the site where the approaching bullet first contacted the metal.

simple inspection, but can be raised or enhanced by dusting with a fingerprint powder chosen to contrast with the particular paint color. The dusting should only be undertaken *after* photographs and any chemical tests for bullet metal transfers are completed and after other means of determining direction of travel have been exhausted.

If present, fine fracture lines simply trap some of the fingerprint powder as the fingerprint brush is gently worked back and forth parallel to the long axis of the ricochet mark. They take the form of a bow wave or shock wave and, like lead-in marks and pinch points, show the direction of travel of the responsible bullet. Once enhanced, fracture lines can, of course, be photographed, but they can also be lifted much like a fingerprint using wide fingerprint tape. The tape is lifted and is then transferred to an appropriate



FIGURE 9.17 Fracture lines in paint around a ricochet site in automotive sheet metal.

The fracture lines in the paint visible around the edges of the *left* half of this ricochet site have been rendered visible by dusting with black fingerprint powder. They can be thought of as shock waves radiating out from a bullet in flight, establishing the direction of travel for this bullet as left to right. Note that in this example there is no lead-in mark or pinch point to aid in determining the direction of travel.

card, dated, marked for identification, and impounded. Figure 9.17 shows fracture lines at the margins of a ricochet mark in painted sheet metal after dusting with fingerprint powder.

Note: Do *not* attempt to use the MagnaBrush® on sheet metal made of steel.

Lead bullets and bullets with exposed lead at their noses, upon low incident angle impact with many surfaces, produce a spattering and vaporization of lead with subsequent down-range deposition. These lead deposits are referred to as *lead splash* and, if necessary, can be rendered visible with the sodium rhodizonate test either by direct application or by transfer (see Chapter 5).

The geometry of the lead splash can provide information on direction of fire. The amount deposited is a function of impact velocity and the nature of the surface struck. Just as with asphalt, a victim located close to the impact site may sustain pseudostippling from lead splash and bullet fragments generated during impact and ricochet. With the sort of orthogonal strikes described in Chapter 8, lead splash can even extend back toward the source of the shot. This can be particularly confusing when a bullet strikes a windowpane after first passing through a curtain or shade. The deposits of lead splash on the *exit side* of the curtain or shade can look like close-range gunshot residue.

Bullets ricocheted from soil, sod, and sand acquire some equally interesting characteristics. Unless small stones are struck, these bullets often emerge intact and with minimal deformation. Here again the ricochet angles can often exceed the incident angles. The sites of such impacts can be exceedingly difficult to locate. Bullets striking a grassy lawn seldom show an entry hole and even the exit can be difficult to find. The channel produced by bullets striking and ricocheting from such a surface is usually on the order of 5 to 10 inches in length and may be located only by carefully “combing back” the grass by hand or by feeling for it. As a bullet plows its way through the abrasive mineral content of these substrates, abrasive particles flow around its nose, ogive, and even bearing surface, leaving a pattern of abrasion that is reminiscent of the flow pattern of water off of the bow of a boat—hence the name, *bow effect*.



FIGURE 9.18 Two FMJ 9mm bullets ricocheted from soil.

These two bullets were recovered after they entered relatively soft soil, plowed through it for about 6 to 8 inches, then emerged. The abrasive action of the soil grains has effectively obliterated the bullets' rifling engravings. The pattern of this abrasive action gives rise to the term "bow effect." Examination of such bullets under SEM will highlight this pattern and show the presence of numerous embedded soil grains.

The bullets shown in Figure 9.18 are a typical example of the bow effect. The presence of this effect is a dead giveaway that the bullet entered soil or sand at a shallow angle, plowed through it for some distance, and then emerged as a ricochet event. If the bullet completely entered the substrate, the abrasive effects enveloped it. If the bullet was not totally surrounded by soil, sand, or sod, only one side of it will display the bow effect. Evidence of late-term yawing as the bullet neared the end of its journey through the material can often be seen as the flow pattern changes direction on the bullet's surface: The new abrasive damage starts to overwrite the earlier damage.

Careful examination of the embedded mineral grains and the flow pattern such bullets possess may provide further useful information. This is most effectively accomplished with SEM/EDX. Just as with hard, unyielding surfaces, a bullet that has passed through some intervening object and then strikes and ricochets from soil or other surface will show a very different pattern of abrasion from its yawed impact with the ground.

THE POST-IMPACT FLIGHT OF RICOCHETED AND DEFLECTED BULLETS

The flight of bullets through the atmosphere is primarily governed by the forces of gravity and air resistance. This will be covered in much more detail in Chapter 13, on true ballistics. For now, it is important to realize that a ricocheted or deflected bullet is typically destabilized and often deformed. These two conditions cause it to lose velocity much faster than it otherwise would in normal, nose-forward, spin-stabilized flight. The implications of this are important regarding the distances at which serious or fatal wounds might be inflicted by a ricocheted or destabilized bullet.

We have carried out a number of measurements of the post-impact behavior and flight characteristics of some common bullets using Doppler radar and the Oehler M43 chronograph system. A couple of examples from these efforts should be helpful.

In one experiment, Speer's 115-gr, 9mm TMJ-RN bullet and Winchester's 147-gr, 9mm JHP SilverTip bullet were fired into hard desert ground, with scattered loose dirt and gravel

on its surface, at a nominal incident angle of -1.5 degrees. The impact area was approximately 50 yards from the carbine from which the bullets were launched. Pre- and post-impact velocities, drag coefficients, and other data were recorded for each bullet's flight for several hundred yards or until the bullet impacted the ground again.

A downrange witness panel consisting of thin cardstock showed that the bullets had not fragmented but were clearly destabilized. The very high and ever-changing drag coefficient values from the radar data also showed that they were tumbling in flight after ricocheting from the ground. Velocity loss values during ground impact for five shots with the 115-gr, TMJ-RN bullets were 82, 98, 230, 230, and 605 fps after an impact velocity of approximately 1150 fps. The 147-gr, JHP bullets experienced velocity losses of 127, 216, 300, and 395 fps for four radar tracks and had an average impact velocity of 1140 fps at the 50-yard mark.

The very high aerodynamic drag on these tumbling and possibly deformed bullets caused them to lose velocity very quickly during their post-impact flight. From an evaluation of the data generated by the Doppler radar system, it was determined that their post-impact velocity would fall to 200 fps after traveling approximately 130 to 260 yards. Had they not been fired purposefully into the ground, these bullets would have had velocities in excess of 1000 fps at 130 yards and 900 fps at 260 yards beyond the muzzle.

The downrange velocity of 200 fps was chosen because it approximates the velocity necessary to produce a perforating injury to skin with subsequent penetration into the underlying tissues. The downrange distances for the 200-fps velocity were optimistic, since the velocity loss during ground impact was not considered in carrying out the calculations. Similar results for velocity loss and post-impact behavior were obtained for 40 caliber and 45 caliber pistol bullets.

WOUNDS FROM RICOCHETED AND DEFLECTED BULLETS

An additional important consideration relates to the yawing or tumbling motion of most ricocheted and deflected bullets. Although such bullets can, on occasion, strike nose-first and produce an entry wound that appears normal, the more common situation is a yawed or keyholed entry. This will usually be described by the pathologist simply as an irregular or atypical entry wound. If the injury is in a clothed area, a detailed examination and testing of the bullet hole can provide useful information through the shape of the hole and the nature of any bullet wipe around it. Direct strikes by stable, nose-first bullets usually produce oval or round holes with bullet wipe around the margin.

Ricocheted or deflected bullets typically produce atypical holes with incomplete or non-existent bullet wipe because of their prior contact with the intervening material. The depth of penetration in the victim will often be less than one would otherwise expect for the particular bullet where the distance between impact site and victim is substantial (e.g. 50-plus yards) because of the increased velocity loss.

Reduced penetration can also occur because the bullet enters the victim with a yawing motion. A bullet fired directly into a body will maintain its nose-forward orientation for some distance before it begins to yaw, whereas a ricocheted or deflected bullet will enter the victim already in an unstable and yawing condition. This means that its velocity will decelerate more quickly in tissue than will that of a direct shot. The only complicating factor arises with hollow-point bullets.

A properly designed hollow-point bullet fired directly into tissue will expand or mushroom. This, of course, greatly slows it down and limits penetration. The same bullet ricocheted that does not strike nose-first will not expand and will likely penetrate more deeply than a properly expanded bullet. The resolution to this is the careful laboratory examination of the recovered bullet for ricochet damage and/or trace evidence acquired from an intervening object.

Most of these phenomena can be demonstrated with a few simple tools and materials. Figure 9.19 shows a section of flagstone, a series of cardstock witness panels, and a block of tissue simulant used to record the behavior and ricochet angles of three shots previously ricocheted off of the flagstone. The ricocheted bullets passed through the witness panels and entered the tissue simulant. Their orientation at each downrange position as well as the ricochet angle can be derived from inspecting the bullet holes and measuring their height in the panels.

Nearly all holes in this type of demonstration will show the particular bullet in a state of yaw, but occasionally what appears to be a perfectly normal round hole will be present,

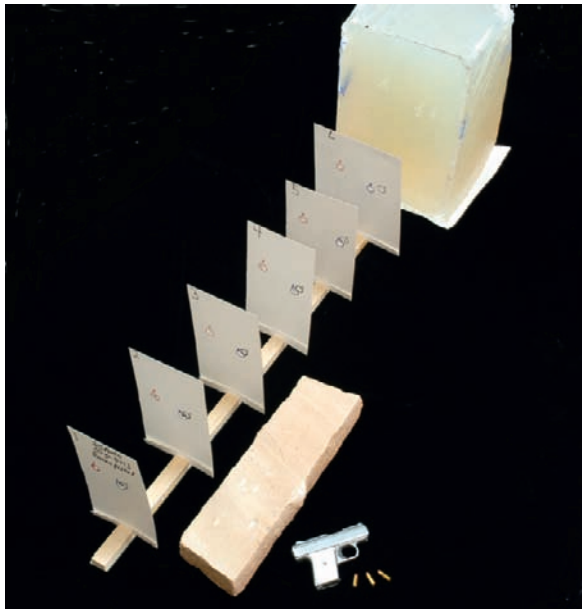


FIGURE 9.19 Bullet ricochet through witness panels.

This figure shows an inexpensive apparatus for recording the post-ricochet behavior of fired bullets. The six numbered cardstock witness panels are mounted in thin slots in a strip of balsawood that has been glued to a metal strap to provide extra strength. The spacing shown here is 6 inches between each card. The assembly is mounted at an appropriate position downrange of the “target” material—in this example, the rectangular section of stone.

A medium such as ballistic soap (shown), ordnance gelatin, or a used Kevlar vest is positioned just beyond the last witness panel for recovery of the ricocheted bullet and/or for wound ballistic evaluation. Multiple shots can usually be ricocheted through such an arrangement, and the orientation of each ricocheted bullet can be evaluated through a careful inspection of the witness panels. The ricochet angles can also be determined by measuring the change in height between the first panel and the last panel for each bullet.

showing that a ricocheted bullet can pass through with a nose-forward orientation during its post-impact flight. This is an important phenomenon to witness because more than one pathologist and at least one ballisticians of considerable experience have testified that a round (normal) entry wound precludes the possibility of a ricocheted bullet. The simple design of this experiment, the equipment used (shown in Figure 9.19), and the round bullets holes in several post-ricochet witness panels quickly refute the experts' claims.

The ricochet damage to bullets and their penetration depths in tissue simulant can also be ascertained through the simple demonstration just described. Several direct shots into the same tissue simulant with the same gun and ammunition and from the same distance can be used to compare penetration depths.

Shotgun Discharges and Pellet Ricochet

The ricochet of shotgun pellets represents a special situation in the following respects:

- The projectiles (customarily lead pellets) are relatively soft and are usually damaged significantly upon impact, particularly with unyielding or abrasive surfaces.
- With close-range impacts (e.g., 10 yards or less), the pellets often collide with each other during and immediately after impact and ricochet. This may complicate their ricochet behavior and result in the likelihood of some pellets fusing together during the ricochet process.
- Lateral deflection due to projectile rotation is a moot point, as is destabilization of the projectiles.
- The approximate incident angle can often be determined from the arcsine function of the ratio of the maximum and minimum diameters of oval pellet patterns on relatively flat surfaces.

Approach to Casework Involving Ricochet

If a ricochet occurred in *this* case, ask yourself *what you would expect to see* in the following instances:

- At the scene (impact site)?
- On the bullet?
- With or in the victim (bullet hole in clothing, wound appearance, penetration)?

Start with what is known (not in dispute) regarding the following:

- The recovered projectile (impact damage, weight loss, embedded trace evidence)
- The wound (entry wound appearance, satellite injuries, pseudostippling, wound track, penetration depth)
- The bullet hole (size, shape, bullet wipe, satellite defects)
- The scene geometry and behavior of ricocheted projectiles

Design and carry out any empirical tests necessary to evaluate or illustrate the post-impact behavior of ricocheted projectiles of the type involved in the incident under investigation.

Any account of a ricocheted shot resulting in an injury must consider:

- The location and nature of the injury (and any bullet hole in clothing)
- The nature of the surface(s) between the gun and the victim
- The appearance of the bullet (if recovered)
- The distance between the gun and the victim
- The geometric constraints imposed by the scene
- The ricochet behavior of the bullet–surface combination

Remarks Regarding Ricochet

Efforts to predict the specific ricochet behavior of projectiles during and after impact with a surface must consider a number of variables, some of which play major roles in bullet behavior while others play minor roles.

- Measuring ricochet angle for a particular bullet/incident angle/impact velocity/surface does *not* always allow one to determine, by calculation, the ricochet angle for some new incident angle, nor is there necessarily a linear relationship between a series of values for incident versus ricochet angle.
- Empirical testing will often be necessary to gain some insight into the ricochet behavior for a particular bullet–surface combination before any meaningful back-extrapolations are carried out.
- The general behavior of bullets ricocheted from hard, unyielding surfaces and those ricocheted from yielding surfaces can be useful in searching for the bullet or for subsequent downrange impact sites.
- The appearance and nature of impact damage to recovered bullets can provide considerable insight into the pre-impact orientation of the bullet and the type of surface struck, as well as the composition of the struck surface.
- The approximate angle of incidence can often be estimated from the impact damage suffered by the bullet.
- An examination of the impact site can provide information about the design and composition of the projectile, the approximate angle of incidence, and possibly the responsible firearm.

PERFORATING PROJECTILES AND PERFORATED OBJECTS

The behavior of bullets that have struck objects (but not ricocheted from them) is a necessary subject in any discussion of ricochet, but there are distinct differences between the two events (e.g., *deflection*, as previously defined and discussed). Some of the phenomena described for ricocheted bullets are also relevant to bullets that strike or perforate objects. These include sudden velocity loss, bullet deformation and destabilization, trace evidence transference, and changes (damage) to the impacted surface.

In the case of *perforating* bullets, ricochet angle becomes *deflection angle*: a departure angle, commonly stated in degrees and position on the clock face, from the normal, pre-impact flight path of the bullet. For most objects struck in a *grazing* manner (e.g., branches, small

limbs), the direction of deflection generally correlates with the side struck; for example, a left graze to an erect sapling will usually deflect toward 9 o'clock, resulting in a destabilized bullet. The direction of twist seems to play no significant role in this situation.

Perforated *objects* can be subdivided into "thin" and "thick." Although no numerical values can be assigned for these distinctions, a thin object would be represented by sheet metal or panes of common window glass. In such objects the track of the bullet is significantly *less* than the bullet's overall length.

Examples of thick objects would be human bodies, the trunks of small trees, and containers of liquid. In these objects the track of the bullet substantially *exceeds* the bullet's overall length. These distinctions are made because it appears that twist rate, pre-impact yaw, and/or bullet stability, as well as entry angle, may have some influence on deflection direction in strikes to thick objects.

Another group of objects falls somewhere between thick and thin. Common examples are fence boards and Sheetrock. The tracks through these objects provide a marginal inference as to the bullet's pre-impact flight path. (See Chapter 10, on trajectory, for examples.) Bullet deflection in these materials, on the other hand, is minimal to nonexistent as a practical matter.

Bullet yaw at impact also appears to play a role in direction of deflection and influences the magnitude of any deflection in thick objects. This means that bullets striking these objects at close range, where they are seldom fully stabilized, might do so with substantial yaw and thereby experience more deflection than when striking the same objects at greater distances. The classic example of this is illustrated in *Hatcher's Notebook* (see References), where a 30-'06 bullet, after traveling 200 yards, penetrated 32.5 inches of oak, remaining point-forward throughout its track. Another shot with the same ammunition, fired from only 50 feet, resulted in only 11.25 inches of penetration with considerable deflection.

This same effect can be observed with close-range shots (a few feet or yards) into ballistic gelatin as compared to long-range shots (50 to 100-plus yards) using the same bullet and firearm. Delayed to little measurable yaw will typically take place with long-distance shots, whereas rapid yaw will usually take place with shots fired at close range.

Figures 9.20 and 9.21 depict simple setups for studying the behavior of ricocheted and deflected bullets and for measuring ricochet and deflection angles. The materials shown require a minimum of expense, a relatively small investment in time, and the use of a pocket calculator with trigonometric functions.

Assume that two projectiles were recovered at autopsy for examination. Both are 45 caliber, rifled-8 right polygonal, but one is a Hydra-Shok hollow point (Figure 9.22) and the other is a generic FMJ (Figure 9.23). In this case the bullets are examined long after the homicide took place, and no impacts were observed by investigators at the scene. Additional information includes the following:

- One adult male (the shooter) was chasing another adult male (soon to be the decedent) through a neighborhood. The total distance traveled during the chase was approximately several blocks through numerous residential yards.
- Most witnesses heard a total of two shots fired.
- The decedent was found on a front lawn.
- A sparse blood trail leads through the front yards of three houses and right to the body.



FIGURE 9.20 Materials for basic ricochet tests and measurements.

Here a pistol is secured in a Ransom Rest with an inclinometer positioned on the barrel for the selection of the desired incident angle. A smooth stone slab has been leveled with a bubble level and equipped with a built-in co-aligned laser. The orange tape measure (*middle*) will be used to measure various distances depending on the number of witness panels used (one or two). The frameworks for the panels (*right*) are constructed from plastic pipe.

There is no single mandated procedure for measuring ricochet angles. If only one downrange witness panel is used, the distance from the bullet impact site to the base of the panel must be measured as well as the height of the ricocheted bullet hole above the plane of the target material. In this method, the tangent function is used to calculate the ricochet angle by dividing the true height of the bullet hole by the distance from the bullet impact site.

The use of two witness panels obviates identifying the specific bullet impact site and measuring the distance to the first panel. In this method the height change between the first and second witness panels (WP1 and WP2) (positioned a known distance apart) is used to calculate the ricochet angle through the arctangent function. The use of two witness panels also provides more information on post-impact bullet behavior.

For photographic purposes, all items depicted have been grouped much closer together than they normally would be. Other items that can be integrated into this technique are one or more chronographs and a bullet recovery medium (loose Kevlar in a box, ballistic soap, or ordnance gelatin) behind the second witness panel.

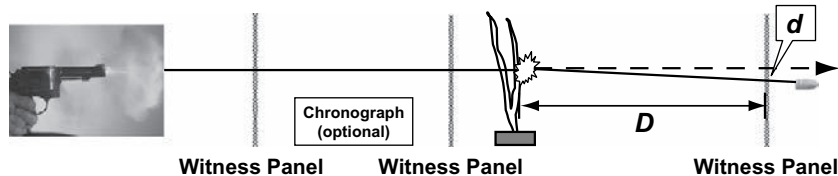


FIGURE 9.21 Materials for basic deflection tests and measurements.

This diagram illustrates a simple and inexpensive setup for measuring bullet deflection and post-impact bullet behavior. The target material (in this case a tree branch) is mounted in a secure fixture. One or more cardstock witness panels are mounted downrange (one is shown in this figure) positioned approximately 3 to 4 feet apart and in front of the target material. A Ransom Rest is preferable for the firing of the gun but not essential. A shot is fired at the target and through the two pre-impact witness panels. If the bullet misses the target, the bullet holes are marked in some way so they will be disregarded.

Such a missed shot can be useful, however, in making a subsequent sighting correction. When a shot hits the target material, a small laser pointer is directed through the two bullet holes in the pre-impact witness panels and on to the downrange witness panel where the beam's intercept point is marked. This is represented by the dashed line. The distance (d) to the bullet hole associated with the strike to the target is measured and its clock direction noted. The deflection distance d is divided by the distance between the strike of the target and the downrange witness panel (D) followed by the use of the $\tan^{-1}$ function on a pocket calculator. This calculation gives the degrees of deflection experienced by the bullet. Multiple downrange witness panels at selected intervals will allow study of the yawing behavior of the destabilized bullets.



FIGURE 9.22 A 45 Automatic Hydra-Shok hollow point bullet with specific damage, which can be seen if the eye is educated.



FIGURE 9.23 Another 45 Automatic generic FMJ bullet with a different story to tell.

Figure 9.22 depicts the projectile recovered from an almost exiting wound to the decedent's right lower leg. Figure 9.23 depicts the projectile recovered from the decedent's lower abdomen.

Take a moment to think about what observations you can make regarding the properties and characteristics of each bullet. Now that you have read this chapter, you should be able to classify the materials each struck. Several aspects of gunshot wounds and wound ballistics can be seen in this hypothetical, but for now we will confine the discussion to the matter of ricochet.

While the nose of the bullet shown in Figure 9.23 can be seen to have sustained damage (in this case most likely from bone impact), the reader should have immediately focused on the bow effect visible on the bullet's underside. The way this pattern comes up and around the ogive, but down the long axis, also suggests that the bullet was *stable* when it struck the dirt. Given the scenario above, where might this bullet have encountered dirt?

What type of damage is present on the bullet shown in Figure 9.22? The flat spot on the right side (as viewed) is the type we expect with unyielding surfaces. Furthermore, the *texture* of the damage is most consistent with concrete as opposed to marble, thick steel, or any other very smooth surface. Once again, given the scenario, where might this bullet have struck prior to penetrating the decedent's body?

Since this scenario has the investigator examining the bullets some time after the scene was cleared, the probability of finding a ricochet mark in the lawn of one of the houses in

the area is extremely low; no matter how much later this exam takes place, however, the possibility of finding copper and lead deposits at the impact site for the bullet shown in Figure 9.22 is fairly high. Because these metals are elemental, and not particularly water soluble, we have had great success in locating impact sites weeks, months, years, and even decades old.

While it may be tempting to think that the bullet showing the bow effect was fired last, into the front lawn near where the decedent was found, there is no way to establish this with the information given. It could be that this was the first shot that began the bleeding. A more scientific method would be to recanvass the scene, and the locations of any recovered cartridge casings, in an attempt to find the impact on concrete. Another approach might be to apply the limited universe concept to the headstamps of the cartridge casings, their locations in the scene, and the two very different bullets recovered. The concrete-ricocheted bullet is a Hydra-Shok with lead post in the cavity, so for this bullet we would expect a nickel-plated cartridge casing with an “FC” or “Federal” headstamp. The other bullet is a generic FMJ bullet, so we might expect a plain brass cartridge casing, but could encounter any number of headstamps associated with it.

Even with decades of experience with shooting scenes, homicides, and so forth, absolute determination of how rapidly an individual may or may not have become incapacitated is not possible. One individual may have been shot in the heart and fought on for a significant time. Another may have been shot in the thigh and simply fallen to the ground to die. These topics will be covered further in Chapter 11, on gunshot wounds.

SUMMARY AND CONCLUDING COMMENTS

There are many aspects of ricochet that have reconstructive value. Although a conclusion is not guaranteed for every scenario, simply throwing up one’s hands and saying, “It’s too complicated” is an uneducated position to take. We can classify the world’s materials into one of several categories: unyielding, yielding, heterogeneous, and so forth. Depending on the bullet’s type, mass, composition, and speed, and on the characteristics of the impact site, we may be able to glean some information about the angle of impact, the angle of departure, and what we would expect the bullet to have done next.

As many types of surfaces as possible were presented in this chapter, but all investigators should be wary, and *excited*, when they find a new type of interaction to study.

The information presented in this chapter was gained from some simple shooting experiments, and should provide forensic examiners with some approaches and methodologies for measuring bullet performance and behavior, as well as some ability to predict general bullet behavior after ricochet or deflection. The interpretation of bullet impact marks, damage to bullets due to impact, and trace evidence were also illustrated for several common examples of ricochet. Nonetheless, it must be reaffirmed that a critical assessment of either the incident or the ricochet angle, the limits of deflection, the velocity loss, or other parameter of interest in casework *will* require some empirical testing. The design of the test should include evaluating the role of any variables that stand to influence the outcome of the impactful event(s) under consideration.

CHAPTER KNOWLEDGE

- Can you effectively describe the concept of the critical angle? Is this a constant numerical value for all ricochet scenarios?
- What are some of the variables that contribute to a critical angle?
- Most of the examples in this chapter dealt with ricochet scenarios from a plane oriented horizontally. Reflect on the effect of lateral deflection from surfaces oriented vertically (such as a wall) or even from inverted surfaces (such as a ceiling).
- If you are an uninitiated reader, look at your surroundings and decide which objects would most likely function as unyielding, yielding, or heterogeneous.

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The Principles of “Trajectory” Reconstruction

INTRODUCTION

It is unfortunate that the tracking and back-extrapolation of bullet paths through various materials has come to be called “trajectory” reconstruction, but there seems little likelihood of correcting this misnomer. Even the various straight probes used for the procedures described in this chapter are often called “trajectory” rods.

A true trajectory is a *curved* path. Such flight paths and their reconstruction are illustrated and discussed in Chapter 13, dealing with long-distance shootings. The distances involved in most shooting cases are on the order of a few feet to 10 to 20 yards—shots fired inside a room, for example, or fired across a backyard, or from the street to the front of a house. As a practical matter, the flight paths of projectiles over these distances for common handgun and rifle cartridges are effectively straight lines, as the amount of curvature in the flight path of even low-velocity bullets amounts to less than an inch. The uncertainty in our ultimate measurements is usually greater than this, so considering short-range trajectories as straight lines is not particularly troublesome.

BULLET HOLE LOCATION AND ANGULAR COMPONENTS OF A PROJECTILE’S PATH

Whether one uses probes, string lines, a laser, surveying equipment, or some other technique, there are *three* elements that remain constant and critical to the reconstruction of a bullet’s pre-impact flight path:

- The *location* of the entry bullet hole or impact site
- The *vertical angle* or component of the reconstructed bullet path
- The *azimuth angle* (or “compass” angle) of the reconstructed bullet path

The location of the bullet’s entry point *must* be associated with one or more locatable reference points. The location of a bullet hole in the wall of a residence, for example, would be

satisfied by a description of the wall (e.g., the east wall of the living room), the height of the bullet hole above the floor, and its distance from a referenced corner (e.g., 9 feet north of the southeast corner and 20 inches above the floor).

Every bullet path can be resolved into two angular components. We have chosen the term *vertical angle* to describe any ascending or descending angle possessed by the projectile as it penetrates or perforates one or more objects. A downward angle of travel is given a negative (−) sign and an upward angle of travel, a plus (+) sign. A projectile with *no* discernable upward or downward component relative to the normal horizontal plane would be described as having a 0.0-degree vertical angle, and a bullet fired straight down into the floor or other substrate would have a −90-degree vertical angle.

Once the best estimate of the bullet's path has been established with an appropriate tool such as a trajectory rod, the vertical component can be measured a number of ways. Digital inclinometers, angle finders, special protractors, mitering gauges, surveying equipment, laser devices, and/or simple measurements of height changes along a selected distance out from the bullet hole can be used to ascertain this angular component of the projectile's path.

The *azimuth component* can be thought of as a compass direction as one views the bullet's flight path from above. Others have referred to this component as the side or the lateral angle. In measuring azimuth, it is often easiest to use the struck surface as the plane of reference, defined as 0.0 degree. A shot fired straight (orthogonally) into the wall would have an azimuth component of 90 degrees and a vertical component of 0.0 degree.

Note: It should be pointed out that this is contrary to the NATO method of defining incident angles, but is more useful in shooting scene reconstruction.

Using String Lines

String lines are inexpensive, relatively easy to see, and easy to photograph. Kits are available from forensic equipment suppliers that contain various bright colors of string. One supplier offers a string that contains reflective particles for use in nighttime scenes. The primary shortcomings of string lines are that they are nonrigid and therefore sag as soon as the horizontal distances exceed a few yards. The one exception may be that they are a good demonstrative tool for representation of a trajectory over relatively long distances if the investigator can take a photograph looking straight down over the area. From this vantage point, any sag in the string is not seen. A helicopter or fire truck ladder may be used to gain sufficient height.

A string line requires an anchor point that is sufficiently firm that the string can be drawn taut. String can be difficult to thread through multiple bullet holes, and great care must be taken that it passes through the center of the holes without experiencing a change in direction as a consequence of pressing against the hole's edge.

On the other hand, in one case, colored string held an advantage over a probe inserted in a bullet's path through the center console of a vehicle for illustrating an officer's approximate shooting position. In this particular case the string was anchored at the final resting point of the bullet, drawn back through the center of the bullet hole in the plastic console, out through the open side window, through the bore of the officer's 9mm semiautomatic pistol, and finally out through the ejection port, where it was anchored by the pistol's slide as the officer held the pistol in his recollected shooting stance. Photographs were taken at

a right angle to the string line that included the officer, the string line, and the decedent's vehicle, and were later used to illustrate the approximate path of the bullet and the associated separation distance between the shooter and the side of the vehicle.

Using Probes and Trajectory Rods

Rigid probes, ranging from cleaning rods and wooden dowels to professionally manufactured rods specifically for shooting reconstruction, have been used to probe and illustrate the paths of penetrating and perforating projectiles. Cleaning rods are not recommended, particularly if gunshot residues such as bullet wipe around the margin of the entry bullet hole are of importance. Photographs and any chemical tests for bullet metal that are to be conducted should be done prior to any probing of a bullet hole.

Various diameters, colors, and compositions of trajectory rods have been offered through law enforcement suppliers. The most elaborate of these is a set of threaded and plastic-coated metal rods available in several diameters and colors that can be assembled to almost any reasonable length. Each set comes with centering cones to assist in aligning the probe in the center of each bullet hole. One section has a bulletlike tip to aid its insertion in tight-fitting bullet tracks in materials such as wood and rubber. This same set of rods will also accept a small, cylindrical laser that can be used to forward-project or back-extrapolate the path of the bullet once the rod is properly positioned in the bullet track and co-alignment of the laser with the rod has been ensured.

Even something as simple and inexpensive as hollow brass rods of various diameters available in hobby shops can be used, as long as any necessary tests for copper around the margin of the bullet hole have been carried out first. These inexpensive hollow rods allow the investigator to peer through the rod and locate possible shooting positions and down-range bullet impact sites. Portable lasers have also been passed through such rods. This can be particularly helpful when dealing with bullet paths through wood, where the wood fibers otherwise get in the way of the laser beam.

MEASUREMENT PROCEDURES

Properly executed, a photographic method provides the simplest technique for documenting and later measuring.

Vertical Angle Determination

It is important to measure both vertical and azimuth components of a projectile's path. This method can also be employed (and is strongly recommended) as an adjunct to any other techniques employed in determining these angles.

There are *two* critically important steps in the photographic method. The camera lens must be at the same height as that portion of the trajectory rod or string line being plotted, and it *must* be perpendicular to the vertical plane in which the line or probe lies. These two steps are of *critical importance*. Failure to carry them out is the most common mistake in this

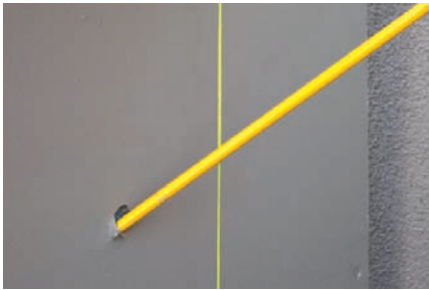


FIGURE 10.1 Proper profile view of a trajectory rod through a perforating bullet strike to an interior residential wall.

The camera is at the same level as the trajectory rod and at a right angle to it. A plumb bob and line have been brought in immediately adjacent to the rod. Although slightly out of focus, the corner of the room can serve as a vertical reference line. The vertical component of the bullet's trajectory can be measured with a protractor from an enlarged view of this photograph. As defined in text, the path of this perforating bullet has a vertical component of -36 to -37 degrees.

method, the effect of which will be illustrated later. A suitable vertical reference line must also be in the field of view.

In some scenes there will be natural reference lines in the immediate background; as long as they are in adequate focus they will suffice. A preferable technique is to drop a plumb line through the center of the field of view so that it just touches the probe or string line. The known vertical reference line in the resultant photograph is subsequently used to measure the vertical angle of the probe or string line.

Figure 10.1 illustrates the proper orientation of the camera for a trajectory rod passed through the entrance and exit holes in a simulated residential wall composed of 5/8-inch Sheetrock, a 4-inch air space, and 3/8-inch exterior wooden siding. The vertical component of the probe was determined to be -37 degrees. This was accomplished by enlarging this digital photograph on a flatscreen monitor and measuring the relationship of the probe to the vertical reference line with a common protractor.

Figures 10.2(a–c) show the effect of taking photographs from popular but *improper* positions if one wishes to ascertain the vertical component of a projectile's preimpact flight path. The camera in Figure 10.2(b) is at the same height as the probe and directly in front of the wall. In this view the apparent vertical angle is -53 degrees, for an error of 16 degrees (or 43%) as a consequence of improper camera position. The camera in Figure 10.2(c) has been positioned against the wall and at the same height as the probe. In this view, because of improper camera position, the apparent vertical angle is -41 degrees, for an error of 4 degrees (or 11%).

Alternatively, an inclinometer or digital level can be carefully positioned on the trajectory rod (or carefully juxtaposed with a string line or laser line) and the vertical angle simply read from it. This is depicted in Figure 10.3. The vertical angle can also be determined with a zero-edge protractor¹ positioned vertically with the index mark at the junction of the probe and the

¹A zero-edge protractor is one that lacks any protruding legs or tabs and so allows one to place its baseline edge directly against the plane of the struck surface. Such a protractor is shown later in Figures 10.5(a) and (b).

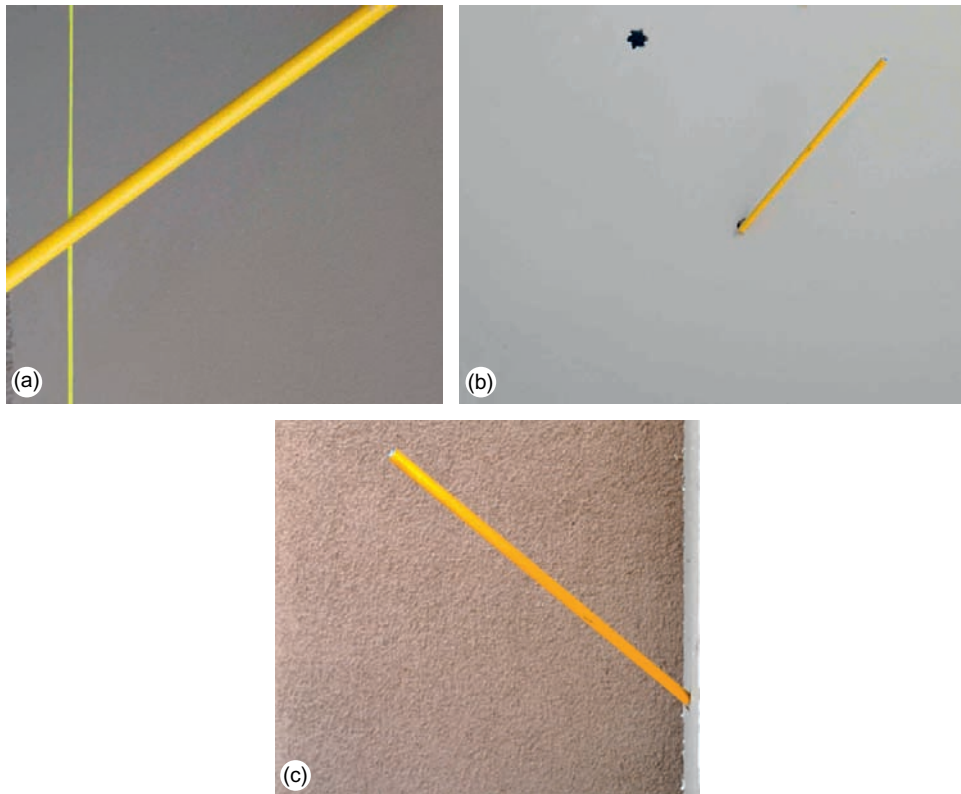


FIGURE 10.2 Three improper views of the trajectory rod through the perforating bullet strike shown in Figure 10.1.

- (a) In this view the camera is flush against the bullet-struck wall and at the same level as the trajectory rod. As in Figure 10.1, a plumb bob and line have been brought in immediately adjacent to the rod, but this camera position provides a slightly erroneous value for the vertical component of the strike. This camera position would be correct if the strike had no right-to-left azimuth component.
- (b) In this view the camera is directly in front of the bullet hole in the wall and at the same level as the trajectory rod. Although a popular view in many scene photographs, it provides an erroneous value (approximately 255 degrees) for the vertical component of this right-to-left and downward strike.
- (c) In this view the camera is flush against the bullet-struck wall and at the same level as the trajectory rod. The surface of the struck wall and the intersecting corner of the wall beyond the trajectory rod provide a vertical reference line, but the camera position provides an erroneous value (approximately 240 degrees) for the vertical component of the strike because it is not perpendicular to the rod.

bullet hole, after which it is carefully hinged over so that it is in full contact with the probe. It is critical that the zero edge of the protractor be oriented vertically and that its flat plane be in the same vertical plane as the probe or string. The degrees above or below the protractor's horizontal line are then read at or under the probe.



FIGURE 10.3 Vertical angle determination with a digital inclinometer.

This is the same view shown in Figure 10.1. A digital inclinometer has been carefully juxtaposed along the trajectory rod and photographed to memorialize the rod's vertical component. An inexpensive angle finder available in most hardware stores can be used in the same manner.



FIGURE 10.4 Photographic method for determining the azimuth component of a trajectory.

In this view the camera is flush against the wall and directly above the trajectory rod. The junction of the wall and the floor serves as a reference line for this photographic method of azimuth angle measurement.

Azimuth Angle Determination

A zero-edge protractor, a plumb bob and line, and a means of leveling the protractor are needed to measure the azimuth angle on site. The photographic method in this case is usually much simpler, but as before, the azimuth angle will have to be derived from the photograph or image at a later time. The azimuth angle can also be thought of as the shadow or track that the bullet would have cast on the floor or ground when viewed or illuminated from directly above. In fact, this is what one is accomplishing with a photograph taken from directly above a probe extending out of the bullet's path in a wall or other structure. This line or path will ultimately be drawn in a plan-view, scale diagram of the scene.

If the bullet hole is high on a wall, the azimuth component can be derived from an upward photograph taken with the camera once again against the wall and the lens directly under the probe or string line. The junction of the ceiling and the wall can serve as a subsequent reference line as long as it is in reasonable focus.

Figure 10.4 depicts a downward view of the probe shown in Figures 10.2 and 10.3. The junction of the carpeted floor and the wall becomes the reference line for the subsequent

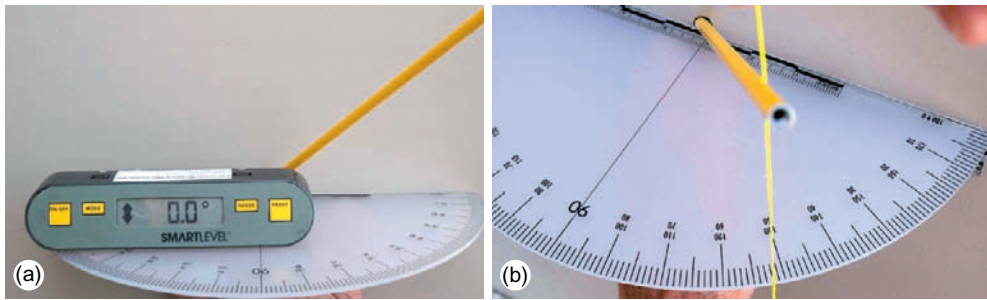


FIGURE 10.5 (a) First of two steps for azimuth angle determination with a zero-edge protractor. (b) Second of two steps for azimuth angle determination with a zero-edge protractor.

- (a) The zero-edge protractor is leveled and butted up against the trajectory rod, with its centering mark at the appropriate edge of the rod in preparation for the dropping of a plumb bob and line as shown in Figure 10.6 on the next page.
- (b) The position along the trajectory rod where the plumb bob just touches the curved edge of the protractor is located and the azimuth angle read from the protractor (52 degrees in this illustration).

derivation of the azimuth angle. The angle derived from this photograph was determined to be 54 degrees right to left as one faces this wall. The NATO angle would be equal to 90 degrees minus 54 degrees, or 36 degrees.

If, in a real case, the probe and the junction of the wall and floor cannot be kept in reasonable focus, something like a yardstick should be leveled and taped to the wall just below the probe. This will provide the necessary reference line and will be in good focus in the resultant photograph.

Warning: Placing the protractor in contact with the probe, as one would to measure a vertical angle, will *not* give the correct result for the azimuth angle.

The use of the zero-edge protractor for azimuth angle requires several steps. First, position it flush against the wall and parallel to the floor (i.e., in the horizontal plane) with the central index mark at the same side of the probe along which the angle is to be determined. This arrangement is shown in Figure 10.5(a).

Now carefully bring in a plumb bob and line to the point that it just touches the probe while also just touching the outer edge of the protractor with the degree marks; read off the azimuth angle; see Figure 10.5(b). This is much easier to accomplish with the help of a colleague or assistant. A mitering gauge can be used in essentially the same way, but is usually more difficult to maintain in a flat orientation while one of the arms is flush with the wall.

The azimuth angle can also be determined by dropping a plumb line to the floor and marking this spot at some distance out from the wall and at the end of a probe (e.g., 2 feet or 24 inches out). This can also be done if one is using a laser line directed through the entry and exit holes. The distance from this spot to the spot on the floor immediately below the entry hole represents the hypotenuse of a right triangle that is completed by measuring the direct perpendicular distance to the wall across the surface of the floor.

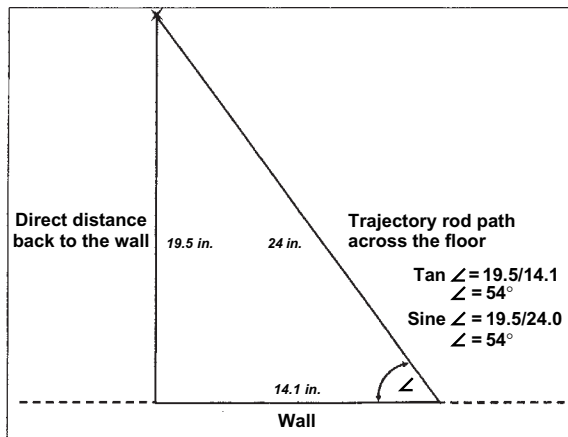


FIGURE 10.6 Useful trigonometric relationships for right triangles.

A right angle square is useful in ensuring that this direct line to the wall is truly perpendicular to the wall's surface. The legs of the resulting right triangle and the tangent function on a pocket calculator will provide the azimuth angle. In the 24-inch-out example for the simulated wall and probe in previous figures, the direct distance to the wall is found to be a little less than 19 1/2 inches and the distance from this point back over to the point directly below the bullet is found to be 14 1/8 inches.

A review of the important properties and trigonometric relationships of right triangles is shown in Figure 10.6. The tangent relationship for the legs of a right triangle is the most useful trigonometric function for the reconstruction of shooting incidents. In this example the tangent of the angle we wish to determine is equal to 19.5 divided by 14.1. This division gives the number 1.38. We enter this number into a pocket calculator, depress the shift key and then the $\tan^{-1}$ key. An angle of 54 degrees will now appear on the display.

In addition to its use in calculating the azimuth angle as just described, the tangent relationship can also be used for the vertical angle. This is particularly handy when lasers are used and have been positioned somewhere in the room so that the laser beam passes through the entrance and exit holes.

A plumb bob and line are dropped to the floor at almost any distance out from the bullet hole in the wall and this spot on the floor is marked as in the previous example. The height of the beam above the floor at this point is measured and recorded. Then the distance from this point back across the floor and under the laser beam to the wall immediately below the bullet hole is measured. The difference between the height of the bullet hole above the floor and the height just measured, divided by the distance value, represents the tangent of the vertical angle. The arctangent function ($\tan^{-1}$) on a pocket calculator will yield the value of the vertical angle.

Lasers have another advantage in this application in that they can be set up at much greater and more useful distances out from the bullet hole than probes. Improved accuracy and reliability are gained by dropping a plumb bob to the floor 10 or 15 feet out instead of the mere 2 feet out used in the previous example for azimuth angle determination.

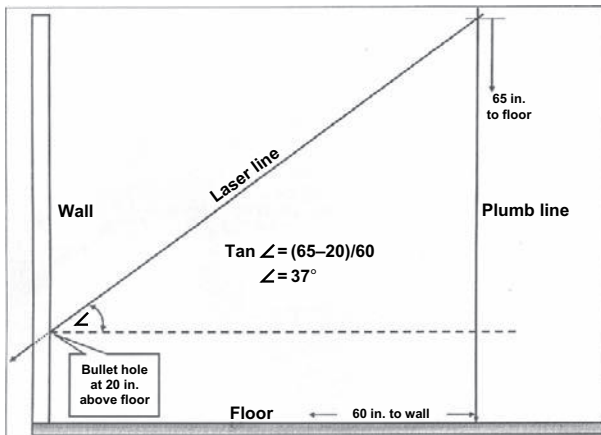


FIGURE 10.7 Use of the tangent function to calculate the vertical component of a perforating projectile's flight path.

Recall that the photographic method and inclinometer gave values of -37 degrees for the bullet track through the simulated wall. A co-aligned laser attached to the trajectory rod is beamed across the living room and a plumb bob and line passed through the beam at a distance of 5 feet (60 inches) out and across the floor from the wall below the bullet hole. The height above the floor of the laser beam striking the plumb line is found to be 65 inches.

Since the bullet hole is 20 inches above the floor, the height *change* over the 5-foot distance across the floor is $65 - 20$, or 45 inches. Dividing 45 by 60 gives 0.75, the arctangent of which is 36.9 degrees. This example is diagramed in Figure 10.7. A final description of the shot through the simulated wall previously cited might be:

The bullet struck the east wall 20 inches above the floor at a distance of 9 feet north of the southeast corner of the room. The vertical component of the bullet's path through the wall was approximately 37 degrees downward (-37 degrees), and the azimuth component was approximately 53 degrees out of the plane of the struck wall with a right-to-left track (NW to SE) as one views this wall.

NONPERFORATING BULLET PATHS

There are situations where a projectile perforates the first layer or panel of a wall, ceiling, cabinet, and so forth, but fails to produce an exit hole. Many interior walls are mounted on two-by-four studs (wooden boards) that are secured to a solid block or brick wall. In other situations the bullet may have come to rest in one of these studs, the floor inside the wall, or other substantial structure after perforating the outer panel or layer. Many of these walls are filled with loose fiberglass insulation. Even in the absence of such insulation, it can be difficult to follow the path of the bullet with a small light or probe.

For these situations some sort of view window is needed that does not disturb the entry hole or the subsequent impact point(s) or the bullet's final resting place. This can be

accomplished with a relatively simple technique and a little bit of effort. After the location of the entry hole is thoroughly measured and documented, an adjacent viewing window can be cut out with a small keyhole saw or a sharp utility knife. It should be large enough for subsequent good viewing and photography. This window should allow the embedded bullet or downrange impact site to be located.

At this point an appropriate probe can be carefully passed through the entry bullet hole and placed against the embedded bullet, the next bullet hole, or the bullet impact site. Once this is accomplished and documented, one or more of the previous methods can be applied to ascertain the angular components of the projectile's flight. A slight alternative to this approach involves cutting out the area containing the bullet hole itself.

Either way, some sort of hole must be cut to recover the projectile and one might as well collect the actual bullet hole in the process. To do this, a pair of strings is pinned to the wall above and to the right and left of the bullet hole. These are brought across the bullet hole and taped at the bottom ends to form an X at the center of the hole. Locator marks for the 8 o'clock and 4 o'clock positions of the secured strings are made; see Figure 10.8(a). The strings are temporarily removed, after which an irregular area containing the bullet hole on the order of 4 to 8 inches "square" is cut out of the wall. This excised section is marked for identification and impounded.

The intentional irregularity of the cutout comes into play if a need arises to remount the cutout section or if an aid is needed for later recalling its original orientation in the wall. Now the strings are repositioned using the pair of locator marks and secured as before; see Figure 10.8(b). Once the downrange impact point or embedded bullet inside the wall is

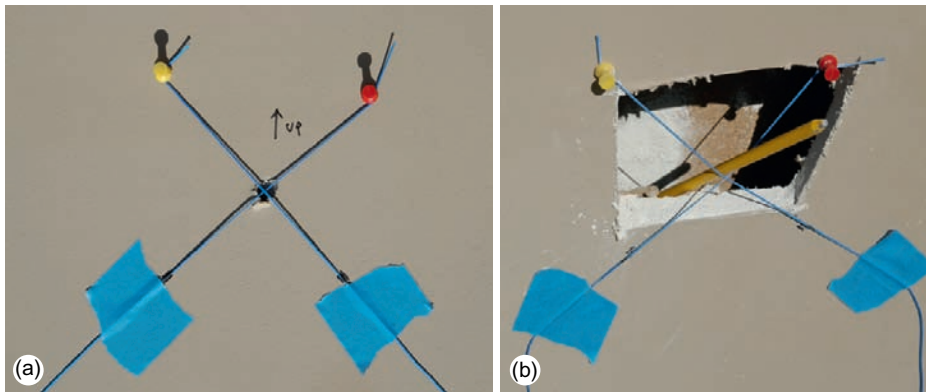


FIGURE 10.8 (a) Preparatory step for bullet path tracking and bullet recovery in a nonperforating strike to a wall. (b) Reconstruction step for tracking a bullet's path in a nonperforating strike to a wall.

- (a) An X is temporarily formed across the entry bullet hole with a pair of strings. Black index marks (just above the pieces of masking tape) are added so that the proper position of the strings can be reestablished after a section containing the entry bullet hole is cut out. The tape holding the strings is temporarily removed so that the strings do not interfere with the removal of a section of Sheetrock containing the bullet hole.
- (b) The section of Sheetrock containing the entry bullet hole has been removed and the two strings repositioned, with the intersection point representing the former center of the bullet hole. Once the subsequent downrange impact point of the bullet has been located, a laser beam or trajectory rod can be aligned with these two points and the angular components of the bullet's pre-impact flight path determined by one or more of the methods described in the text.

located, a suitable probe or string line can be positioned in such a way that it passes through the saddle of the X and out into the room or area from which the bullet was fired. After the probe or string line is properly positioned, any of the various techniques previously described can be used to determine the azimuth and vertical components of the projectile's pre-impact flight path. Lasers are especially useful in situations involving nonpenetrating bullets, as will be seen in the next section of this chapter.

LASERS' USE, ADVANTAGES, AND LIMITATIONS

A variety of small, portable, battery-powered lasers have become available, ranging from simple shirt-pocket pointers to units with integral inclinometers, theodolites, and optical sighting devices. Laser beams follow straight lines, they have no weight, they do not sag, and they do not and cannot alter the bullet hole in any way.

In all applications, lasers can be thought of as an alternative to probes and string lines with some additional advantages. For example, scene investigators can step into and out of the laser beam without disturbing the setup of the laser or the bullet holes through which it passes. If we know where a gunshot victim was struck by a bullet that first perforated a door, window, curtain, or other object, and the general path of his gunshot wound, we can position a suitable stand-in for the victim in those orientations that will satisfy the reconstructed flight path of the bullet at the scene.

With lasers, moveable objects that have been struck or perforated by a bullet (a hollow-core door, a plastic patio chair, a cereal box on a kitchen counter, for example) can be moved into and out of the laser beam. Another major advantage is that lasers cannot alter the physical items that were struck by bullets, such as a tempered-glass side window in a car, a window screen, or a curtain. Because the use of any physical object to attempt a trajectory reconstruction would disturb the object, the laser becomes the method of choice for these delicate materials.

One of the special applications of these devices is locating downrange impact sites and bullets from perforating shots through materials. In these situations an external laser is directed through the center points of the entrance and exit holes. This requires some trial and error and can be the source of some aggravation. It is best accomplished with the laser mounted on a fully adjustable tripod with a gimbaled head.

An alternative is specially designed trajectory rods that will accept a screw-on laser, but it is critical that the laser be co-aligned with the trajectory rod before relying on its projected beam. In either arrangement, a piece of white paper or cardstock is used to track the laser beam as it exits the perforated wall or material. Even though destabilized, deformed, and even tumbling, exiting bullets will follow relatively straight paths over short distances out to as much as 10 to 20 yards.

The reverse application is also very useful. Passing a laser beam through an exit hole and out the entrance hole allows one to find possible to likely shooting positions in indoor scenes. The shooter or a suitable stand-in can take various shooting positions in the actual room so that the laser beam passes right up the barrel of the gun or skims across its sights. This is not easily accomplished with string lines or probes (with the previous exception of the specially designed probes that are threaded to accept a special laser). The shooting

positions can be photographed and the distance out from the struck surface, as well as the height of the gun, can be measured.

In outdoor scenes this technique can be quite helpful in locating the source of the shot and in the search for additional evidence such as expended cartridge cases. The ultimate system employs two lasers aligned and pointing in opposite directions, allowing for down-range projections and back-extrapolations from a single setup.

The situation described in the previous section for nonpenetrating shot is especially amenable to laser use. After the location of the entry hole is thoroughly measured and documented, the same choices of viewing window are considered. The laser is subsequently positioned in such a way that the beam passes through the bullet hole or across the saddle of the X in the crossed-strings technique (refer to Figure 10.8(b)) and then on to the embedded bullet or bullet impact site in the wall. Once the laser is properly positioned, any of the various nonphotographic techniques previously described can be used to determine the azimuth and vertical components of the projectile's pre-impact flight path.

Outdoor scenes and situations, where there can be substantial distances between two or more bullet holes or impact sites caused by the same shot, are much more amenable to a laser than to probes or string lines. Consider a situation where a bullet passed through a thin wooden fence and then embedded itself in the stucco wall of a house 100 feet downrange. Even the distance between a bullet-perforated front door and a subsequent bullet hole at the end of a hallway beyond the door would be very difficult to work with using string lines or probes. The alignment of a two-directional laser on a suitable tripod with the bullet hole in the fence and the impact in the stucco wall would be the method of choice in this situation.

There are a few drawbacks to lasers. The laser beam can be difficult to see in bright light and can only be photographed in very subdued-light to near-dark conditions. The special technique required to do this is described in the Appendix in the section Digital Photography of Laser Paths.

THOUGHTS ABOUT RECONSTRUCTED ANGLES

The examples described and illustrated here involve perfectly perpendicular walls and flat, level floors. Real scenes are seldom so simple, and changes in height between rooms, the inside floor, and the outside ground must be dealt with. The trueness of walls and floors should be checked at some point with a level or inclinometer and right angle square, and any deviations should be noted. These can be addressed later as long as they are recorded in an understandable way—for example, *"the east wall leans away (toward the east) by 1 degree off true vertical, and the floor of the living room slopes down toward the east by 21 degrees."* It may be necessary to enlist the help of a surveyor for outdoor scenes with complicated and substantial changes in terrain.

An interior wall made of Sheetrock was used as an example in this chapter. It is nearly ideal in that very little to no measurable deflection occurs when it is perforated by bullets. Nonetheless, there will still be uncertainty in our reconstructed trajectories. Some of it arises from the very short distances between two reference points or from our inability to identify the true centers of multiple bullet holes or to perfectly center a probe, string line, or laser line through them. Then there is the human factor of two examiners measuring the same

angle differently by a degree or two. Also, other intermediate materials may induce varying amounts of deflection in a totally random manner.

Carrying out the reconstructive techniques described in this chapter involves a certain degree of acquired skill. Participants in our reconstruction course measuring multiple bullet paths through a simulated wall comparable to that illustrated here obtained values that varied by about 5 degrees around the average for the group. From this practical exercise, an approximate 5 degrees is a reasonable uncertainty level for any numerical value for most bullet paths derived from actual scene work.

The end result is that, while we may draw a single line across the floor of a plan view of a room representing the azimuth angle and draw a similar line for the vertical component in a profile view, we should be prepared to discuss or illustrate these components as a cone rather than a line. This cone is formed from our best estimate of the bullet's flight path plus and minus our uncertainty limits. A more critical assessment of any particular perforated material and the uncertainty of our measuring technique can always be carried out through empirical testing if the need arises.

Aside from the geometric constraints of any particular shooting scene, the more interesting and useful component of a bullet's flight path is the vertical angle. In most scenes, steeply rising or descending angles quickly place the firearm very close to the struck object or surface. Consider a bullet hole in an interior wall that is only 24 inches above the floor. The track is found to be upward at 45 degrees. The tangent of 45 degrees is 1, which means that the back-extrapolation of this bullet's path intercepts the floor 24 inches from the point directly under the bullet hole in the wall.

The gun, in this case, had to be held near or essentially on the floor to fit the geometry of the scene. Such a shot could not have been made by a standing subject. Steep downward angles accomplish the same thing. If the entry bullet hole is inside a confined location, back-extrapolation of such angles quickly results in very awkward or impossible gun positions for even a standing shooter in the absence of ladders, stairways, or other elevated sites.

In the example used in this chapter, the -37 -degree vertical angle for a bullet hole 20 inches above the floor quickly lead back to gun heights on the order of 5 to 6 feet at similar distances from the wall. A simple calculation of the height of a shot from a doorway located 12 feet away from the bullet-struck wall produces a gun height of over 10 feet in a room with an 8-foot ceiling.

The same situation arises in an outdoor shooting scene, where one must consider the following with steep vertical angles: a shot from very close range, a shot from an elevated location (such as a multistory building or a hill), or a bullet on the descending path of a very long trajectory. This last situation will be discussed in Chapter 14. Relatively flat vertical angles, on the other hand, and the absence of gunshot residues around the bullet hole often leave open a considerable range of distances from which the shot could have occurred.

TRAJECTORY RECONSTRUCTION TECHNIQUES, TOOLS, AND SUPPLIES

There are presently very sophisticated pieces of equipment and instrumentation available to make many, or perhaps most, of the measurements described in this chapter, and no

A deliberate and thoughtful assessment of each shooting scene, followed by a strategy tailored to the particular situation, is required. The scene should be released only when all the data and measurements necessary to reconstruct the flight path(s) of the shot(s) have been gathered and all the appropriate photographs have been taken, to the point that a mock-up of the room or scene can be constructed if some future issue or hypothetical scenario is raised.

CHAPTER KNOWLEDGE

- What three main pieces of information are needed to document a projectile's path through a scene?
- If you are an inexperienced reader, take a moment to create a mock trajectory rod in the room and decide how you would photograph it, document the impact location, and take both azimuth and vertical component measurements.
- What kind of variations in uncertainty do you think might be attributed to perforations and penetrations of the materials you see around you?

References and Further Reading

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Determining Bullet Track ("Trajectory") in Gunshot Victims

INTRODUCTION

As previously pointed out in Chapter 10, the term "trajectory" rightfully belongs to that aspect of exterior ballistics that deals with bullets following long-distance flight paths through the atmosphere. That having been said, the reader will be regularly confronted with investigators, lawyers, and even pathologists who insist on referring to wound tracks and the paths taken by bullets in gunshot victims as "trajectories." The preferred phrases are *wound track* or *wound path*, but no doubt we will continue to hear them described as trajectories.

Projectiles penetrating or perforating bodies travel over *very* short distances (compared to shots in the atmosphere) and *may* follow straight paths, but since they are not moving through air, they may also deviate as they pass through tissue, organs, or other structures. Impacts with bone also increase the likelihood of deflection. This is a result of the varying densities and strengths of such tissues or organs and to the fact that bullets cannot maintain their spin stabilization in media other than air.

Elongated bullets (e.g., most rifle bullets) because of their aft centers of gravity, are more susceptible to deviation from their initial path when penetrating tissue than are short, nearly round pistol bullets. Pistol bullets tend to follow straight paths in tissue unless destabilized prior to impact with the victim or deformed in some asymmetrical manner during tissue penetration. (See Figures 11.1 and 11.2.)

It should also be realized that various structures and organs inside the body are not absolutely fixed in their positions. The course taken by a bullet through some of these organs may have been slightly different in life than it later appears during the autopsy. Additionally, a body at the moment it sustains a gunshot wound may be in some twisted or bent position, only to be straightened out later on the autopsy table, where the tracking and description of wound paths takes place.

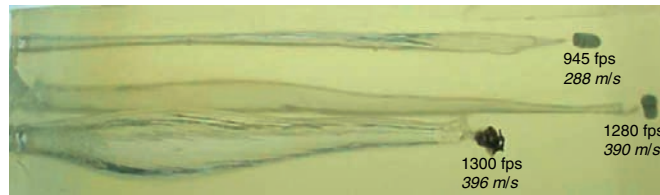


FIGURE 11.1 Paths of contemporary bullets in a tissue simulant.

These three 40-gr, 22 caliber LRN bullets struck this block of MBM tissue simulant at the impact velocities shown. They all followed relatively straight paths in this homogeneous medium. It should be noted that the fastest bullet did not achieve the deepest penetration, because it expanded as it entered the tissue simulant, thereby presenting a greater cross-sectional area to it. Areas of bullet expansion and yaw are shown by diameter increases in the "wound" tracks.



FIGURE 11.2 Path of an unstable bullet in a tissue simulant.

The 62-gr, 22 caliber (5.56 mm) SS109 bullet is a representative example of a bullet that quickly yaws and loses its pre-impact stability as it penetrates tissue or tissue simulants. This bullet penetrated the medium in a nose-first attitude for the first 3 inches, then achieved maximum yaw after about 6.5 inches of penetration and came to rest after 13 inches of penetration. It also deviated from its initial course by about 10 degrees because of its long, pointed shape and aft center of gravity. This particular bullet was fired into this block of MBM tissue simulant from a distance of 100 yards (91 m) and impacted it with an impact velocity of 2688 fps (819 m/s). Bullets previously destabilized due to ricochet or impact with some intermediate object usually achieved less penetration and often followed deviated paths in tissue and tissue simulants.

The path of a gunshot wound is often useful in evaluating the position of a gunshot victim at the moment the causative bullet arrived, as long as certain physical facts are recognized. A wound path *does not* and *cannot* tell us what the victim was doing or what position he was in seconds, or even fractions of a second, before the arrival of the bullet. Because the production of a gunshot wound occurs in a few thousandths of a second, one should think of such an event as if it were a stroboscopic or flash photograph where everything is frozen in time and space.

A related, but separate, matter is the time interval for the shooter to make the decision to shoot followed by the actual discharging of the firearm. An adversary can change his or her position significantly during this short interval before the bullet's actual arrival at its target. These facts should be kept in mind when considering competing opinions regarding the direction of one or more wound paths in gunshot victims or what the direction of a gunshot wound tells us about the subject's movements and/or body position during a shooting incident.

Many forensic pathologists routinely prepare anatomical diagrams that depict wound paths produced by projectiles. These diagrams, by convention, show the body in an erect, standing position with the hands fully open and the palms turned out or forward. As a consequence, many attempt to apply the descriptions and illustrations of gunshot wounds in this position to the moment the gunshot wounds were sustained at the actual shooting scene. This, of course, can give rise to some strange and erroneous body positions at the scene, at the moment the decedent was shot.

Gunshot wounds are customarily numbered, with the top of the head used as a starting point. By this method gunshot wound #1 (GSW-1) would be nearest the top of the head. Although there will be a warning somewhere in the pathologist's report that these numbers are *not* an indication of wound sequence, they are occasionally taken as such. On occasion the pathologist can sequence certain gunshots, but this finding will be specifically described in the autopsy report. An excellent example arises from the "crack rule" or "T" test described for shots through plate glass (see Chapter 8, on glass). Bone can behave in the same manner as single-strength glass, so multiple shots to the head can potentially be sequenced in the same way. Radial fractures from a second shot will be stopped by the intercept fractures from a previous shot.

Because gunshot wounds must often be integrated with other "trajectory" information from the crime scene, there is a clear need to have some insight into the limitations and uncertainties associated with wound paths due to gunshots. The pathologist's information and observations regarding each gunshot wound is the starting point but not necessarily the ending point. It may be necessary to later follow up and discuss certain aspects of one or more gunshot wounds with the pathologist before his or her findings are incorporated into the on-scene reconstructive efforts.

Finally, there is considerable variation among forensic pathologists regarding their knowledge of wound ballistics, to the point that it may be desirable to confer with a pathologist having special training and knowledge in this area. Issues relating to penetration depths for a particular bullet, fragmentation characteristics, wound path deviation, and incapacitation due to specific gunshot wounds are all examples.

ENTRY AND REENTRY WOUNDS

Entry and reentry wounds can be of immense help in determining what did and did not occur during a shooting incident. Consider a situation in which a police officer's bullet entered the dorsal side of the left hand and exited the decedent's wrist and then entered the sternum slightly in yaw and followed an essentially straight path described as front to back at a downward angle. The officer claimed that the subject was holding a rifle up to his right shoulder in a shooting configuration and that it was pointed toward him when he fired multiple shots. The wife of the decedent claimed that her husband had dropped the rifle and had raised his hands above his head (in a surrender position) when the shots were fired. The value of the autopsy findings is obvious in this case, although examining the rifle for spattered bio-matter (from the hand/wrist wound) and any bullet damage might be of additional value in evaluating these two divergent accounts.

Shored Gunshot Wounds

Shored gunshot wounds are of special reconstructive interest and value. The appearance of this term in an autopsy report should always attract the reader's attention. The term "shored" has been used to describe a situation where the skin at the wound site was reinforced in some way at the moment the projectile produced the wound. Both *entrance* and *exit* wounds can be shored.

A shored entrance wound is typically associated with perforating gunshot wounds to the upper arm, with the arm in contact with the chest. Both the exit in the arm and the reentry wound to the chest display atypical but characteristic features to the experienced pathologist. The skin around the margin of the exit site in the arm is shored by the skin of the chest. The skin around the reentry site in the chest receives a slap from the shored skin at the exit site in this unique configuration. The position and alignment of these wounds have obvious reconstructive value particularly when the position of the struck arm is in dispute.

Shored *exit* wounds are more common and also arise in situations where the skin around the exit site is abraded at the moment the bullet stretches and breeches the skin. A subject lying on the ground or against a wall when shot, and with the bullet's exit site supported by the surface, will sustain a shored exit wound. An exit can even be shored by a car's seatbelt across the wound site. Shoring can also be the result of tight supportive garments and clothing such as a belt or girdle, but these potential sources can be evaluated from a subsequent inspection of the decedent's clothing.

Substantial shoring combined with a bullet that barely has the remaining energy to perforate the skin may result in the bullet being retained at the exit site. One of us once received a bullet removed from a split in the skin at a shored exit site in the left cheek of a decedent. This bullet was found to contain embedded asphalt and mineral particles along with the expected blood and bone particles. The decedent was found in an asphalt parking lot next to an aluminum baseball bat that the shooter said was being swung at him when he defended himself by shooting the subject.

A witness described the incident quite differently. According to this witness, the shooter was confronted by the decedent, who threatened him with the baseball bat. The shooter produced a gun, whereupon the decedent tried to run but fell instead, at which time the shooter fired a shot into his head. This bullet, as recovered at autopsy, is shown in Figure 11.3. A large bone chip *and* the black asphaltic material can be seen embedded in it. The former is no surprise

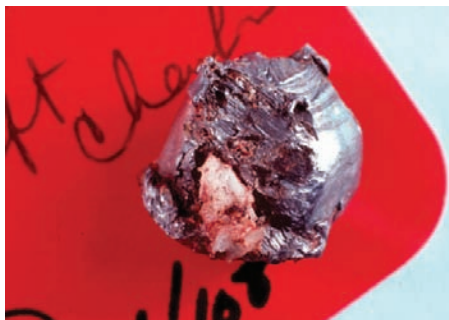


FIGURE 11.3 Bullet recovered from a shored gunshot wound.

This photograph shows the heavily damaged nose of a 38 caliber lead bullet resting on the medical examiner's "red tag" immediately following its removal from the partial exit wound in the decedent's head. The large white particle is a bone chip. The embedded black material at several locations in the gray lead and on the bone chip is asphalt acquired when the bullet attempted to exit the victim but was shored by the exit site resting against asphalt at the scene of this homicide.

after the bullet's journey through the decedent's skull, but the asphalt and mineral inclusions in the bullet, in combination with the shored "exit" wound, show the witness's account to be correct and the shooter's account to be false.

GUNSHOT WOUND PROJECTILE PATH DETERMINATION

A number of sources and methods are available for estimating a bullet's path in a gunshot victim. These are described in the following subsections.

Medical Examiner's Description

Many forensic pathologists, after tracking the course of a projectile, will provide their assessment of its angular components (in the vertical and horizontal planes) relative to the body in the anatomically erect position. For example:

After entering the sternum, the bullet proceeded front to back, downward 20 degrees and left to right 45 degrees, coming to rest just under the skin in the mid-back.

The pathologist's tracking process can involve visual assessment during the internal examination or insertion of a probe in the wound track, followed by an estimate or even measurement of the track relative to the planes of the body.

Note that, while one might reasonably assume that pathologists would look for evidence of projectile deviation or deflection, it may be prudent, when angular components are described in the report, to ask the pathologist who performed the autopsy about his or her methodology. Inquiry should also be made into the level of certainty that the pathologist is prepared to give to each such wound track, particularly if numerical values have been stated.

Most forensic pathologists are loath to commit to numerical angles, for good reason. Consequently, their autopsy reports will often describe the wound track in much more general and subjective terms:

After entering the sternum, the bullet proceeded from front to back, slightly downward, and left to right, coming to rest just under the skin in the mid-back.

In this situation and in the absence of a diagram illustrating the wound paths, it may be desirable to ask the pathologist for a more detailed description or illustration of the wound track, explaining that he or she is the proper source of this information and that it is needed to assist in the reconstruction of the shooting scene. Offer to provide one or more blank anatomical diagrams (see the Appendix) on which the pathologist can draw in the best estimate of the path of the projectile for each gunshot wound.

It is important to recognize that even the best measurement is an estimate and has some uncertainty associated with it. Based on numerous test shots into tissue simulants with a wide variety of bullets, an uncertainty of approximately 5 to 10 degrees for wound paths is not unrealistic.

While around the world there are many coroners, pathologists, and medical examiners who are qualified and well educated in firearms matters, it is important to understand

that just as many have little to no formal education in firearms, ammunition, or gunshot wounds. Many have never even held or fired a gun. Even worse, increasingly large numbers of individuals in forensic medicine (including emergency room physicians) take on faith what they hear from other uneducated individuals, including law enforcement officers professing to have factual knowledge of gunshot wounds and wound ballistic properties. This chain of the "blind leading the blind" simply propagates myth and misconception regarding what firearms and ammunition do or do not do.

Professionals with these backgrounds may have *seen* many gunshot wounds, but that does not mean they are effectively analyzing them from a scientific perspective. To do so requires a significant amount of background knowledge about the scene, the events in question, and the nature of guns and ammunition. From experience, both sides of the investigative equation—the forensic investigator and the medical personnel—have key information to be shared back and forth. When one side fails to listen to the other because of ego or omission, a correct result is in question.

Autopsy Photographs

Autopsy photographs showing probes inserted in wound tracks, *if* taken from the appropriate viewpoints, can be used to derive the nominal angular components of a bullet's track. Unfortunately, just as with many scene photographs, the appropriate camera positions are not always represented. If this is the case, angular estimates derived from them will be compromised or cannot be made. You would be well advised, after having personally made such estimates of the angular components from autopsy photographs, to consult with the pathologist who performed the autopsy and obtain his or her concurrence with your estimates.

It should also be realized that such probed tracks *may not* be truly representative if the body was twisted or in some orientation substantially different from the usual supine position on the autopsy table. As just mentioned, it may be desirable to discuss the probing process with the pathologist who inserted the probe(s) and to take advantage of his or her recollection, methodology, and so forth. Such consultation and the information derived from it should be added to your note package on the case.

Locating Projectiles' Entry, Exit, and Recovery Sites and/or Structures

Nearly all pathologists will record, in a coordinate system, the location of bullet entry wounds, exit wound, and/or recovery sites for projectiles. These are typically referenced to a datum (e.g., top of the head, planar surface of the foot, side of the body) on which the wound or projectile recovery site is located. Common anatomical reference points, such as the umbilicus, may also be noted. Photographs are invariably taken during the autopsy, copies of which should be obtained or studied in all cases where bullet path is of interest.

A few pathologists will also provide the *length* of the bullet's path. This is very useful because a simple trigonometric calculation (the sine function in this case) can provide the angular components when combined with the measured locations of the entry and exit wound or the recovery site of a bullet in the body. However, another word of caution must be offered.

A bullet that entered at point A and exited at point B may not necessarily have followed a straight line. This is particularly true with elongated rifle bullets, which often deviate from their initial path after they have penetrated a few inches. In these situations the bullet's initial path is a much better indicator its pre-impact flight path relative to the position of the body at the moment the wound was sustained (refer to Figure 11.2).

The entry and exit site locations, plotted on an anatomical diagram, a computer model, or a living model comparable in size, weight, and proportions to the decedent represent an additional means of *estimating* the path of the projectile in the decedent's body.

Ancillary and Supplemental Information

X-ray films of the decedent represent potentially useful supplemental information, since they may reveal a trail of small bullet (lead) fragments along the bullet's path. This phenomenon can provide additional information regarding the track of the projectile. Struck or fractured bones may be visible as well as the location of any bullet(s) that failed to exit the body. It is important for pathologists and investigators to realize that many important forensic and reconstructive pieces of evidence may either not show up on an X-ray or show up very faintly. Some examples of this include shotgun wads (plastic or fibrous), glass (pseudo-stippling), and particular components of ammunition (plastic caps, base inserts).

The *clothing* from a gunshot victim should *always* be sought and examined when available, especially in cases where the victim has survived. In such cases the clothing is often discarded by the hospital without early interdiction by investigators. On rare occasions, such clothing has been found in the possession of the decedent's family.

The nature of a bullet hole in clothing can reveal much regarding the bullet's pre-impact stability, its design (e.g., spitzer point versus hollow-point), and whether it passes through some intermediate object prior to striking the victim. This information should be compared to the findings and observations of the pathologist regarding the entrance wound.

Examination of a bullet recovered from the body of a victim is also very useful in assessing its probable behavior as it made its way to its final position of rest. The type of bullet, the nature and location of any damage to it, and symmetrical versus nonsymmetrical expansion or deformation are all useful properties in evaluating the probable behavior of the bullet during its passage into or through the body. For example, an evenly expanded hollow-point bullet was likely to have followed a straight course in soft tissue. The same bullet that is expanded on only one side of the hollow point will have been prone to deviating during penetration into the body.

BLOOD SPATTER AND GUNSHOT WOUNDS

Many texts and articles dealing with blood spatter production and pattern interpretation provide little or no significant information related to gunshot-generated blood spatter, or provide only a superficial treatment of the subject. Some literature sources and blood spatter experts make pronouncements that are simply untrue, for example, that blood droplets are *always* propelled from an exit wound by the responsible bullet.

Several otherwise experienced experts have even claimed that the absence of "high-velocity blood spatter" around the margin of a bullet hole in a nearby, downrange surface is proof that the hole was the consequence of a nonwounding bullet. In some cases, "experts" who testify to such nonsense are simply ignorant; others are too deprived of practical knowledge and experience.

Readers who have examined a large number of shooting scenes and bullet-struck objects from such scenes know that there are situations in which, for whatever reason, all exiting bullets from gunshot wounds do *not* necessarily eject recognizable or detectable quantities of blood.

As a corollary, bullets from perforating gunshot wounds in human victims do not always possess detectable traces of blood. This may seem difficult to believe, particularly by laypersons who serve on juries. Some of the misinformation regarding the seeming certainty of blood spatter production may arise from limited case experience and the intuitive "logic" that blood is always expelled by the bullet from the exit wound and/or is detectable on the recovered bullet. Perhaps the most likely reason for holding these views is the design of most blood spatter demonstrations involving gunshots.

The previous statement is not to suggest that these demonstrative experiments are inappropriate; rather, their design ensures the production of copious "high-velocity/high-energy blood spatter" as both projected and back-pattered droplets. The common design consists of a suspended sponge saturated with blood or a blood simulant that is then shot with a particular gun-projectile combination. A suitable witness panel is typically positioned a short distance downrange to record the blood spatter pattern that will be distributed around the bullet hole.

Other witness panels may be arranged in a particular manner to record back-spattered blood. In this design the projectile strikes the bare blood source with its full velocity. Not only does this experiment usually lack clothing or potential hair simulants, but there is also no skin or skin simulant on either side of the blood source, even though skin is elastic and tends to close up and nearly seal after the passage of most handgun bullets. A similar effect stands to take place on bullet exit, especially if the bullet has been greatly slowed during transit through the victim's body.

Bullet deceleration and/or expansion during penetration into soft tissue is also not achieved in the simple bare sponge design, with one outstanding exception, described in an article by Dr. Boyd Stephens regarding firearms-generated back-spatter published in 1983. At that time there were some who denied the existence of back-spattered blood from gunshot wounds. Dr. Stephens pointed out something that many of us have realized, that under certain circumstances small blood droplets can be propelled back toward the firearm, often depositing themselves on it and in the bore and on the shooter's hand, forearm, and/or sleeve.

Dr. Stephens reported that back-spattered blood from gunshot wounds was most common in contact and loose-contact gunshot wounds of the head. He opined that the mechanism for this phenomenon was most likely the momentary pressurization of the wound cavity immediately behind the bullet, which occurs as powder gases that follow the bullet into the body. He went on to construct one the first realistic models for the study of back-spatter. This involved encasing a blood-soaked sponge in various membranes, including rubber and Naugahyde, to simulate the unclothed human body.

The test firearm was a 38 Special caliber revolver. Regrettably the barrel length and ammunition employed were not mentioned, but, not surprisingly, Dr. Stephens found that as the space between the muzzle and the simulated skin increased, the amount of back-spatter decreased. Even a standoff distance of only 2 to 3 millimeters markedly reduced back-spatter; at a distance of 1 centimeter, back-spatter was negligible with the model used. When back-spatter did occur, the fine mist of blood droplets traveled 30 to 50 centimeters back along the line of fire.

Dr. Stephens also pointed out (from his considerable experience as a forensic pathologist and medical examiner) that back-spatter from gunshot wounds of the abdomen and chest is rare, that overlying clothing can hinder the production of back-spattered blood, and that size matters (the larger the caliber, the more likely that back-spatter will occur). He concluded his article by stating that the phenomenon is undoubtedly complex and not fully understood, but likely involves factors such as caliber, barrel length, bullet velocity, gas volume, standoff distance, and, of course, anatomy.

We would add that, keeping all other factors the same, penetrating wounds would seem more likely than perforating wounds to produce back-spatter and that bullet behavior during wound production (no expansion versus full expansion for soft- and hollow-point bullets) would play a role in back-spatter production. The latter parameter clearly must be a factor in blood and tissue expulsion from an exit wound.

This discussion is yet another example of a common situation where myth and misconception have leaped ahead of correct, empirically based observation.

In the last five years, we have seen a sizable increase in the number of medical examiners, attorneys, police officers, and laypersons who believe that all gunshot wounds produce blood spatter, or that all bullets and cartridge casings can be identified with or excluded from a specific gun. This is unfortunate, and the forensic scientist must be ever vigilant to guard against these preconceived opinions. The truth and heart of the matter is that the evidence of each specific incident must be weighed and measured. The correct method is the null hypothesis, and the correct starting opinion is inconclusive. Until sufficient evidence exists to sway the decision in one direction or the other, "Inconclusive" is the correct answer.

SURVIVORS OF GUNSHOT WOUNDS

Gunshot survivors make for interesting subjects, particularly if they are willing to assist or participate in the investigation. Their entry and exit wounds (if present) can usually be seen as unpigmented skin or scar tissue. This will hold true for many, many years, but the passage of time and changes in the survivor's physique will make the locations of these sites difficult to establish. Many gunshot victims still carry the bullet in their bodies for the reason that it was deemed safer and less invasive to leave it in place rather than remove it surgically.

The presence of the bullet provides a real advantage as long as it is still in its original position of rest. This can be determined with the help of a radiologist and the subject's cooperation. A contemporary X-ray film is prepared using the same view as in one or more archival X-rays taken immediately after the incident. The two are compared and any relocation of the projectile noted. If the gunshot victim is willing to have new X-rays taken, the

investigator should contemplate and discuss several views with the radiologist. If the victim has changed very little in height and body weight since the incident, we recommend placing a small lead or radio-opaque marker on the entry wound site. With the knowledge of this location and the location of the bullet, the subject should be oriented so that the wound track is in profile (or parallel) to the film plane. If there are remaining issues about the design (brand) of the bullet, lateral and anterior/posterior exposures should be taken.

One of the views should reveal anything unique about the bullet such as the Hydra-Shok post, the talons of the Black Talon, or the separated jacket and small pellets of the Glaser Safety Slug. Bullets and any other radio-opaque object will appear slightly to substantially larger on an X-ray film, depending on where it is in relation to the film plane. This is because X-rays emerge as a cone of radiation and thereby produce a magnifying effect at the film plane.

Reasonable estimates of the bullet's caliber are possible if a suitable scale is positioned at the height of the bullet above the film plane and if the shank of the bullet can be seen. In this way an appropriate correction can be made and the bullet's diameter estimated. Since bullet caliber is not an infinite variable—calibers come in steps such as 22, 25, 30, and so on—such a measurement may allow the elimination of certain choices until only one candidate remains among a limited universe of contenders.

Survivors who sustained one or more *perforating* gunshot wounds present a special problem unless they were struck in a clothed area of the body and the clothing has been retained. In the absence of clothing, we are often left with the victim's recollection and the opinion of the emergency room doctor regarding the direction of fire. The first can be in error and the latter often is in error. Emergency room doctors are in the business of saving lives, not documenting or interpreting the directionality of gunshot wounds. Even their sketches in ER documents are of little or no use. Their knowledge and training in the interpretation of gunshot wounds are usually inadequate, and the views they hold about wound ballistics appear to be derived from movies and television.

It will be an especially fine day when the reader-investigator finds photographs of any kind of the entry and exit gunshot wounds amid the patient's medical records. With the popularity and simplicity of digital cameras, it is hoped that this will change so that an experienced forensic pathologist can study and interpret the wounds.

One might think that asking the gunshot victim would solve the dilemma, but we have seen more than one case where the subject's account was incorrect, as evidenced by the obvious entry and exit holes in the retained clothing. These accounts may have been failures of memory or intentional deception. Either way, the subject's recollection is not physical evidence. Inaccuracy in a witness's account is not at all uncommon in crime scene and shooting incident reconstruction.

Yet another interesting fact is that in many cases individuals who have been shot do not even know it. Time and again, when discussing a shooting event with a victim, a common response is that he or she became aware only later of having been struck. While the physiology or psychology of why this happens is not our area of expertise, the fact remains that an individual may not be *able* to tell exactly when in the shooting incident he or she was struck.

The one remaining hope is the existence of X-ray films taken prior to any surgical procedures. The fracturing of bones and the distribution of resultant particles or fragments of bullet metal could answer the question of directionality.

PROJECTILE DEFORMATION IN BODIES

A discussion of the observed effects on bullets taken from bodies could easily take volumes. Here we will focus on some main categories of bullet types: expanding rifle, nonexpanding rifle, expanding pistol, and nonexpanding pistol.

Other chapters give numerous examples of bullets striking materials that are harder than tissue or tissue simulants. Take a moment to go back through these chapters to compare and contrast what happens to bullets when they strike concrete, asphalt, glass, steel, sand, and other materials that leave specific, visible, and characteristic damage. Unyielding materials like concrete leave flat spots on the ogive and bearing surface from shallow angle impacts, and they typically fragment bullets impacting at high angles. Sand and soil leave bow effects and sand-blasted surfaces. Glass impacts can leave embedded areas of white powder, flat spots, or jagged facets.

When observing bullets that have only hit soft materials such as tissue, tissue simulants, and water, we see a different type of deformation. To appreciate the significant change in the distinctiveness of the “soft” damage observed, see Figure 11.4.

Expanding Pistol

One of the first traits that is apparent in bullets 3, 5, 7, and 10 in Figure 11.4 is the smooth and/or “river rock” appearance of the exposed lead. This alone should suggest that a fluid has passed over the exposed gray lead of these bullets at a fast rate. Practical experience with lead will show that it can be easily marred with a knife, a coin, or even a fingernail. For these hollow-point bullets, the actual process by which they are “mushroomed” is one of fluid dynamics.

If the bullet is traveling nose first, and *if* it is delivered with sufficient speed, and *if* the bullet’s nose is undamaged, then fluid will begin to be pressed into the cavity. Forward motion attempts to press more fluid into the cavity. Because fluids generally do not compress, the pressure *inside* the cavity builds up, and the edges of the nose begin to peel away from the bullet’s central axis.

In all of the examples in this figure, note how the lead flows out and over the jacket material that once made up the ogive. Bullet 10 is a common, hollow-point, pistol bullet that was



FIGURE 11.4 Assemblage of bullets representing classic forms of “soft” damage.

loaded at a common pistol velocity. There is a significant amount of cylindrical area left below the mushroomed area, just as there is in bullet 7.

Compare bullet 7 to bullets 3 and 5 (refer to Figure 11.4). All three were loaded to significantly greater than normal muzzle velocities, and the degree of expansion down their axes reflects this. In fact, bullets of this type tend to fragment when entering tissue. Bullet 7 is a good representation of a relatively new technique in bullet manufacture called *bonding*, which actually melts the soft lead core to the jacket. Close examination of the junction of the nose portion of the expanded bullet shows that there is no separation of the lead core. This increases the degree to which the two components remain together during terminal ballistic interactions.

Nonexpanding Pistol

Bullet 2 in Figure 11.4 is a nonexpanding bullet; its shape and characteristics are relatively unchanged from the firing and impact processes. Nonexpanding bullets are commonly used for target practice as opposed to law enforcement or personal protection. In the handgun realm, they are not fast enough to create significant temporary cavities or to yaw and deform themselves during deceleration. Because this example hit soft tissue as opposed to bone or another hard object, the characteristic here is a *lack* of damage and deformation.

Remember that copper and lead traveling together at approximately 1000 fps (305 m/s) are relatively soft when compared to concrete but relatively hard when compared to tissue. Even sand grains will etch their way into copper jacket material, but liquidlike compositions simply allow the bullet to pass by. Do not expect biological material to adhere to these bullets.

Nonexpanding Rifle

Nonexpanding rifle bullets can be found in two general categories depending on their composition. Harder, steel-jacketed rifle bullets are represented by bullet 4 in Figure 11.4. This sample is of a caliber that tends not to yaw in tissue as much as some other rifle calibers, so the amount of deformation observed is decreased. Note that the bullet is still cylindrical at the base and is not snapped at the cannelure.

Example 6 in the figure is a more classic demonstration of a nonexpanding, plain copper jacketed rifle bullet that entered tissue, became unstable, yawed, and crushed itself down laterally against the resisting tissue material. The bullet then snapped at the weak spot in the copper jacket, which is commonly the seat line crimp area.

The base of a bullet in this class commonly has the shape of a kidney bean. Wound paths through bodies created from bullets such as these can commonly deflect in path greatly after the first 5 to 10 centimeters of travel. From a pathology viewpoint, this means that an estimation of the angle of impact relative to the body is best determined from this initial path. Estimates based on an entrance and exit alone for nonexpanding rifle bullets may be significantly in error. On a related note, these bullets will begin to create significantly large temporary cavities in tissue when they begin to yaw. This also means that this temporary cavity begins after the initial 5 to 10 centimeters.

Expanding Rifle

Bullets 1 and 9 in Figure 11.4 are examples of the expanding category of rifle bullet; however, 1 is a solid copper alloy bullet, while 9 is the remnant of a lead core soft-point bullet. Solids tend to remain intact to a much greater degree in this category. The deformation of both examples takes place down the long axis. Particularly in the case of a lead core, the bulk of the ogive and shank fragment into small pieces that may be found along the wound path. This expansion begins very quickly on contact with tissue, and unlike in nonexpanding rifle bullets, the large temporary cavities are created at the beginning of the wound track.

This is one of the key reasons that Declaration III of the Hague Conference of 1899 restricted the use of expanding rifle bullets in warfare. By allowing only nonexpanding bullets, it was hoped that the likelihood of large exit wounds in appendages would be reduced. Identifying one versus the other in gunshot victims can be exceedingly difficult, however, because yawed or unstable rifle bullets of either type can cause surprisingly large entrance and exit wounds.

The key characteristics to take away from the simplified examples shown in Figure 11.4 is the different types of damage to be seen when bullets of various types impact “soft” versus hard materials. Figure 11.5 shows pistol bullets, but the differences in where a temporary cavity is (or is not) created for expanding versus nonexpanding bullets can still be observed. Nonexpanding pistol bullets typically move too slowly, with too little surface area presented to the direction of travel, to create significant temporary cavities.

In Figure 11.5, the expanding pistol bullet on the right mushroomed close to the beginning of the path, creating a temporary cavity. Based on practical experience with shooting incidents, as well as information gathered from knowledgeable, well-informed pathologists and medical examiners, the temporary cavities formed by expanding *pistol* bullets have little effect on tissue or “wounding capacity.” They do, however, stop in notably shorter distances than their nonexpanding counterparts.

Having now discussed how expansion occurs, and how an expanded/mushroomed bullet looks, it is important to reinforce that true expansion is a fluid dynamic mechanism. Compare



FIGURE 11.5 Both bullets perforated 1.5-inch blocks of inelastic ballistic soap from left to right as viewed. On the left, a FMJ nonexpanding bullet; on the right, an expanding hollow-point bullet.

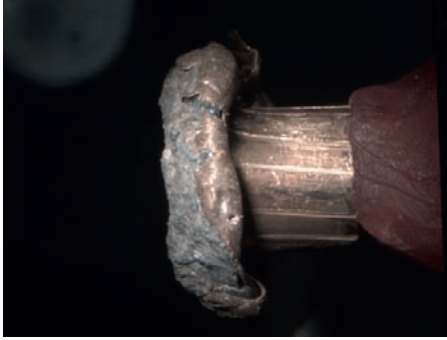


FIGURE 11.6 This bullet is *not* mushroomed or expanded. It was deformed along its long axis by orthogonal impact with a hard material rather than expanded due to pressure within the hollow-point cavity cause by impact with liquidlike material.

the collage of bullets in Figure 11.4 to the bullet shown in Figure 11.6. While the bullet in the latter figure has a mushroom-like shape, it was deformed in a manner wholly different from true expansion. It impacted a building material called stucco, which is common in the south-west, at a nearly orthogonal angle. This should not be difficult to discern from true expansion on two levels: (1) The *texture* of the now exposed lead is very rough and packed with embedded aggregate, and (2) the jacket material that was at the nose is still facing forward as opposed to having been peeled backwards and away from the direction of travel.

SUMMARY AND CONCLUDING COMMENTS

It has been said elsewhere in this book but deserves repeating at this point: *All measurements are estimates*. There is some degree of uncertainty in every measurement we take. This is not a fatal flaw in our efforts, but we simply must be prepared to provide reasonable and demonstrable uncertainty limits for the type of measurements we are making. Following this, we must assess what effect our measurements might have on the determination we are trying to make. One of the very first questions to be asked in any reconstruction is *What is in dispute?*

Consider a situation where the pathologist is able to say that a wound path was front to back and downward after the bullet entered the decedent's chest at a height of 52 inches. When pressed for numbers, he concedes that he could be off on the height of the entry wound by about 1 inch and that the downward angle could be as low as 10 degrees to as much as steep as 30 degrees, a threefold range in values for the angle. A bullet graze mark on the edge of a doorway at the shooting scene shows the fatal bullet to have been traveling essentially parallel to the floor and at a height of 48 inches before it struck the decedent.

The shooter says that the subject was approaching him in a slightly crouched and forward-leaning posture (scenario 1). Because the decedent was found on the floor on his back, it has been suggested that he was reeling back and leaning away from the shooter when he was shot (scenario 2). Scenario 1 is supported by the scene and autopsy findings; scenario 2 is excluded by the same findings despite the seemingly wide margin of error in the medical examiner's estimates of the wound path.

CHAPTER KNOWLEDGE

- Watch as people walk by you on the street and notice how quickly their body orientation changes relative to your point of view. In a 1- or 2-second time span, how many different angles are presented to you relative to arms, legs, head, and torso? Imagine now how quickly the orientation might change if you were in a struggle with the individual.
- What is the main reason an individual (law enforcement or other) would want to carry hollow-point ammunition as opposed to full- (or total-) metal-jacketed ammunition?
- Four main categories of bullets were discussed with regard to soft damage, or deformation, caused by a body: expanding pistol, expanding rifle, nonexpanding rifle, and nonexpanding pistol. Clearly these are simplified categories. What other types of bullets and projectiles can you think of that may not easily fit in them? How would you expect them to behave in bodies or tissue simulant?

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Trace Evidence Considerations Associated with Firearms

INTRODUCTION

There is a failing in some forensic laboratories that deserves to be rectified if the complete and reliable reconstruction of certain shooting incidents is to regularly take place. It is regrettable that some firearms' examiners consider themselves exclusively examiners of firearms and ammunition components. Similarly, many crime scene investigators only collect evidence instead of thinking critically about what they are seeing at a scene and why.

This is shortsighted and contrary to good forensic science, particularly when it comes to the various types of trace evidence that might be present on fired bullets or expended cartridge cases. The usual reasons given for such a narrow view of one's role are the following:

- "It's not my job" or the corollary "That's someone else's job."
- "I don't do that." [trace evidence analysis]
- "I'm not qualified and/or trained in trace evidence analysis."
- "No one asked me to look for trace evidence."
- "I didn't know that trace evidence was of interest [important] to anyone" or the corollary "I wasn't told anything about the case."

All of these reasons are those of an individual operating at the technician level. They are *not* satisfactory explanations for an individual who professes to be a forensic scientist.

While it indeed may not be within the personal skill of every person carrying out firearm examinations to analyze or identify trace evidence associated with shooting incidents, it *is* incumbent upon him or her to be diligent and observant; to note the presence of such evidence when able; to document and protect it for others to examine; and to have some understanding of its potential value (i.e., to know what sort of tests can be performed on such evidence and what such tests can show).

Failing to consider the presence of trace evidence on and in submitted firearms, fired cartridge cases, and recovered bullets will result in missed opportunities to answer critical questions in some future investigation or legal action. Trace evidence on any one of these

items can be more important than matching of the evidence bullet or cartridge case to the submitted firearm. This then, is the purpose of this chapter.

LOCARD'S PRINCIPLE REVISITED: TRACE EVIDENCE TRANSFER AND DEPOSIT EXAMPLES

The Locardian concept of mutual evidence transfer is the guiding theme in this chapter. Trace evidence that may be *left by* a bullet or cartridge includes the following:

- Metal (copper, copper/zinc alloy, lead, alloyed lead, aluminum, nickel at impact sites and/or in the bore of the firearm)
- Powder residues in the bore of a firearm or in a fired cartridge casing from the last shot fired
- Lead splash
- Bullet wipe
- Bullet lubricants
- Colored primer lacquer on the breechface of a firearm following discharge of the cartridge
- Paint from the tips of color-coded bullets (tracer, AP, API) in the magazine or feed ramp of a firearm
- Impressions left by decelerated bullets in wood, sheet rock, sheet metal
- Impressions by bullets in soft, plastic surfaces such as polypropylene bedliners in pickup trucks
- Cast-off blood from a bullet exiting a wound

Trace evidence that may be *on* a bullet includes

- Powder particles/powder imprints in the base of a fired bullet
- Primer residues in the base of a fired bullet
- Powder particles from the bore/chamber of the gun embedded in the bearing surface of a fired bullet
- Paint, asphalt, concrete, wood, soil grains, glass, and so forth, from an impacted surface.
- Threads, fibers from the perforated clothing worn by a gunshot victim
- Bone, hair, brain matter from organs or structures in the human body

Trace evidence that may be *on* or *from* a firearm (not previously mentioned) includes

- Back-spattered blood from close-proximity and contact gunshot wounds
- Fibers from the garment in which the firearm was carried or in which it was in contact
- Impact damage to the firearm with inclusions associated with the impacted surface
- Impact damage to the surface struck by a dropped or thrown firearm
- Unique or novel debris associated with sound suppressors (GSR-containing steel wool)
- Metal transfers on skin or other surface from intimate contact with the firearm
- Tissue from abrasions or lacerations sustained during the discharge and cycling of a semiautomatic firearm by the hand or fingers in an inappropriate location (such as the sharp corners at the rear of the slide)
- DNA from one or more persons who handled the firearm

Common Trace Evidence and Applicable Analytical Methods

Examples of common trace evidence that may be on or embedded in recovered bullets and their corresponding analytical method include the following:

- Imprints of fabric patterns, wire screen, “facets” from struck, failed tempered glass, and the like. Photography for this and all remaining examples.
- Propellant imprints/powder particles in the base of bullets. Removal and retention of any powder particles.
- Glass (powdery appearance; unique morphology and composition under SEM). Tests of refractive index, density, color, appearance under UV light, chemical properties by SEM/EDX analysis.
- Sheetrock/wallboard (chalky appearance) composed of calcium sulfate (gypsum). Particle morphology and chemical composition by SEM/EDX analysis.
- Soil (abraded surface with directionality; embedded sandlike particles). Polarized light microscopy of soil grains; in situ analysis by SEM/EDX.
- Asphalt (heavy damage with white chalky mineral inclusions and brown/black tarlike deposits). Asphaltic material is soluble in toluene; its evaporate on filter paper/TLC plate is fluorescent under UV light. HPLC analysis; mineral material by SEM/EDX.
- Wood/plant material (fibrous appearance). Polarized light microscopy examination; plant DNA tests; hair/hair fragments (characteristic appearance in most cases); polarized light microscopy; in situ characterization by SEM; mitochondrial DNA.
- Paint transfers/paint chips (at the “pinch point” for strikes to painted metal surfaces; painted bullet tips; paint chips in hollow-point cavities; lacquer sealants). Infrared spectroscopy; microspectrophotometry; elemental composition in situ by SEM/EDX.
- Plastic/rubber (smeared appearance). Infrared spectroscopy; elemental composition in situ by SEM/EDX.
- Fibers (characteristic appearance). Infrared spectroscopy; polarized light microscopy; morphology by SEM.
- Bone particles (waxy, translucent appearance). CA and P (calcium phosphate) and morphology by SEM/EDX.
- Tissue (stringy, amber-colored uneven diameter). Serological tests; DNA tests. Blood (characteristic appearance in most cases). Serological tests; DNA tests.

Examples of Shooting Scene Trace Evidence

Some examples of commonly encountered trace evidence found on bullets are presented in Figures 12.1 through 12.4. While these images should give the reader a good idea of what to look for, they cannot be construed as an inclusive or exclusive guide for what the investigator may encounter.

The two bullets in Figure 12.1 perforated tempered glass. Besides the facet characteristics present on the bullet that indicate the subsequent perforation, there are significant amounts of glass embedded in both bullets. While usually visible with an attentive naked eye as white powder, the glass will appear as glistening little specks on the sides of the bullet. On a stable bullet typically most of the powdered glass is in the nose. On unstable bullets the glass will be embedded in the area presented to the impact.



FIGURE 12.1 Two unstable bullets that impacted a glass windowpane. The location of the glass in the bearing surface and the size of the trace evidence tell us about the impact conditions.



FIGURE 12.2 This bullet ricocheted from wood (note the curved damage to the ogive) and then struck a pane of glass while in yaw.



FIGURE 12.3 The entire ogive and the sides of this bullet have glistening embedded glass. In many cases, this can be seen by the trained eye at a shooting scene.

The bullet in Figure 12.2 was first ricocheted from a yielding surface, as demonstrated by the rounded, longitudinal damage to the ogive. The impact damage to its side, or bearing surface, was created at the secondary impact site, which was glass.

Glass “checking” is shown in Figure 12.1 and Figure 12.3. Figure 12.2’s bullet does not display as much of the checking phenomenon because of the lower speed at impact with



FIGURE 12.4 In this photograph, wood is trapped in a hollow-point cavity. Do not expect to see this in rifle bullets or FMJ or soft-point pistol bullets.



FIGURE 12.5 A bullet that perforated a panel of drywall; notice the bearing surface and nose.

the glass. The lower the speed at impact, the less pulverization of the material occurs and the less force exists to drive the glass particles into the bullet or bullet jacket. This is usually discernable with the naked eye at a shooting scene.

The nose of the hollow-point bullet shown in Figure 12.4 has trapped substantial amounts of wood because it perforated some pine boards. The color and texture of the fibers will be different depending on the type of wood perforated, but the overall appearance of wood is fairly easy to spot. The presence of many types of trace evidence such as wood is most likely to be found in hollow-point bullets. Full-metal-jacketed (FMJ) and even soft-point bullets are far less likely to have collected soft materials, even biological matter, during terminal ballistic interactions. This should caution the reader not to jump to conclusions about where a bullet may have been when no transfer material is observed.

By far, one of the most common trace evidence types observed on bullets is gypsum or drywall. This is, of course, because this substance is so common at shooting scenes in the form of walls and ceilings. Like glass, drywall appears as a white powder, but unlike glass it is not embedded in projectiles. In most cases, drywall can be washed off, so the investigator must use appropriate care in how the items are treated.

The bullet shown in Figure 12.5 actually perforated a pane of plate glass; the core and jacket separated, and the jacket struck a wall. Note the embedded glass in the nose to the right in the image and the patchy appearance of the drywall on the bearing surface. Unlike in perforation of glass, none of this material is embedded in the jacket and there is no checking of the ogive.

Figure 12.6 shows the somewhat common example of paint adhering to the mouth of a cartridge casing fired, extracted, and ejected from a gun that was in close proximity to a wall inside a house. While the positioning of the gun is approximate at best, this conclusion may be critical to a shooting reconstruction.

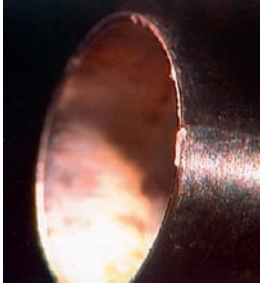


FIGURE 12.6 Here white paint is adhered to the mouth of a 40 Smith & Wesson cartridge casing.

In many cases, the crux of a dispute may be differing witness statements about whether the shooter and gun were in a confined, indoor painted entranceway or just outside the door on an open patio. The casing itself may have bounced outside, but this type of transfer could have been accomplished only in association with the force of ejection. Merely tossing the casing against the wall would not have allowed Locard's Exchange Principle to take effect.

Examination Protocol and Common Analytical Techniques

Techniques for examining and analyzing bullets include the following:

- Stereomicroscopy
- Documentation
- Photography
- Polarized light microscopy
- SEM/EDX
- FTIR (infrared spectroscopy)
- Microspectrophotometry
- Chemical tests
- Thin-layer chromatography/HPLC
- Serology/DNA

TRACE EVIDENCE SEQUENCE OF EVENTS: THREE CASE EXAMPLES

The *order* and/or *location* of multiple sources of trace evidence relates to the sequence of ballistic events encountered by the recovered bullet.

CASE EXAMPLES

Case 1

Consider a shooting event in which multiple pistol shots were fired at a motorcyclist traveling on a concrete highway. One of these shots perforated the motorcycle's rear tire, causing the rider to lose control, crash, and suffer fatal injuries. A grouping of fired cartridge cases effectively

located the shooter's position, but the important issue is whether the motorcyclist was approaching or departing that position.

One of several damaged bullets recovered from the roadway shows transfers of white paint in a flat, low angle ricochet mark. This damaged site on the bullet is partially overwritten by another ricochet event that occurred with the bullet in yaw and is later found to contain concrete particles. Overlying both of these marks are smears of black rubber.

A careful inspection of the shape of the entry hole in the rear motorcycle tire shows it to have been caused by a destabilized and deformed bullet. A subsequent search of the scene reveals a low incident angle ricochet mark in the white paint of the highway's fog line. A few feet downrange of this mark is another mark containing bullet metal on the concrete highway divider.

Putting It Together

There is only one solution to this arrangement of trace evidence. The bullet that perforated the rear tire of the motorcycle (rubber transfers) did so in a destabilized orientation (irregular entry hole in the tire and the location of the rubber transfers on the bullet). The bullet first struck the white fog line at a low angle and ricocheted into the concrete divider in a destabilized orientation (bare concrete damage partially overwriting the ricochet site containing white paint). It then ricocheted from the bare concrete divider and perforated the motorcycle tire (rubber transfers on top of both areas of ricochet damage).

The question of *who* shot the tire was never in dispute, so matching. The bullet to the shooter's gun is hardly necessary. The critical issue is the location of the motorcycle relative to the shooter when this shot was fired. The trace evidence on this bullet, combined with the locations of the two bullet impact marks on fixed surfaces and the behavior of ricocheted projectiles, allows this question to be answered.

Case 2

An alleged gun-wielding subject was fatally shot by a police officer in a public park. It is not in dispute that the officer fired three shots with his 9mm pistol. He later describes the distance between them as about 10 feet for all three shots. Two of the shots struck the subject and produced the following wounds (GSWs).

GSW-1 (fatal) entered the upper left chest passing between the third and fourth ribs, then entered the thoracic cavity, where it perforated the heart. It then exited the back after passing just to the right of the fourth thoracic vertebra. The path was front to back, left to right, and slightly upward.

GSW-2 (nonfatal) entered the right mid-anterior thigh, passed through soft tissue, grazed and fractured the femur, then exited at the rear of the right thigh. The path was front to back and downward about 30 degrees. This was a survivable wound according to the medical examiner.

Note: The numbering system used by forensic pathologists for multiple gunshot wounds is *not* an effort to assign shot sequence but merely a method for later reference.

The first paramedics on the scene found the decedent on his back and as they moved the body they observed a fired bullet in some bare dirt in an area underneath the body. A search of the ground with a metal detector revealed no other bullets in the area where the decedent fell, nor were any bullets subsequently found in his clothing.

In a later interview the shooting officer and his partner describe the subject as falling over backwards *after* the third shot, whereupon the shooting officer rushed forward and secured what was later found to be a BB pistol next to the subject's body. Several citizen witnesses, on the other hand, come forward and claim that the officer fired two quick shots, whereupon the subject staggered back and fell onto his back. According to these witnesses, the officer then moved forward, stood directly over the body, and fired a shot into the subject's chest. This precipitates much political and public furor, including the formation of a special review committee and a march on city hall by outraged citizens.

A careful and thorough laboratory examination of the three fired cartridge cases, the one recovered bullet, the officer's 9mm pistol, and the decedent's clothes reveal the following information.

The three cartridge cases are of the same brand but from different lots or production periods, in that one cartridge is plain brass and the other two are nickel plated. Additionally, the plain brass cartridge holds residues of flattened ball powder and shows a ring of black sealant material inside the case mouth. The two nickel-plated cartridge cases contain a few particles of unperforated disk-flake powder and no sealant.

A clean cotton patch pushed through the bore of the officer's pistol shows a few particles of unperforated disk-flake powder. No powder residues are found around the bullet holes in the front of the decedent's red wool pullover sweater or on the upper portion of his cotton blue jeans. Examination of the bullet found under the body shows loosely adhering soil grains on nearly all of it but no impactively embedded soil grains. Traces of black sealant material are present on the bullet's shank. Further inspection reveals a large bone chip in the partially expanded hollow-point cavity. Underneath this bone chip is a small wad of blue cotton fibers.

Subsequent test-firing of the officer's 9mm pistol with both types of ammunition produces easily discernable powder patterns out to 2 feet with cartridges loaded with the unperforated disk-flake powder, and clear powder patterns out to 3 feet with cartridges loaded with the flattened ball powder. Ejected cartridges of both types land to the right and rear of the gun when held in the normal position: grip down, barrel parallel to the terrain. When pointed essentially straight down and fired, the ejected cartridge cases go to the right and slightly forward.

Putting It Together

The bullet on the ground is associated with the nonfatal leg wound (blue cotton fibers and bone). Recall that *no* bones were struck by the bullet that produced the fatal chest wound and that the clothing in this area is composed of red wool. This bullet is associated with the plain brass cartridge (containing black sealant material and flattened ball powder). It *cannot* have been the last shot (the bore of the pistol contains unperforated disk-flake powder residues from the last shot, and the plain brass cartridge contains flattened ball powder).

The soil adhering to the bullet is of no reconstructive value, but the absence of *impact* damage with the ground is an important observation that suggests that this bullet simply fell out of the decedent's clothing as he struck the ground or as he was moved by the paramedics. This type of damage due to *impact* was illustrated earlier in Figure 9.21.

When the shooting officer is asked to position himself over a suitable stand-in for the decedent and to point his gun at that person's chest (as described by the citizen witnesses), the separation distance measures 8 inches $\pm$ 2 inches. Since there is no suggestion or likelihood of an intervening object, the absence of any gunshot residue pattern on the decedent's sweater effectively excludes

the citizens' account. The absence of the bullet from the fatal wound being under the body also refutes the scenario of a *coup de grace* to the chest.

A subsequent review of the scene photographs and diagram show the three fired cartridge cases to be in a relatively small area to the right and rear of the position where the shooting officer places himself. This is in agreement with the normal ejection characteristics of his pistol and ammunition, and does not support the citizens' account. It does support the shooter's account.

Aftermath and Further Work

Within a year of the shooting, a civil lawsuit is filed despite these findings. This prompts a renewed and extended search for the fatal bullet. Approximately 70 yards from the decedent's position and what would be downrange according to the police account, a 9mm bullet is found embedded approximately 1 inch in the trunk of a large elm tree. This bullet shows little evidence of expansion but appears to have struck the tree somewhat in yaw. Its hollow-point cavity is plugged with bark and wood fibers. It is ultimately matched to the officer's pistol but DNA tests for traces of biological material associated with the decedent are negative.

This is another example of the adage, *The absence of evidence is not necessarily evidence of absence*. The reason is that some bullets make it through gunshot victims without picking up identifiable DNA. Moreover, the passage of time combined with microbial activity can degrade any DNA traces that might have been present if this indeed had been the fatal bullet and not the missed shot. But how can this final question be resolved?

Penetration tests (discussed more in Chapter 13) can be carried out with the idea that direct shots over the 70-yard distance with the gun-ammunition combination might provide a means of discriminating a direct strike from a decelerated strike. However, careful removal of the bark and wood from the hollow-point cavity might be more productive and certainly much easier. If this is the fatal bullet, it passed through the red wool sweater first, then the decedent's body, then the rear of the sweater, and finally on to embed itself in the tree. This question is answered upon the discovery of several red wool fibers underneath the plug of bark and wood in the bullet's hollow-point cavity.

Case 3

Arson investigators at a suspicious warehouse fire noted what they believed to be a bullet hole in a smoke-stained but surviving window. Before the window was removed for laboratory examination, they also found a perforating pair of holes through opposite sides of a metal drum of solvent. Using these three points of reference, the investigators found an irregular hole in the wall opposite the window, from which a heavily damaged rifle bullet was ultimately recovered.

The projectile turns out to be a WWII-vintage 30-'06 U.S. military M1 tracer bullet fired from a rifle with 6 land-and-groove rifling, with the land widths one-third the width of the grooves. It also shows conspicuous "checking" of its ogive from having perforated glass. (This type of damage was illustrated in Figure 8.15.) Glass particles have a unique appearance under SEM and can be easily distinguished from soil grains by an experienced microscopist.

The investigators now believe that this fire was started by a shot fired from a distant knoll on the warehouse owner's property. The owner denies any involvement but does volunteer his .30-'06-caliber hunting rifle when asked if he owns any firearms in this caliber. He also tells investigators that he only shoots one brand of commercial hunting ammunition in this rifle and does

not own tracer cartridges of any kind. A box of the hunting ammunition is also turned over to investigators.

Evidence Examination and Findings

Careful laboratory examination of the rifle reveals that it has not been cleaned since it was last fired, as evidenced by sooty residues on a previously clean cotton patch pushed through the bore. The general rifling characteristics of the rifle (6-right, $L_{\text{wdt}} = \frac{1}{3}G_{\text{wdt}}$) do not allow it to be excluded, but the evidence bullet has no surviving individual characteristics that would allow the responsible rifle to be identified.

Prior to any test-firing of the rifle, a few particles of what appears to be red paint are noted adhering to the feed ramp leading to the chamber. A faint ring of clear red lacquer particles is also observed on the bolt face around the firing pin aperture. Infrared spectroscopy, microspectrophotometry, and nondestructive elemental analysis by SEM/EDX show these materials to compare favorably to the red primer annulus lacquer on WWII .30-'06 cartridges and the red identification paint used on the tips of M1 tracer bullets of the same period.

This revelation leads to testing of the bore residues collected on the cotton patch by SEM/EDX. Residues of corrosive perchlorate primer mixtures used in WWII .30-'06 ammunition and traces of the elements found in the igniter and tracer compositions are identified. *None* of these materials are used in contemporary .30-'06 ammunition.

Likewise, the commercial hunting ammunition volunteered by the warehouse owner *lacks* any red sealant around the primers, possesses standard noncorrosive lead styphnate primers, and is loaded with jacketed soft-point bullets containing lead cores.

All of the findings will be very useful to investigators when they next question and confront the warehouse owner.

SUMMARY AND CONCLUDING COMMENTS

It is neither our purpose nor our expectation to convert the reader into a trace evidence analyst. Rather, we hope to acquaint the reader with the great variety of trace evidence that may be found on firearms and associated firearms evidence, and with the reconstructive implications of such evidence. The hypothetical examples presented in this chapter were all constructed from real cases. They show that a fiber, a few particles of glass or bone, or a paint chip in the hollow-point cavity of a bullet recovered at a shooting scene can be as important as, and sometimes more important than, the matching of the bullet to an impounded firearm.

Yet these minute materials may go unnoticed and even be lost during subsequent comparison if the firearm examiner does not have an appreciation for their potential value and does not take measures to note and protect them. The same is true for fired cartridge cases that may bear fragile transfers of paint or mineral material on their rims or mouths from an impact with an adjacent surface. Trace evidence on a firearm or in the bore of a submitted firearm is quickly lost or destroyed if the examiner's first action is to test-fire the gun.

Checklists and written examination protocols alone are not enough. Individuals who collect and impound firearms evidence and those who first receive and examine it in the

laboratory must think beyond their specialty. While it is true that the analysis of trace evidence may be someone else's job, recognizing, documenting, and protecting it falls squarely on the individuals who collect firearms evidence and on the forensic scientist who first examines it.

As was illustrated in the hypothetical case examples, trace evidence can exonerate the innocent as well as implicate the guilty. It is neither prosecution evidence nor defense evidence. It is evidence that we must protect and hold in trust until it can be fully and properly analyzed, at which time its story will be told.

CHAPTER KNOWLEDGE

- To what other forensic disciplines besides firearms and trace evidence can Locard's Exchange Principle be applied?
- What examinations or instrumentation would you use to detect bullet metal (copper, lead, or otherwise) at a suspected impact site on a bronze statue? What would you do to detect the statue's material on a recovered bullet?
- Is there always material transfer during a bullet's impact? Can we always determine if a suspected impact is bullet related? Specifically why or why not?
- While opening the packaging of a hollow-point bullet recovered at autopsy, you find a small blue thread inside but not attached to the bullet. What does it mean? What is your next step?

References and Further Reading

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- McCrone, W.C., McCrone, L.B., Delly, J.G., 1978. *Polarized Light Microscopy*. Ann Arbor Science Publishers, Ann Arbor, MI.

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True Ballistics: Long-Range Shootings and Falling Bullets

INTRODUCTION

For several centuries there has been a special fascination with exterior ballistics and long-range shooting. The fact that bullets travel faster than the eye can see immediately instills a degree of mystery and awe in the process of a bullet's flight from muzzle to target. Add to this the ability to strike very small targets at very long distances, and the wonder intensifies. Long-range shooting contests were once the sort of events that kings, queens, and presidents opened and often attended. Participating in the long-range rifle matches at Camp Perry, Ohio, is the dream of most every American rifleman.

The seemingly incredible long-range feats with muzzle-loading black powder rifles equipped with metallic sights in the late 1800s can be read about in books by Ned Roberts and F.W. Mann (see end-of-chapter References). Such matches are still held every year in Raton, New Mexico, at a special range designed for shooters of black powder firearms. The German *Schützenfest* is another example of the use of beautifully crafted muzzle-loading black powder rifles fired over long distances. These rifles fire lead bullets at relatively low muzzle velocities (on the order of 1200–1400 fps). Since the invention of smokeless powder, stronger steels, and jacketed bullets, muzzle velocities have moved into the 2000- to 3000-fps regime.

Modern breech-loading rifles using high-velocity smokeless cartridges with jacketed bullets and optical sights advanced the marksman's capabilities during the last century so that targets as small as an 8-inch pie plate can now be consistently struck from a range of 1000 meters, and skilled marksman with a high-quality benchrest rifle can regularly put 10 bullets in the same hole at 100 yards. The Summer and Winter Olympics offer several types of rifle competition with participants from many countries.

None of these examples of long-range marksmanship could take place if the flight of projectiles did not obey certain laws of physics and if scientists and engineers had not developed the necessary mathematics to both describe and predict this flight though the

atmosphere. It is this same knowledge and the application of relatively complex equations through modern computer programs that are brought to bear in shooting incidents involving shots from substantial distances.

BASICS OF EXTERIOR BALLISTICS AND THEIR FORENSIC APPLICATION

Whether deliberate or unintentional, modern bullets, even from handguns, can easily travel a mile or more if launched at a relatively high departure angle. Bullets from center-fire rifles are capable of several miles of flight before impacting the ground or an object. Although greatly slowed by air resistance, such bullets usually retain sufficient velocity and energy to produce serious and even fatal wounds.

A basic understanding of exterior ballistics only requires one to grasp a few fundamental concepts. While it is true that there are a number of forces acting on a projectile in flight that will never be accurately known, we would point out that there are typically more and greater uncertainties associated with an actual incident than those associated with any subsequent ballistic calculations we might carry out.

There is an important distinction between the forensic scientist dealing with a shot from long range and a ballisticsian intent on delivering a particular type of bullet or artillery projectile to a distant target with extreme accuracy. The military and research ballisticsian knows the muzzle velocity of his projectile and the existing meteorological conditions with exactitude. The forensic scientist, on the other hand, will never know the actual muzzle velocity associated with a long-distance shot. The environmental conditions at a shooting scene might be known with a little more certainty depending on scene location and knowledge of the time of the incident.

The uncertainties that confront the forensic scientist are not fatal to many reconstructive efforts involving exterior ballistics. The substantial analytical power of contemporary exterior ballistics programs and the speed of modern computers allow the effects of these variables on a bullet's flight to be assessed. Crosswinds can be introduced, changes in air temperature, barometric pressure, and relative humidity, and, of course, variations in muzzle velocity can all be isolated with these programs and their effect on bullet path and flight time calculated for any set of conditions.

The military ballisticsian or high-tech target shooter knows much more about his firearm, the performance of his ammunition, and the meteorological conditions under which the shot will be fired. But his purpose is to hit a specific target. In a forensic investigation, a bullet has arrived at some known location after traveling a considerable distance. Here, exterior ballistic calculations are used to locate a search *area* from which a long-range shot could have originated and to rule out other areas. A subsequent search of the area of interest may lead to the recovery of pertinent physical evidence or the location of important witnesses. Either or both of these outcomes can result in a solution to the incident and the apprehension of the shooter.

A number of parameters are associated with a bullet's flight that are either essentially constant or readily measurable with modern instrumentation. The foremost of these is gravitational attraction, which is, for all practical purposes, constant and its effect on a bullet's

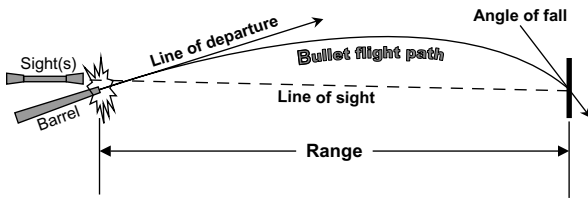


FIGURE 13.1 Basic parameters and components of a long-range trajectory.

This drawing is a view of a long-range trajectory with the x -axis (range) greatly compressed and the y -axis expanded. The relationship of the sight to the axis of the barrel is especially exaggerated to illustrate the relationship between the line of sight and the path of the bullet. The effect of gravity acts on the bullet immediately as it emerges from the barrel, causing it to follow a curved path that is always below the line or departure. It should be noted that the angle of fall is always greater than the angle of departure and that the highest point in a bullet's trajectory is beyond the true midpoint.

flight quite predictable. The average, sea level value for the earth's gravitational acceleration is 32.174 fps/s (9.807 m/s/s). A fired bullet, regardless of its muzzle velocity, will be acted on immediately after it leaves the muzzle and will ultimately fall to the ground.

If, for example, a shot were taken with the centerline of the bore pointed directly at a distant target, the fired bullet would always strike low. It is therefore necessary to elevate the gun's bore *above* the shooter's *line of sight* (LOS) sufficiently to strike the intended target at a particular distance. The LOS is, of course, a straight line through the particular sighting system to the intended target or *point of aim* (POA). Since the sights on a firearm are typically above the centerline of the bore, the bullet's path (for a properly sighted-in rifle) will pass through the LOS (usually about 20 to 30 yards beyond the muzzle for most rifles), rise above it, and reintercept it at the distance for which the gun and sight system have been set (the POA). Once a bullet has exceeded this distance, it will continue to fall below the POA.

The properties and parameters of a bullet's flight from gun to target are depicted in exaggerated form in Figure 13.1. An inspection of this figure reveals that a bullet will strike either high or low on a target or object at any point other than the two points where it intercepts the LOS. These two points can be referred to as *near-zero* and *far-zero*. The distances to these two points depend on the nature of the sighting system (its height above the centerline of the bore), the angle between the axis of the bore and the LOS, the muzzle velocity of the bullet, the bullet's exterior ballistic characteristics, and the properties of the atmosphere through which the bullet moves.

Atmosphere, in the form of air resistance, is the other major force acting on a projectile. This is the same force we feel on our hand when we hold it out the window of a fast-moving car. While there are some weaker and much more subtle forces acting on a bullet in flight, gravity and drag are the two most important. Readers who desire a more thorough description of these other forces are directed to Nennstiel's excellent article in the *AFTE Journal*. The extensive section on exterior ballistics in the *Sierra 5th Edition Reloading Manual*, and the very cerebral book by Robert McCoy are two additional choices. (See the References section at end of this chapter.) The primary forces of gravitation attraction and air resistance (drag) are depicted in Figure 13.2.

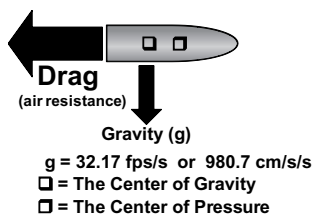


FIGURE 13.2 Primary forces acting on a bullet in flight.

The primary forces are aerodynamic drag and gravitational attraction. Gravitational attraction is constantly accelerating whereas drag is constantly changing. Drag forces are many times that of gravity at high velocities, particularly when the projectile is supersonic. Other more subtle and much smaller forces acting on projectiles in flight are not illustrated here.

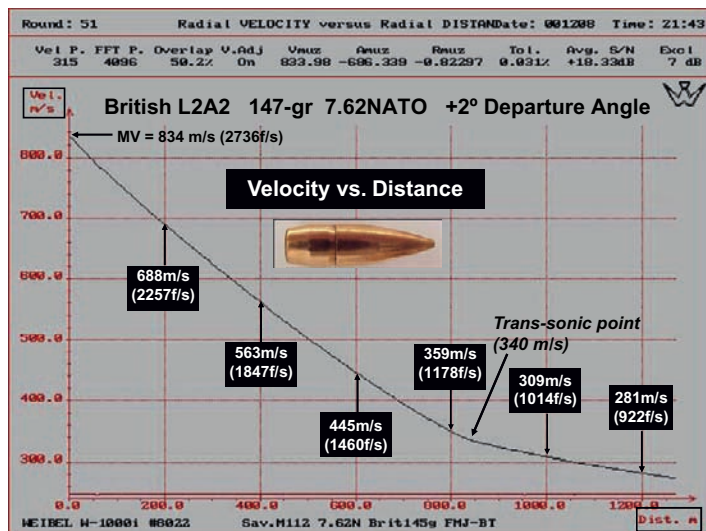


FIGURE 13.3 Plot of velocity versus distance for a supersonic rifle bullet.

This plot illustrates many interesting properties of a bullet in flight. Note the very rapid loss of velocity over distance while the bullet is supersonic followed by a sudden change in slope at the transonic point and then by a much reduced loss of velocity in the subsonic region.

Air resistance slows the bullet down and gravity pulls it back to earth. At high—especially supersonic—velocities, deceleration as a result of air resistance is substantial. At subsonic velocities it is much less. Figure 13.3 is a typical plot of velocity versus distance for a 7.62 NATO bullet. This plot is quite useful in showing the initial steep drop in velocity when this bullet is substantially supersonic. The inflection point in the otherwise smooth curve at about 340 m/s (1115 fps) is the nominal speed of sound below which one can see that the bullet's velocity loss per unit of flight distance nearly flattens out. The plotting of velocity versus time gives a very similar graph.

The slowing of a projectile in flight can be expressed by this equation:

$$F = -\frac{1}{2}\rho V^2 AC_D$$

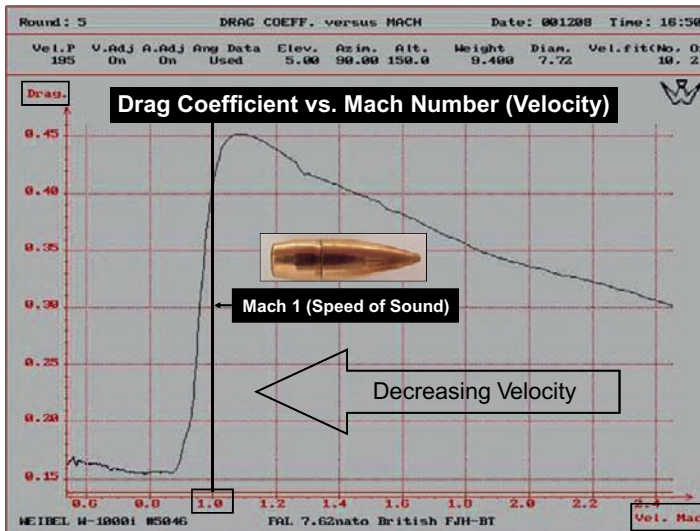


FIGURE 13.4 Plot of drag coefficient versus Mach number for a supersonic rifle bullet.

This graphic, generated from a Doppler radar track of a 7.62 NATO bullet, shows the gradual increase in drag coefficient as a supersonic bullet approaches the speed of sound (Mach 1 under the site conditions), followed by a rapid drop to a much lower and near-constant value in the subsonic region.

where F is the decelerative force or drag, and ρ (rho) is the density of the atmosphere, which depends on barometric pressure, altitude, temperature, and humidity. The ICAO standard sea-level value for the density of air is 0.076474 pounds per cubic foot (0.01226 grams per cubic centimeter). The standard atmosphere is 59 degrees F, 78% relative humidity, and pressure of 29.53 in. Hg (750 mm Hg). V in the equation is the velocity, A is the cross-sectional area of the projectile, and C_D is the drag coefficient. C_D is an experimentally derived factor that makes the equation fit the data. Drag coefficient is *not* a constant and varies with velocity as well as the properties of the projectile, including its stability in flight.

Figure 13.4 shows the relationship between C_D and bullet velocity expressed as a Mach number for the same 7.62 NATO bullet. This figure was produced from a Doppler radar track of an actual shot fired from one of our rifles. The Mach number is determined by dividing the velocity of the projectile by the speed of sound for the atmospheric conditions present at the time of the shot. Note the radical drop in drag coefficient as the bullet passes through Mach 1.

The V^2 parameter in the previous equation should help one understand the rapid increase in decelerative force with increasing velocity. For example, a velocity difference between 100 fps and 3000 fps represents a 30-fold increase in velocity but amounts to a 900-fold increase in decelerative force acting on the bullet based on the square of velocity in the drag equation.

It is not so much that this drag formula will be of use in casework. Rather, it is presented for readers interested in the scientific basis of exterior ballistics. The decelerative drag force, F , can be thought of as an ever-changing braking force (ever-changing because of changing velocity and changing drag coefficient) applied to the nose of the bullet. These forces are

substantial at high velocities such as 2700 and 3200 fps (the nominal muzzle velocities of the 7.62 NATO and M193 5.56 mm bullets).

By way of example, the drag equation was used along with the C_D values from Figure 13.4 to calculate the drag forces acting on the nose of the 7.62 NATO bullet in the standard atmosphere and at velocities of 2700 and 900 fps (Mach 2.4 and 0.8, respectively). The computations yield drag forces of 1.39 pounds and 0.080 pounds for the two selected velocities acting on a bullet that weighs 0.021 pounds. These, in turn, translate to decelerations of 2130 fps/s (feet per second per second) and 123 fps/s, which are many times that of gravity (32.174 fps/s) and should help the reader understand and appreciate the primary forces acting on a bullet in flight. An inspection of the drag equation also shows that factors that increase or decrease the density of the atmosphere (ρ) directly affect the decelerative force, F . Variations in atmospheric conditions are easily handled by all of the currently available exterior ballistics programs for PCs.

The *ballistic coefficient* (BC) is another form-fitting factor that can be related to the performance of a standard bullet. The BC adjusts or scales the drag deceleration of a standard bullet to fit a nonstandard bullet, that is, our evidence bullet. There have been a number of “standard bullets” developed and thoroughly studied over the last century, but the gold standard is the G_1 and the exterior ballistic tables that go with it. No one is likely to be shot, or shot at, with a standard bullet because it is a 1-inch-diameter, 1-pound bullet with a form or shape factor of 1. The BC of the G_1 is 1.00 by definition.

The BCs of actual bullets are derived from test firings and performance measurements. Another way to view their numerical values is as a performance indicator. Bullets with high BCs will retain their velocities better than bullets with low BCs. An example should improve the reader’s understanding of BC and the effect of bullet shape on exterior ballistic performance.

The standard bullet fired under standard atmospheric conditions at sea level with a muzzle velocity of 3000 fps will have a velocity of 2902 fps at 100 yards. The Sierra Bullet Company makes two 150-gr, 30-caliber jacketed rifle bullets that have very different nose shapes. Their sharply pointed FMJ-BT bullet (very similar to the 7.62 NATO bullet) has a nominal BC of 0.40 for velocities in the area of 3000 fps. It has a 100-yard velocity of about 2759 fps. Sierra’s round-nose (RN) bullet of the same weight has a BC of about 0.20. With a muzzle velocity of 3000 fps, it will fall to 2531 fps after 100 yards of flight.

An inspection of velocity *loss* values should bring the concept of ballistic coefficient into sharper focus. The standard bullet lost 98 fps over the 100-yard flight. The 30-caliber FMJ-BT bullet lost 235 fps, and the RN bullet lost 469 fps over the same distance. Dividing 98 by 241 and 448 gives 0.41 and 0.21, respectively. It should be noted that the velocity loss for the RN bullet with the nominal BC of 0.20 was *twice* that of the FMJ-BT bullet with the higher BC of 0.40. This is not coincidence.

The ballistic coefficient for a particular bullet typically does not perfectly parallel the performance of the standard bullet at all velocities, and consequently varies with velocity. As a result, some databases for exterior ballistic programs provide adjusted BCs for selected velocity zones. These programs improve the accuracy of any computations but are not absolutely critical for most forensic applications.

Not knowing the exact ballistic coefficient of a particular brand, weight, and design of a bullet is not critical as long as we have a reliable or measured BC close to the expected

muzzle velocity and over the range of fire involved in the case under investigation. BC values for virtually all common military and commercially available bullets are readily obtainable from a number of sources. They can also be measured with the Oehler M43 PBL chronograph system or derived from actual performance data.

This equipment is easily within the budget of nearly any laboratory and is capable of providing reliable and useful measures of G_1 ballistic coefficients of any projectile that can be accurately fired over a 50- to 100-yard distance. Whether taken from the bullet manufacturer's literature, ballistic reference sources, or Doppler radar data, or derived with instrumentation such as the Oehler M43 PBL system, it is the G_1 ballistic coefficient that is utilized by all currently available exterior ballistics programs for PCs to carry out any number of exterior ballistic calculations.

CASE SITUATIONS: AN OVERVIEW

All of the shooting incidents considered in previous chapters involved relatively close-range events where the distances were sufficiently short that the flight time of the bullet amounted to a few thousandths of a second and the flight path was, for all practical purposes, a straight line. In these close-range situations any objects or victims that were in motion at the time of a shot can be considered stationary insofar as the bullet's flight is concerned.

Think of these situations as a flash photograph, where the resultant picture shows people known to have been in motion as frozen in time and space. A 115-gr, 9 mm bullet with a muzzle velocity of 1250 fps fired from the sidewalk 10 feet away from a passing car traverses this distance, strikes and perforates the sheet metal of a car door, and then strikes the driver in a time frame of about 0.01 seconds. At 30 mph, the car has moved only 5 inches between the discharge of the gun and the impact of the bullet in the driver. In this situation, the pistol was pointed at the driver's door when it was discharged.

Now consider this same bullet traveling over a distance of 500 yards, requiring a flight time of about 1.7 seconds. It arrives with a residual velocity of about 665 fps sufficient to perforate the sheet metal door and interior door panel and wound the driver. Questions immediately come to mind: Where was the vehicle when the shot was fired? Where was the gun pointed when the shot was fired? What were the shooter's view of the car and the ultimate impact area of the bullet when the shot was fired?

Long-distance shootings (100 yards and beyond) are more complicated and more interesting from a scientific and reconstruction standpoint. In these situations the curved flight path of the bullet and the bullet's flight time may become important issues. Likewise, back-extrapolations designed to locate a shooter's possible and/or probable position must now take into account fundamental terminal and exterior ballistic phenomenon.

Figure 13.1 showed the principal aspects of long-distance shooting. In this diagram, the positioning of an optical sight and the associated LOS have been exaggerated to illustrate the relationship between the LOS and the path of the bullet. If a cardstock witness panel were to be located at any point other than the previously defined near-zero and far-zero positions, we would have a bullet hole above or below the LOS. This is referred to as the *point of impact* (POI).

If one were looking through the rifle's optical sight for any of these shots, the position of the crosshairs on the witness panel would be the POA. LOS and POA are, in effect, the same thing. It is only a matter of the view. In a profile view, such as shown earlier in Figure 13.1, LOS would be applicable. Looking through the sights of the gun, POA would apply.

The vertical distance between the LOS and the bullet's path is one of the many items of information provided by contemporary exterior ballistics programs that are of value to the shooting reconstructionist. If one has the necessary information regarding gun, ammunition, range of fire, scene topography, and meteorological conditions, an appropriate exterior ballistics program can provide useful information regarding the relationship between the sight picture (POA) and the entry wound position (POI).

These same programs provide bullet drop data, time of flight (TOF) data, downrange velocity, and energy and momentum of the bullet, as well as the amount of wind drift for any particular crosswind. Any of the meteorological parameters previously described can be varied and their effect on the bullet's flight calculated.

Table 13.1 is an abbreviated ballistics table for a 168-gr, 30 caliber bullet used by many S.W.A.T. marksmen in the United States. A table very similar to it was prepared for a high-profile case involving a relatively long-distance shot by a law enforcement marksman who was positioned approximately 200 yards from his target, located across a small canyon. The shooter was positioned on a mountain side at an elevation of about 7000 feet mean sea level. The nominal muzzle velocity of this bullet-rifle combination was 2800 fps. The rifle was sighted in for 200 yards (POA = POI at 200 yards). The BC values for the bullet were 0.462 for the velocity region of 2600 fps and above, and 0.447 for the region of 2100 to 2600 fps.

An inspection of Table 13.1 and others like it provides further insight into the flight of bullets through the atmosphere. For example, the time of flight for this bullet to cover 200 yards was a little less than one-quarter of a second.

This is a potentially useful piece of information because it bears on how much movement a target or adversary can undergo while the bullet is en route. If the target was actually at a distance of 160 yards, the bullet would have struck 1.33 inches above the point of aim as viewed through the telescopic sight. If one could have directed a laser through the bore of the rifle just as the bullet was fired, the beam would have illuminated a spot 9.56 inches above the bullet point of impact 200 yards away. A simple arctangent calculation using a bullet drop value of 9.56 inches and a range of 200 yards (7200 inches) can provide an estimate of the departure angle (line of departure) for the particular shot: in this case +0.076 degrees if the target was at the same elevation as the shooter.

A more familiar plot, Figure 13.5, shows a profile view of a maximum-range shot for 00-B (buckshot) tracked by Doppler radar. The classic asymmetrical shape of a trajectory in air is clearly evident. The plot also shows that the *angle of fall* is significantly steeper than the *angle of departure*.

For a particular projectile, muzzle velocity, and environmental conditions, there is a relationship between the angle of fall at the impact site and the range from which the shot occurred. Sophisticated programs such as Nennstiel's EB4.1 allow the user to reconstruct and back-extrapolate a bullet's trajectory based, in part, on terminal ballistic information from the scene. With a little work, the trial and error method can be used with simpler programs to accomplish the same thing.

Table 13.2 provides a computation with Sierra's Infinity program for a standard 230-gr, FMJ-RN 45 Automatic bullet fired at sea level out to a distance of 1000 yards over level

TABLE 13.1 Trajectory for .308-in.-Diameter 168-gr, JHP-BT (2800-fps muzzle velocity)

Range (yd)	Velocity (fps)	Bullet Path (in.)	Bullet Drop (in.)	Time of Flight (s)
0	2800	21.50	0.00	0.00000
20	2769	20.48	20.09	0.02155
40	2738	0.35	20.36	0.04334
60	2708	1.00	20.82	0.06538
80	2677	1.46	21.46	0.08766100
2647	1.73	22.30	0.11020120	2617
1.80	23.34	0.13300140	2587	1.67
24.58	0.15606160	2556	1.33	26.02
0.17939180	2526	0.77	27.68	0.20300200
2496	0.00	29.56	0.22689	

Notes: G₁ ballistic coefficients = 0.462 @ 2600+ fps; 0.447 @ 2100–2600 fps

Site altitude = 7000 ft. MSL

Barometric pressure = 29.92 in. Hg

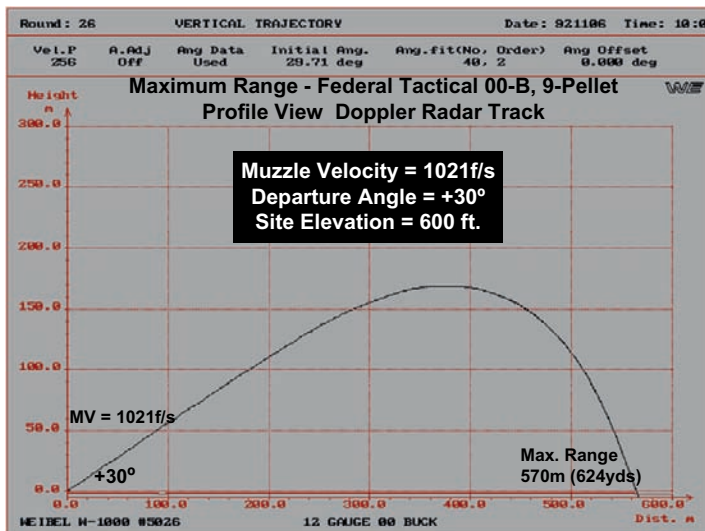
Temperature = 55°F

Humidity = 30%

Crosswind = 0 mph

Far zero = 200 yd

Rifle sight height above bore = 1.5 in.

**FIGURE 13.5** Doppler radar plot of a maximum-range discharge of 00 buckshot.

This profile view of a maximum-range shot for 00 buckshot was derived from a Doppler radar track and is similar in many respects to the drawing in Figure 13.1.

terrain. The *angle of fall* can be calculated by taking the *change in height* for the bullet path over a relatively short distance at the end of the trajectory (1000 yards in this example).

For this purpose, the range increment value was reset in this computation to give 5-yard intervals (see the lower bold values in Table 13.2). A height change of 36.44 inches over a

TABLE 13.2 Trajectory for .452-in.-Diameter 230-gr, FMJ-RN .45 Automatic

Range (yd)	Velocity (fps)	Bullet Path (in.)	Bullet Drop (in.)	Time of Flight (s)
0	850	20.50	0.00	0.000
50	814	212.77	26.19	0.180
100	781	412.95	225.48	0.368
150	751	598.89	259.00	0.564
200	722	769.42	2107.93	0.768
250	695	923.27	2173.54	0.980
300	669	1059.11	2257.17	1.200
350	645	1175.49	2360.25	1.429
400	621	1270.88	2484.32	1.666
450	598	1343.61	2631.06	1.913
500	577	1391.87	2802.26	2.170
550	556	1413.72	2999.87	2.436
600	536	1407.04	21226.01	2.714
650	516	1369.53	21482.99	3.002
700	498	1298.66	21773.32	3.301
750	480	1191.71	22099.73	3.613
800	463	1045.68	22465.23	3.938
850	447	857.28	22873.09	4.276
900	432	622.91	23326.93	4.628
950	417	338.60	23830.69	4.995
1000	403	0.00	24388.76	5.378
995	405	36.44	24330.38	5.339
1000	403	0.00	24388.76	5.378

Notes: 850-fps muzzle velocity

G1 ballistic coefficient = 0.166

Sea level site elevation

Barometric pressure = 29.92 in. Hg

Temperature = 59°F

Humidity = 60%

Crosswind = 0 mph

Far-zero = 1000 yd

Rifle sight height above bore = 0.5 in.

distance of 5 yards (180 inches) forms a right triangle, and the tangent of the *angle of fall* is equal to 36.44 divided by 180. The use of a pocket calculator with $\tan^{-1}$ capabilities will show the *angle of fall* to be about -11.4 degrees. Inserting this value in Nennstiel's EB4.1 program along with the estimated muzzle velocity of a standard 230-gr, 45 Automatic bullet of 850 fps gave a calculated range of fire of 986 yards, a flight time of 5.32 seconds, and an *angle of departure* of $+6.91$ degrees. This is in good agreement with the 1000 yards and $+6.95$ degrees derived from the Sierra Infinity program.

The starting point at a shooting scene for any retrograde trajectory extrapolation is angle of fall, penetration, or a combination of the two. Consider the following hypothetical case.

A bullet, later determined to be a standard, 230-gr FMJ-RN .45 Automatic, entered a residence through a screen window, nicked the edge of a table, after which it just had sufficient energy to perforate a Sheetrock wall and fall to the bottom of the space behind it. No recognizable mark was left on the next surface about 4 inches downrange of the bullet hole. A check of the alignment of these three points with a laser positioned outside the screen window shows them to form a straight line over a distance of 10 feet. The vertical component of the bullet's entry into the residence measures -12 degrees ± 0.5 degrees.

In this example we have both trajectory information and terminal ballistic information in the form of penetration/perforation behavior. While *two* reference points *may* represent a straight line, *three* points in alignment *do*. This obviates any concern regarding deflection in this hypothetical case, so the three points provide a very reliable expression of the bullet's final flight path. The normal muzzle velocity of 45 Automatic ammunition loaded with this bullet is well known (approximately 825–850 fps). The observable facts fit a long-range shot.

Conversely, a shot fired from somewhere immediately outside the window with a downward angle of 12 degrees can be effectively eliminated because of the minimal penetration of the evidence bullet. Occupants of the house, on being interviewed, reported hearing what they thought was the impact of a rock or a golf ball inside the house. No loud sound like a gunshot was heard nor was any fired cartridge case found on the property along a back-extrapolation of the laser path. Controlled tests could be carried out in the laboratory to establish and refine the penetrative capabilities of this type of ammunition striking sheetrock at various impact velocities.

Ultimately any one of many contemporary exterior ballistic programs can be used to calculate various angles of fall from selected ranges until a nominal value of -12 degrees is obtained. This may require multiple computations, but once the approximate range is found, other parameters such as flight time, terminal velocity, and angle of departure can be extracted from the ballistic data. Aerial views, topographical maps, city or county maps, or satellite images, in conjunction with the range-of-fire estimates and the azimuth of the bullet's approach, are then used to establish the search area.

Let us further assume in this example that a teenage subject is found and later admits to taking his father's pistol and firing a shot at a bird on top of a telephone pole in his backyard. The astute investigator asks the shooter to show him where he stood and how he held and sighted the pistol. This angle is later measured and found to be $+35$ degrees.

There is little need to run the calculations in this example because the angle of fall (-12 degrees) for projectiles fired in the atmosphere will always be greater than the angle of departure. In this case the angle of fall was *less* than the angle of departure. The final exercise should involve returning to the shooter's location and photo-documenting any view of the victim's residence from the shooter's location and employing some means of illustrating the calculated $+7$ -degree departure angle for the actual shot. This parameter is calculated from the arctangent relationship of the 1000-yard drop value of 4389 inches (refer to Table 13.2) divided by the distance of 1000 yards (36,000 inches).

MAXIMUM-RANGE TRAJECTORIES

The explanation given by the shooter in the previous hypothetical case raises the issue of maximum range for small arms projectiles. There is published data on this subject, but

TABLE 13.3 Some Maximum-Range Calculations for Common Bullets*

Bullet	Muzzle Velocity (fps)	Departure Angle (deg)	Maximum Range (yd)
<i>Pistols</i>			
50-gr FMJ 25 Auto	760	+30	1212
71-gr FMJ 32 Auto	905	+30	1630
95-gr FMJ 80 Auto	955	+27	1176
115-gr FMJ 9mmL	1190	+30	1885
Note: YPG 1996 shot # 127 9mm 115-gr FMJ @ 135°/600ft. MSL/21°C/MV = 1167fps traveled 1982 yd, $V_{REM} = 281fps$, angle of fall = -67° .			
124-gr FMJ 9mmL	1120	+30	1920
158-gr LRN 38 Special	850	+31	1900
158-gr JSP 357 Magnum	1235	+30	1955
180-gr JHP 40 S&W	1015	+30	2094
Note: YPG 1996 shot # 135 .40 S&W 180-gr FMJ @ 135°/600ft. MSL/21°C/MV = 1025fps traveled 1878 yd, $V_{REM} = 290fps$, angle of fall = -67° .			
240 gr JSP 44 Magnum	1180	+29	2112
185 gr JHP 45 Auto	1000	+30	1862
230 gr FMJ 45 Auto	850f	+31	1806
Note: YPG 1996 shot # 140 .45 auto 230-gr FMJ @ 135°/600ft. MSL/21°C/MV = 880fps traveled 780 yd, $V_{REM} = 288fps$, angle of fall = -67° .			
<i>Rifles</i>			
55 gr FMJ 5.56mm	3200	+28	3414
110 gr FMJ 30 Carb	2400	+28	2577
123 gr FMJ 7.62mm	2300	+29	3417
168 gr JHPBT 30-caliber	2800	+30	4905
123 gr FMJ 7.62mm	2300	+29	3417
250 gr SPJ 338 Winchester	2600	+31	4954
300 gr JHP 45-70	2000	+30	2920

Note: Standard sea level conditions—Sierra Infinity program.

YPG = U.S. Army Yuma Proving Grounds.

*Sea level 59 °F 78% RH 29.53 in. Hg.

several contemporary exterior ballistics programs will provide reasonably accurate answers to this question.

The *maximum* range of typical small arms projectiles discharged in the atmosphere is achieved at departure angles of 30 to 35 degrees, not 45 degrees as one might expect from the elementary physics of such an event. Table 13.3 provides some sea-level examples for a number of common bullets calculated with the Sierra Infinity program, which allows other site elevations and environmental conditions to be entered and the maximum range recalculated. As one would expect, the thinner air at higher altitudes and/or higher temperatures will result in a slightly longer flight in both time and distance.

The ability to set a maximum range value for a particular bullet is useful in casework because such a calculation sets the *maximum distance* from which a recovered bullet could have come. It is also useful in the previous case of the youthful shooter. Had he truly fired a shot at a departure angle of $+35$ degrees, the bullet would have traveled about 1800 yards and returned to earth at an angle of fall of -67 degrees.

A number of firings for maximum range were carried out with some of these bullets at the U.S. Army's Yuma Proving Grounds in Yuma, Arizona, from 1992 through 2005. The Doppler radar tracks and tabular data from these shots provide a very useful comparison with the calculated values. Several of these high-angle, maximum-range shots are included in the data in Table 13.3.

Lagtime

Another interesting property associated with long-range gunfire has forensic implications and value: lagtime. With the blast of a gun, sound marches forward and toward the target at a constant speed. A supersonic bullet will be forward of the sound front and arrive at the target or some downrange point ahead of the sound of the gunshot. A bullet with a muzzle velocity below the velocity of sound will arrive at the target after the arrival of the sound of the gunshot. However, it can, and often is, more complicated than these two examples. The forward speed of a bullet is constantly changing because of air resistance, but the speed of sound remains the same at the particular site location and under the particular meteorological conditions. This means that a supersonic bullet that is initially out in front of the sound of the shot can rapidly become subsonic and continue to lose velocity. In this situation the sound of the shot will eventually overtake and pass the decelerating bullet and arrive at the target before it.

The relationship between the bullet's flight time and the time it takes for the sound of the gunshot to arrive at some selected downrange location is called *lagtime*. If, in some future case, we have a serendipitous audio recording of the arrival or passage of the bullet at a known location and the arrival of the sound of the distant gunshot, we have a very useful piece of information that relates to the range of fire. Such cases are not unheard of and we have used this information in several cases to assess the distance from which a shot could and could not have come.

Let us return to the residence where the 45 Automatic bullet came through the screen window, and imagine that the homeowner was leaving a voicemail message on a friend's telephone at the time of the shot. We learn this because an investigator asked the homeowner what he was doing when he heard the impact of the bullet. The flight time for the 45 Automatic bullet over a distance of 1000 yards was calculated to be 5.38 seconds. The speed of sound at the site elevation and under prevailing conditions is later determined to be 1125 fps. At this speed, it will take sound 2.67 seconds to cover the 3000-foot (1000-yard) distance. Subtracting 2.67 seconds from 5.38 seconds gives 2.71 seconds. An analysis of a copy of the friend's telephone message tape shows a faint *pop* sound 2.70 seconds before the bullet's much louder impact and the homeowner's expletive.

This same concept can be used to test eyewitness accounts of a shooting incident. It is not uncommon that in noninjury cases a complaining witness/victim will describe in vivid detail the sound of a shot and the passage of the bullet just inches away from his head. No bullet or bullet impact site is found, so investigators are left with this account, which, of

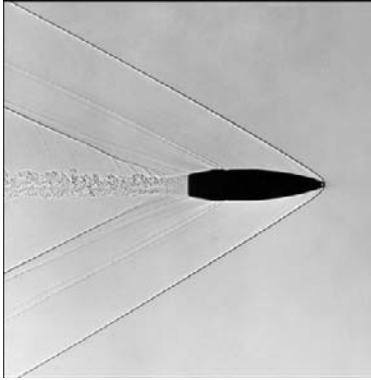


FIGURE 13.6 Shadowgraph of a supersonic rifle bullet in flight.

This shadowgraph, provided by Dr Beat Kneubuehl of Switzerland, shows the multiple shock waves generated by a supersonic rifle bullet. These shock waves are responsible for the loud *crack* heard after such a bullet passes one's location. Wake turbulence can also be seen behind this bullet. Close inspection reveals the reduced drag benefits of the boattail shape. Wake turbulence makes a relatively small contribution to the total aerodynamic drag on a supersonic bullet. Once the bullet becomes subsonic, the shock waves disappear and the aerodynamic drag becomes substantially smaller.

course, may be true and correct in some circumstances. It is relatively easy to evaluate if we know something about the gun and the ammunition purportedly involved.

In this example, the complainant states that while standing in his garden, he saw a hunter with a rifle just beyond a fence at the far end of his property (later determined to be 300 yards away). He heard a shot coming from the location of the hunter, then heard the bullet pass by his ear with a hissing sound. A fired .308 Winchester caliber cartridge is later found at this location.

The hunter is located and admits to firing a shot with his .308-caliber rifle but in a totally safe direction. The gun and ammunition are impounded and subsequently tested in the laboratory. The average muzzle velocity of the ammunition is $2800 \text{ fps} \pm 25 \text{ fps}$, and the ballistic coefficient of the bullet is 0.35. Even the most basic exterior ballistic program will reveal that this bullet is still supersonic at 300 yards downrange. Such a bullet cannot and will not produce a hissing sound as it passes by a listener. Instead it will produce a loud, sharp crack like that of a bullwhip. This is due to the shock wave generated by a supersonic bullet (see Figure 13.6).

A subsonic bullet, on the other hand, will produce a hissing sound as it forces its way through the atmosphere. Moreover, under the conditions in this case the bullet will arrive at the listener's location 0.4 seconds *before* the sound of the gunshot. The complainant's account is mistaken at best.

Penetration and Projectile Deformation as an Expression of Range of Fire

The depth of penetration in gunshot victims and various inanimate materials bears a relationship to impact velocity, as does any deformation or damage suffered by the projectile as it produces a wound in the victim. Both are range-dependent parameters and can be evaluated through test firings into the appropriate medium using down-loaded cartridges and a

suitable chronograph to produce selected impact velocities in the medium. The recovered projectile must be carefully examined for any evidence of impact with intermediate objects. Any bullet hole in clothing, as well as the appearance of the entry wound, is equally critical in addressing the possibility of ricochet, deflection, or perforation.

Penetration depth *may* obey a linear relationship with impact velocity, but this will have to be evaluated through test firings in the appropriate medium. Nonlinearity usually arises from varying amounts of bullet yaw in test media (e.g., ordnance gelatin, ballistic soap) or varying degrees of projectile deformation. For example, double-aught (00B) buckshot pellets will penetrate more deeply in tissue and tissue simulants at 900 fps, where they retain their spherical shape, than at 1300 fps, where they flatten on impact and have a much larger area of presentation as they advance. In the region of 300 fps to about 1000 fps, their penetration depth will obey a linear relationship with impact velocity.

The ultimate object in any evaluation of this sort is to prepare a series of fired projectiles into a suitable medium that show a reproducible relationship between impact velocity, penetration depth, and projectile deformation. The hypothetical case of the residence struck by the 45 Automatic bullet is a relatively easy example. A section of the actual Sheetrock wall can ultimately be used for ballistic testing after some preliminary shots at high and low velocities are fired into Sheetrock of the same thickness. The objective is to find that velocity where the bullet is just able to perforate the Sheetrock and then compare this value with the calculated residual velocities of long-range shots.

Bullets from the Sky

Falling bullets from the reckless discharge of small arms in populated areas become a matter of concern every New Year's Eve and Fourth of July in the United States. This concern has some justification because occasional injuries and even deaths have occurred from apparent high-angle shots. Still, misinformation and misconceptions abound regarding this subject.

The most common is the claim (usually by a police chief or county attorney) that a bullet fired straight up returns to earth with the same velocity with which it left the muzzle of the gun. This, of course, would only be correct if the Earth had no atmosphere. A truly *falling* bullet from a vertical to near-vertical discharge will return to the surface at its terminal or free-fall velocity, where the retarding drag force (air resistance) of the existing atmosphere equals the weight of the projectile.

A bullet's terminal velocity will depend not only on its weight and shape but also on the *way* the bullet returns: base first, nose first, or tumbling. Although not at all likely, a nose-first return would result in the highest free-fall velocity. If the spinning bullet maintained its stability as it reached its apogee, it would very likely return base first. If it lost its gyroscopic stability, a tumbling return would be likely. Of the three choices, the tumbling mode would result in the lowest terminal velocity.

The matter of free-falling bullets has been of interest for many years. Numerous calculations and practical tests around the time of the WWI and for the decade afterward addressed military rifle bullets of the day: the American .30-'06, the British Mark VII .303h, and the German 7.92 × 57mm Mauser. The 174-gr Mark VII 303 bullet with a muzzle velocity of 2440 fps was calculated to rise to an altitude of 9000 feet in 19 seconds, then return in

36 seconds for a roundtrip time of 55 seconds. Actual firings produced roundtrip times of 48 to 51 seconds.

Computations for the 150-gr flat-base 30-'06 bullet with a muzzle velocity of 2700 fps carried out around 1920 gave a calculated roundtrip time of 49.2 seconds and a free-fall velocity of 300 fps. Out of 500 carefully fired vertical shots, Julian Hatcher was able to document four returning bullets all of which were found to have impacted base first. One of these struck a soft pine plank and left a 1/8-inch impression of the *base* of the bullet.

At least one computer program will calculate vertical ballistics, and the answers it obtains appear to be in good agreement with empirical tests such as those just cited and those we have carried out with spherical projectiles. The program, called Baltec1, requires the bullet's weight, diameter, and length, the length of the ogive, the diameter of any meplat, the bullet's G_1 ballistic coefficient and muzzle velocity, and the elevation of the site for the vertical discharge. Nose-first, base-first, and tumbling modes can be selected for the bullet's return to the surface.

Baltec1 was used to calculate the vertical firing results shown in Table 13.4. It was also used to calculate values for the historic examples previously cited. These calculations were in good agreement and provided a useful check of the program. An inspection of the terminal velocity column of Table 13.4 reveals that most common bullets fired vertically return to earth with velocities on the order of 150 to 250 fps. This is of considerable interest since the threshold velocity of the perforation of human skin is on the order of 200 to 330 fps for typical small arms projectiles in their normal, nose-forward orientation.

The substantial range of impact velocities for skin penetration arises from a number of sources: thickness and age, a shored or unshored impact site, and projectile nose shape. Regardless of these factors and the relative wide range of values, being struck by any of the most common bullets truly *falling* from a vertical to near-vertical discharge stands to be a very unpleasant experience but not one likely to produce a deep penetrating or fatal wound.

Note: This should, in no way, be seen as an endorsement or approval of the discharging of firearms into the air for celebration or self-amusement.

The most important fact to emerge from a study of the data in these tables is that relatively deep penetrating and fatal wounds, if the result of distant shots, are *not* from vertical firings but rather from high-angle discharges (e.g., 20- to 45-degree departure angles). In these situations the fired bullets typically arc over in flight and return to earth in a nose-forward orientation. For this reason, such bullets retain their velocity much better than do bullets tumbling from the sky or falling back to earth base-first.

There are other interesting observations to be made from the data in Table 13.4. All of the roundtrip flight times listed are such that the sound of the shot, even if heard by witnesses at a victim's location, will have typically occurred 30 to 45 seconds prior to the arrival of the falling bullet.

Long-Range Unstable Bullets

Since the early 1990s, forensic scientists have been most fortunate to be able to work with some of the most advanced military projectile-tracking devices, specifically Doppler radar. In these past two decades, a wealth of knowledge has been accumulated with regard to all

TABLE 13.4 Vertical Ballistics for Some Common Cartridges and Projectiles

Cartridge	Bullet Weight (gr)	Muzzle Velocity (fps)	Ballistic Coefficient	Maximum Altitude (ft)	Ascent Time (sec)	Terminal Velocity	Descent Time (sec)	Roundtrip Time (sec)
.22 Short	29 LRN	1095	0.098	3014	10.0	168-BF	21.5	31.5
						134-TU	25.0	35.0
.22 long rifle	40 LRN	1255	0.132	3867	12.5	198-BF	23.5	36.0
						142-TU	30.0	42.5
.25 Auto	50 FMJ	760	0.090	2288	9.4	191-BF	15.8	25.2
						146-TU	18.6	28.0
.32 Auto	71 FMJ	905	0.132	3342	11.7	187-BF	21.6	33.3
						158-TU	24.4	36.1
.380 Auto	95 FMJ	955	0.079	2450	9.4	187-BF	16.9	26.3
9mmL (Win)	115 JHP	1255	0.142	4034	12.7	210-BF	23.4	36.1
9mmL	124 FMJ	1110	0.172	4415	13.3	219-BF	24.6	37.9
.38 Spl. (Rem)	158 LRN	755	0.142	3004	11.4	237-BF	17.4	28.8
.38 Spl.	158 LRN	950	0.170	4040	13.2	241-BF	22.0	35.2
Speer pdt. 4647						182-TU	26.0	39.2
.38 Spl.	158 LSWC	950	0.123	3296	11.6	238-BF	19.0	30.6
Speer pdt. 4623						167-TU	23.0	34.6
.40 S&W	180 FMJ	990	0.170	4142	12.9	231-BF	22.6	35.5
						180-TU	26.7	39.6
.41 Mag.	210 JSP	1300	0.165	4537	13.6	247-BF	23.3	36.9
.44 Mag.	240 JHP	1180	0.172	4519	13.6	249-BF	23.1	36.7
.45 Auto	230 FMJ	850	0.166	3661	12.7	230-BF	20.6	33.3
						192-TU	23.0	35.7
5.56 mm (223 Rem.)	55 FMJ-BT	3240	0.250	8024	17.0	244-BF	38.0	55.0
						141-TU	60.0	77.0
.30 Carb.	110 FMJ	1990	0.166	5129	13.7	239-BF	26.0	39.7
7.62 × 39mm	123 FMJ	2400	0.320	8556	19.0	264-BF/158-TU	38.0/57.0	57.0/76.0
30-30 Win	150 JSP	2390	0.217	6539	15.6	282-BF	28.7	44.3
30-'06	180 JSP	2700	0.382	10,103	20.6	323-BF	37.5	58.1
#4 Buck	19.4 sph.	1350	0.025	994	5.3	124	10.6	15.9
00 Buck	53.5 sph.	1350	0.028	1341	6.4	149	12.1	18.5*

BF = base first; TU = tumbling.

*Actual test firings at 3000 ft. MSL gave 19–20 sec.

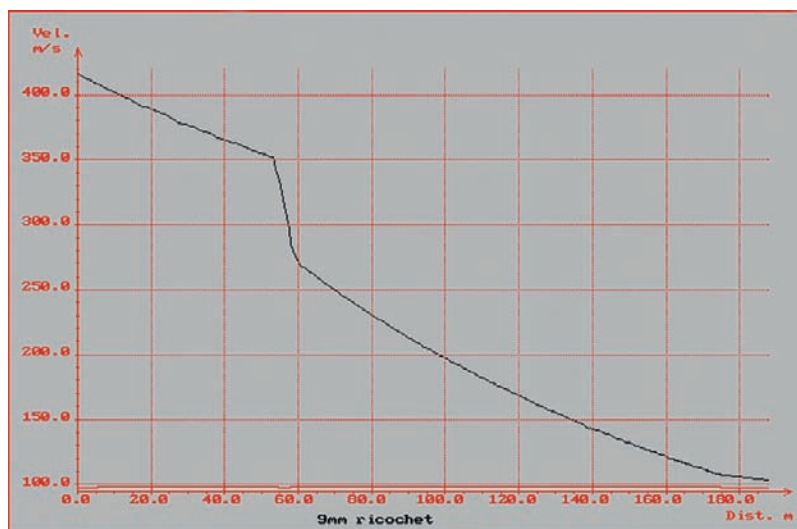


FIGURE 13.7 Doppler radar track of a bullet that ricocheted at the point where a sharp drop is present. The x-axis is the distance from the firearm in meters; the y-axis represents velocity in meters per second.

manner of projectiles in flight, but perhaps most beneficial data collected relate to unstable bullets. The beauty of Doppler radar tracks is, of course, that *real* data are collected on projectile in flight, as opposed to a calculated estimation. An example of a Doppler track for a ricocheted 9mm caliber bullet is presented in Figure 13.7.

In this track, the reader can see that the muzzle velocity was approximately 415m/s (1370ft/s). The bullet struck the ground about 55 meters from the gun position while traveling slightly faster than 350m/s (1150ft/s). The bullet lost a significant amount of speed, emerging from the impact with about 265m/s (880ft/s) remaining. A determination of the ballistic coefficient of an unstable bullet of this particular type can be completed using the portion of the track after impact. This experiment was conducted numerous times with several calibers. The results are tabulated in Table 13.5, which gives us a narrow window of insight into the many different caliber possibilities that we may encounter in casework. It also covers a fairly diverse spectrum of the scope of our work as well.

All of the bullets listed in the table were measurably destabilized by low incident angle impacts and subsequent ricochet. Only two of the 7.62×39 mm shots came close to retaining and regaining their in-flight stability. All of the others displayed large and widely varying drag coefficient values after impact and yielded correspondingly low ballistic coefficients. This, of course, resulted in very rapid velocity loss after impact. The 9mm, 40 caliber, and 45 caliber pistol bullets ricocheted and remained intact (as evidenced by holes in a downrange witness panel). Typical BC values for these three calibers were on the order of 0.01 to 0.02, with a few examples as low as 0.002 and 0.003.

Considerable variation in velocity loss during impact with the ground was observed for these pistol bullets ranging from as little as 38fps for one of the 45 Automatic shots to as much as 605fps for a 9mm shot. The 5.56mm bullets appeared to fragment on impact. The subsequent Doppler tracks are believed to be those for a major fragment of each bullet. These gave very low BCs values (0.008 and 0.013).

TABLE 13.5 Data from Multiple Radar Tracks of Multiple Projectile Types and Calibers

Description	Muzzle Velocity (fps)	Pre-impact BC (fps)	Velocity Loss (fps)	Overall Post-Impact BC
9 mm Luger Ricochet Performance after Low-Angle Impact with Hard Ground – 115-gr TMJ				
Speer	1453	0.11	82	0.018
<i>Note: velocity at 228 yards from the gun was 312 fps</i>				
Speer	1325	0.12	230	0.010
<i>Note: velocity at 136 yards from the gun was 318 fps</i>				
Speer	1309	0.12	605	0.002
<i>Note: velocity at 100 yards from the gun was 47 fps</i>				
Speer	1371	0.12	230	0.018
<i>Note: velocity at 132 yards from the gun was 549 fps</i>				
Speer	1327	0.12	98	0.024
<i>Note: velocity at 122 yards from the gun was 710 fps</i>				
9 mm Luger Ricochet Performance after Low-Angle Impact with Hard Ground – 147-gr JHP				
Win. Silver Tip	1243	0.17	127	0.022
<i>Note: velocity at 124 yards from the gun was 648 fps</i>				
Win. Silver Tip	1238	0.16	395	0.010
<i>Note: velocity at 124 yards from the gun was 304 fps</i>				
Win. Silver Tip	1267	0.12	300	0.013
<i>Note: velocity at 130 yards from the gun was 492 fps</i>				
Win. Silver Tip	1243	0.16	216	0.017
<i>Note: velocity at 125 yards from the gun was 554 fps.</i>				
<i>Note: Radar tracks for several of these bullets extended out to 180 to 360 yards where the velocities were down to 45 to 55 fps.</i>				
40 S&W Ricochet Performance after Low-Angle Impact with Hard Ground – 180 gr JHP				
Speer	1155	0.19	143	0.025
<i>Note: velocity at 125 yards from the gun was 665 fps</i>				
Speer	1119	0.23	Uncertain	0.013
<i>Note: velocity at 128 yards from the gun was 492 fps</i>				
Speer	1133	0.21	124	0.023
<i>Note: velocity at 125 yards from the gun was 658 fps</i>				
45 Auto Ricochet Performance after Low-Angle Impact with Hard Ground – 230-gr FMJ-RN				
Sierra	964	0.21	447	0.003
Sierra	873	0.13	38	0.036
Sierra	965	0.17	175	0.024
Sierra	894	0.16	49	0.035
Federal	3168	0.23	Uncertain	0.008
Federal	3229	0.23	Uncertain	0.013
Wolf (Pb-core)	2477	0.26	Uncertain	0.11
Wolf (Pb-core)	2467	0.23	90	0.19
Wolf (Pb-core)	2500	0.26	257	0.018
Wolf (Pb-core)	2442	0.35	83	0.17
Wolf (Pb-core)	2451	0.29	161	0.066
M43 (Fe-core)	2411	0.32	47	0.047
M43 (Fe-core)	2425	0.27	Uncertain	0.016

The 7.62×39 mm full-metal-jacketed (FMJ) bullets ricocheted and remained intact, with measured velocity losses ranging from 47 fps to 257 fps on impact. These bullets also fared best at retaining velocity and stability after ground impact although all were destabilized.

The ballistic coefficients derived from this work provide the forensic scientist with a means to evaluate claims of ricochet in other shooting cases. The shallow impact angles of -1 to -2 degrees were selected to minimize bullet deformation and velocity loss on impact. The relatively hard impact surface was chosen for the same reason. Clearly steeper incident angles and/or softer impact surfaces would only increase velocity loss and bullet instability as well as the likelihood of bullet fragmentation.

POTENTIAL PROCEDURE FOR LONG-DISTANCE SHOOTING RECONSTRUCTION

We generally frown on boilerplate checklists because of their inability to adapt to the uniqueness of each investigation. However, because long-distance shooting reconstructions are not an everyday occurrence, the following is given as an option should the inexperienced investigator be in need of guidance:

- I. Data and Information Gathering
 - A. Ascertain the most probable bullet type, caliber, and weight. If there is more than one choice, list each in descending order of likelihood.
 - B. Add choices for maximum and minimum muzzle velocity values for each bullet listed in Section A, along with their sources.
 - C. Add the best estimates of the G_1 BC, along with their sources, to the bullet(s) listed in Section A.
 - D. Obtain available information regarding site location and MET data at the time of the incident. Include the sources of information for
 1. Site elevation above sea level
 2. Temperature
 3. Relative humidity
 4. Barometric pressure
 5. Wind speed and direction
 - E. Describe all available terminal ballistic information, such as
 1. Penetration depth
 2. Azimuth angle
 3. Vertical angle
 4. Location of bullet impact site
 5. Scene geometry (particularly along the projectile's approach path)
 6. Amount of deformation to the projectile
 7. Orientation of the projectile at impact
 8. Location and nature of any diagnostic trace evidence on the bullet
 - F. Describe and be prepared to evaluate any audio recordings of the shot and/or the bullet's arrival (impact/passage by microphone).
 - G. Describe and be prepared to evaluate any earwitness's recollection of the shot and/or the bullet's arrival or passage near any such earwitness.
- II. Computations
 - A. Carry out multiple exterior ballistic calculations for each bullet over a suitable range of distances using an exterior ballistics program known to produce satisfactory results.
 - B. Prepare a table containing
 1. Downrange velocities at selected distance intervals
 2. Bullet drop at the same selected distance intervals
 3. Bullet path at the same selected distance intervals
 4. TOF for each distance
 5. Calculated departure angles for each distance
 6. Calculated angle of fall for each distance
 7. Lagtime for each distance

- C. In the heading for the table from Section II-B, include name and version of the exterior ballistics program used, BC value and muzzle velocity employed for these calculations, site elevation and MET data entered in the EB program, and speed of sound at the chosen temperature.
- D. Describe or denote the range of fire (distance values) that most closely corresponds to the known information (e.g., angle of fall, impact velocity estimate, lagtime derived from an audio recording).
- E. Redo Steps II-A and II-B as deemed necessary or desirable using modified muzzle velocities, BCs, and/or MET data.
- F. Compare the results with previous results.
- G. Incorporate the results and information in all of the foregoing sections and steps into the appropriate case file.

CASE EXAMPLE

An individual standing next to a white car in the parking lot of a restaurant suffered a superficial gunshot wound in the upper leg. The victim reported hearing a whizzing sound followed by a *toink* sound immediately prior to being shot. The bullet was recovered on the ground at the scene; see Figures 13.8(a) and (b). A small oval defect was observed on the upright side of the vehicle; the impact site is shown in Figure 13.8(c).

Take a moment to think about possible avenues of investigation. What observations need to be documented immediately, and what will need to be recorded later? Here are some immediate concerns:

1. Photo-documentation
2. Chemical testing of the suspected impact site

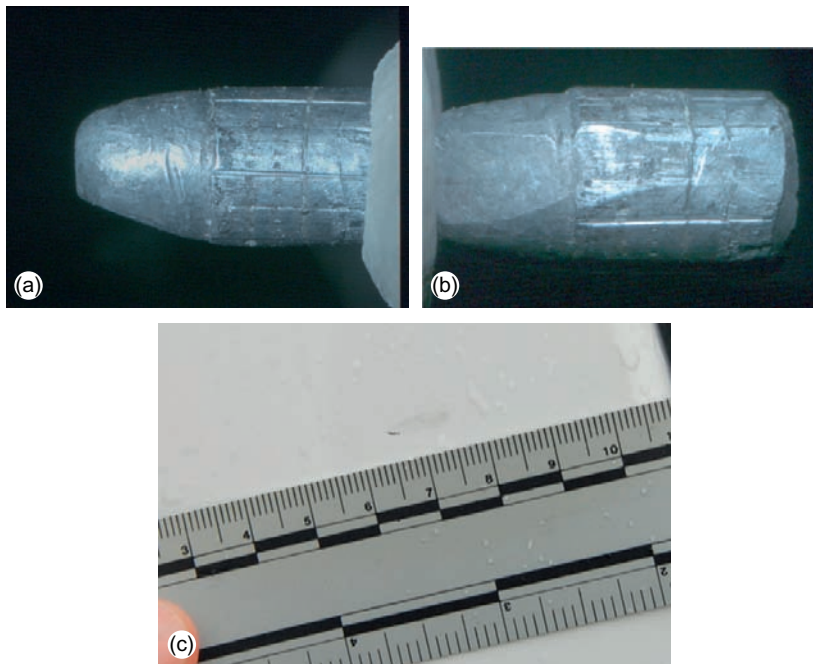


FIGURE 13.8 (a) Side view of a 22 long-rifle caliber bullet showing the damage to the ogive. (b) View of opposite side of same bullet showing the damage to the ogive. (c) Elliptical impact to the side of the vehicle.

3. Documentation of the azimuth and elevation reached from observation of the impact site (including orientation and location of the car)
4. Assessment of the type of impact involved (yielding versus unyielding)
5. Field examination of the bullet

Actions for later include

1. Collection of meteorological data for the time of the event
2. Laboratory examination of the projectile
3. External ballistic calculations

From examination of the projectile, one would hope to gain information on the caliber, cartridge type, and firearm (based on rifling characteristics); terminal ballistics information regarding the impact; estimated ballistic coefficient; and estimated muzzle or impact velocity. Impact velocity estimates may be related to the terminal ballistic event.



FIGURE 13.9 View directly down on the bullet in place as it struck the vehicle.

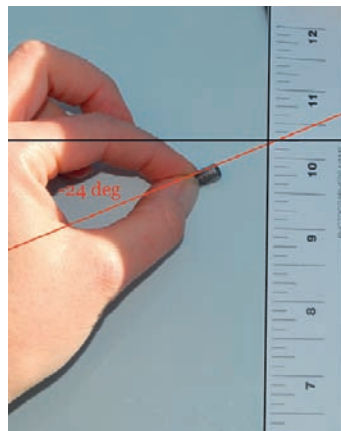


FIGURE 13.10 View perpendicular to trajectory, with the vertical plane flat in the field of view.

In this case, the bullet is a .22 long-rifle caliber, plain lead, round-nose. It exhibits a flat spot on the ogive that should tell the reader that its terminal ballistic interaction was with an unyielding surface. While car bodies most typically behave like yielding surfaces, a quick look at the impact defect shows that there is no deformation of the metal.

In Chapter 9, on ricochet, it was seen that the best representation of angle of impact is the damage to the bullet when dealing with unyielding surfaces; for this reason, and in *this particular case example*, the best way to determine the azimuth approach angle is to physically place the bullet back at the impact site. As seen in Figure 13.9, the flattened area on the ogive allows the bullet to rest in an orientation close to that at the moment of impact.

Taking a view directly uprange along the axis of the bullet allows determination of an azimuth angle of impact in this case, but other coordinate systems or measurement techniques can also be employed. Aerial photography or satellite imagery provides a method of plotting out the azimuth trajectory.

The remaining, and most difficult, step is determining an originating distance along the azimuth, from which the bullet came. One of several methods for this can be based on angle of impact. Referring to Figure 13.10, the vertical angle, or angle of fall at the time the bullet struck the car, was approximately -24 degrees.

Using an estimated muzzle velocity for common .22 long-rifle caliber bullets, sample “shots” are fired with exterior ballistic software. Tabulated results are shown for shots ranging in distance from 330 to 2300 yards in Table 13.6.

TABLE 13.6 Tabulated Results for Multiple Simulated “Shots”

Distance (yd)	Distance (ft)	Angle of Impact	Velocity at Impact (fps)	Angle of Departure	Time of Flight (s)
330	990	1.2	789	1.0	1.1
800	2400	4.8	575	3.2	3.2
900	2700	5.9	541	3.9	3.7
1000	3000	7.3	508	4.6	4.3
1100	3300	8.8	478	5.3	5.0
1200	3600	10.7	451	6.2	5.6
1300	3900	12.8	426	7.1	6.3
1400	4200	15.2	404	8.2	7.1
1500	4500	18.1	384	9.4	8.0
1600	4800	21.3	367	10.6	8.9
1700	5100	25.1	353	12.1	9.9
1800	5400	29.4	342	13.7	10.9
1900	5700	34.2	334	15.5	12.1
2000	6000	39.5	329	17.6	13.4
2100	6300	45.3	327	19.9	14.9
2200	6600	51.5	326	22.5	16.6
2300	6900	58.1	329	25.6	18.6



FIGURE 13-11 Overhead image incorporating approximate distances from which the shot could have been fired.

The angle of fall (downward at 24 degrees) from the actual impact examination can be compared with the tabulated/simulated shots. For simulated shots fired between 1500 and 1800 yards, the angles of fall are comparable to the angle of fall documented at the scene. A report describing the result should include a visual reference, such as in Figure 13.11, indicating an area of interest to investigate.

In a discussion of long-distance shooting reconstruction, it is important to convey the many variables that lead to a certain amount of inaccuracy. Rarely can the forensic investigator calculate a shooter's location within a 100-yard area when the overall distance traveled by the projectile is in excess of 1000 yards. However, it is important to realize that such calculations direct investigators to more focused areas in which to look for additional bullet impact sites, fired cartridge casings, or zones where "shots fired" calls may have been recorded.

SUMMARY AND CONCLUDING COMMENTS

The most important first step in any effort to identify a point, or more correctly, an area of origin for any long-distance shot is exclusion. Determining from where the shot could *not* have come allows us to focus on more productive matters.

Aside from pure luck and/or informants, any hope of solving a long-distance shooting should include:

- Information regarding the appearance of the entry wound
- Detailed description of the wound track, the structures involved, and the depth of penetration, as well as recovery and subsequent examination of any clothing perforated by the bullet
- Careful examination of the bullet for evidence of ricochet or deflection prior to producing the wound, and any evidence of its orientation at the moment of impact with the victim (or nearby intervening object(s))
- Careful examination and evaluation of the scene to isolate zones or corridors from which the injury bullet could and could not have approached the victim
- Careful search of the scene for any bullet-caused damage that could provide directional information regarding the path of the incoming bullet
- Any recollections of witnesses as to any distant sounds shortly before or after the victim received the injury (its character, loudness, and timing)
- Any serendipitous video or audio recordings that might include the sound of the shot and the arrival of the bullet

CHAPTER KNOWLEDGE

- What is a ballistic coefficient, or a drag function?
- Which do you think would be more likely to perforate a piece of sheet metal after freefall: a 147-gr, 9 mm Luger bullet or a 150-gr, 308 Winchester bullet? Are you considering stability during decent?
- Do you recall the meaning of near-zero and far-zero? How does this concept relate to possible calculations of lagtime?

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Cartridge Case Ejection and Ejection Patterns

INTRODUCTION

With automatic and semiautomatic firearms, the location of expended cartridge casings can be important in establishing the approximate location of a shooter's firearm when one or more shots have been fired. It may also be possible to determine whether a shooter moved from one location to another, or failed to move in any significant way, during the discharge of multiple shots. The value of cartridge casing locations improves if one also has an azimuth line or direction of fire for the associated shots.

Ejected cartridge casings may acquire trace evidence deposits if they strike nearby surfaces with sufficient force and the surface is of a type that generates transfer evidence. The paint on most interior walls of houses and office buildings is a good example of such evidence and can be seen in Figure 14.1. In this particular case, an altercation over a gun took place in the entrance to a residence. The red paint adhering to the mouth of the cartridge casing confirmed accounts of the gun having been discharged in close proximity to the wall.

In some instances, where the impact force is sufficient, the mouth of the ejected cartridge casing may leave a faint, crescent-shaped indentation in the struck surface. Such marks are



FIGURE 14.1 Red paint on the mouth of a 7.62 × 39 mm cartridge casing.

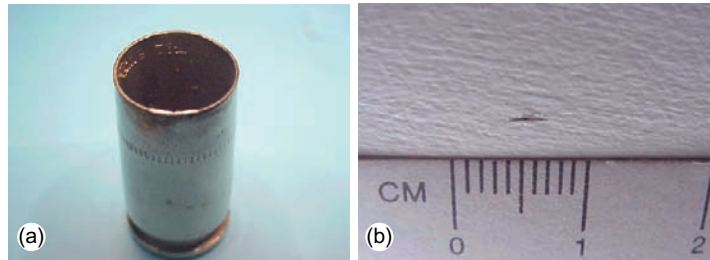


FIGURE 14.2 (a) Fired cartridge casing with adhering paint on the mouth. (b) Shallow impact mark in a painted surface from an ejected cartridge case.

- (a) This 9 mm cartridge case was found on the floor of a shooting scene. Only through careful handling and preservation was the adhering white paint preserved. It is visible on the mouth of the cartridge at the 6 o'clock position. A corresponding crescent-shaped impact site was found many months later when we examined the scene. This mark, combined with the correspondence in color and composition of the paint and the ejection characteristics of the gun, allowed the approximate position of the shooter to be established.
- (b) This crescent-shaped indentation (just above the 0.5-cm mark) in a painted wooden surface at a shooting scene was caused by the impact of an ejected cartridge case. Given their small size, such marks can be difficult to locate and are often overlooked, but they can be very useful in refining the shooter's position.

very subtle and no doubt go unnoticed by many scene investigators. However, combined with the ejection characteristics of the gun used, they can refine the gun's positioning.

Figures 14.2(a) and (b) show an expended cartridge casing with adhering paint on its mouth and the corresponding crescent-shaped mark impressed in the Sheetrock wall within a few feet of where the pistol was fired. From a brief study of the first photograph it should be apparent how delicate this trace evidence is and how easy it would be to lose it by careless handling or improper packaging.

SCENE WORK—TERRAIN/SUBSTRATE CONSIDERATIONS

The issue of cartridge casing location at a shooting scene might seem straightforward. Customarily, each casing's location is entered in a suitable coordinate system followed by individual packaging in appropriate containers. Except for photographs, however, the *nature* of the surface on which such cartridge casings were found is seldom recorded. Examples: "uncut grass, victim's front yard; yard slopes toward the street about -2 degrees"; "level asphalt parking lot with much exposed aggregate"; or "thick green shag rug in living room."

Photo-documentation and a description of the surface are needed because they are of considerable interest and importance in assessing:

- How an expended cartridge casing came to be in a particular location. (e.g., uneven terrain, with significant elevation changes in the area of deposition, versus level terrain).
- How much additional movement, if any, the ejected cartridge casing could have experienced after its initial impact with the substrate (e.g., essentially no further movement would be expected with soft soil or sand; however, a casing may continue to bounce several feet or even yards over smooth concrete).

- How certain trace evidence, physical damage, or changes to the cartridge casing might have been acquired or have been caused (e.g., an ejection port of a semiautomatic pistol within a few inches of a brick wall at the moment of discharge, leaving abrasive damage on the casing with corresponding red mineral inclusions).

Cartridge casings ejected over hard surfaces such as asphalt and concrete will usually show several small impactive sites on the case rim and/or case mouth when examined under a stereomicroscope. If the cartridges were fired from a fast-moving vehicle driven over the same type of surface, these “dings” will be numerous. They often contain small amounts of embedded trace evidence characteristic of the surface on which they fell. With a little experience and test firing over the same type of surface, the examiner can come to recognize this “damage” and differentiate it from later post-impact damage such as described in the next section.

Relocated Cartridge Casings

Post-ejection events *must* be considered prior to any interpretation of the location of a recovered cartridge casing. These include being stepped on or run over by vehicles, events that might cause a fired cartridge case to be moved. Fortunately, the generally soft nature of cartridge casings makes them quite susceptible to impact damage, abrasion, and/or deformation if stepped on, run over, or kicked. These actions *usually* (but not always) leave evidence on or in the cartridge case—for example, multiple deep abrasive gouges in the case wall and/or crushing of the case mouth. These marks, once recognized, evaluated, and properly interpreted can indicate whether or not the casing has gone through a normal extraction/ejection cycle.

These same marks and the trace evidence embedded in them may also provide clues to the type of surface on which the cartridge casing fell or surface against which it was ejected. The laboratory examiner *must* study the marking left on fired cartridge casings during the extraction/ejection cycle of the responsible gun. This should be done using cartridges of the involved *brand* and *load* and after inspecting them to make sure they are free from any manufacturing or other marks that might be confused with marks generated by a firearm.

The isolation and elucidation of other firearm-generated marks, such as magazine lip or latch marks, chamber marks, and/or slide scuff marks, will also be necessary so as not to confuse them with those actually associated with the extraction/ejection cycle. Laboratory familiarity with ejection port dings is also of critical importance because they can crush the mouth of a cartridge casing. These dings are certainly post-firing, but are not the consequence of relocation damage.

Firearm–Ammunition Performance

In semiautomatics and machine guns, certain requirements of impulse to the bolt or slide followed by adequate impactive forces to the cartridge case from the ejector must be met to properly extract and eject the case from the gun. These requirements are directly related to the condition of the gun as well as to the performance of the ammunition during discharge. The corresponding marks on the casings leave a variety of clues regarding the normal/proper performance of both the ammunition and the gun.

Examples of marks left on casings and other characteristics that indicate whether a casing was fired in a normal manner include cartridge casing expansion, firing pin drag, breechface impressions, extractor marks, ejector marks, chamber marks, and/or ejection port dings. Cartridge casings experiencing abnormally high- or low-pressure excursions in performance during discharge often reflect such events in the markings on the casing and/or the casing's degree of expansion when fired.

Comparison of the various markings on evidence cartridge casings with those produced on test-fired cartridges of the same brand, type, and load fired from the same gun permit assessment of which variable or firearm component may be responsible for a particular event under investigation. Varying selected parameters such as bullet weight or powder charge allow one to evaluate the role in or contribution to ejection pattern of any particular ammunition parameter of interest to the examiner. Note that this statement is not an invitation for someone inexperienced in ammunition loading to assemble cartridges of unreasonable or uncertain pressures because there can be a high degree of risk associated with such endeavors.

REVIEW OF MARKS ON FIRED CARTRIDGE CASINGS

Figure 14.3 summarizes nearly all of the markings that might happen to a fired cartridge casing. Some of these are or may be generated *prior* to discharge, and are included in the

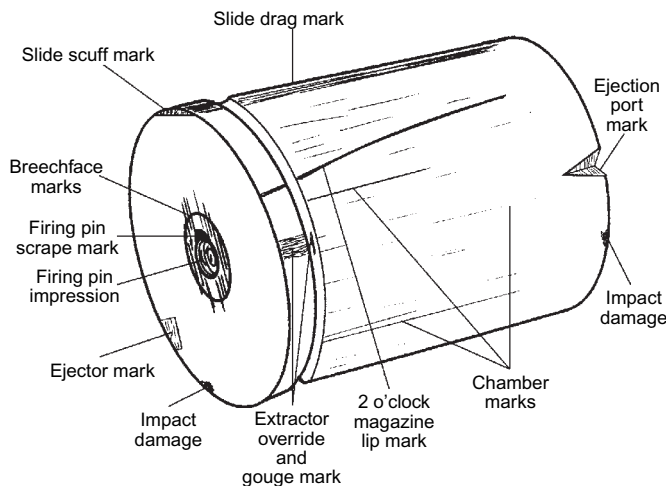


FIGURE 14.3 Marks on fired cartridge cases.

This figure summarizes the various firearm-induced marks that can be found on cartridge cases that have been chambered, fired, and ejected from a semiautomatic pistol. Many of them possess individuality and can be associated with the responsible firearm. Others have reconstructive value and allow one to determine how the cartridge came to be loaded in the firearm (e.g., manually inserted in the chamber or stripped from a magazine after slide retraction as shown). Any impact damage as a result of ejection over hard surfaces such as concrete and asphalt usually takes the form of small dings around the mouth and/or rim of the cartridge case. Two such areas of impact damage are shown. These often contain minute particles of mineral material that can be further characterized under a suitable microscope.

general category of *chambering* marks. They may occur while the live cartridges are retained in the magazine of the firearm (e.g., latch marks on the head of a shotgun shell when it becomes the next cartridge to be chambered). They *may* occur as well while the bolt or slide of a semi-automatic pistol is *retracted* and its underside drags along the length of the top cartridge in the magazine (i.e., slide drag mark) or when the cartridge is stripped from the magazine (i.e., magazine lip marks). Scuffs on the cartridge case body and/or its head (e.g., a 12 o'clock slide scuff mark) may occur as the breechface impacts the 12 o'clock position of the head of the top cartridge in the magazine, as it is forced up the feed ramp and into the chamber.

Depending on how the gun is designed and how it has been loaded, the extractor may strike the head/rim area of the cartridge casing, ride up and over the rim, then snap down into the extraction groove, leaving as many as three marks. A cartridge dropped in the chamber, followed by the release of the slide into the battery, stands the greatest likelihood of creating these types of marks on pistol cartridges. Such a chambering process could be repeated multiple times, creating numerous marks of interest, but *none* the consequence of cartridge casing extraction. If the gun's design calls for the cartridge to slip under and behind the extractor during loading, then the only mark produced by the extractor at this point might be a small nick or gouge in the bottom of the extraction groove or immediately next to the rim in cartridges lacking an extraction groove.

Finally, during the discharge phase the extractor *may* produce an indentation on the forward-facing side of the rim as it forcibly pulls the cartridge casing from the chamber. This type of mark is particularly likely with locked breech guns as opposed to straight blowback guns. The extractor in a straight blowback design is not functional because the cartridge casing is literally blown out of the chamber. An extractor is present in blowback guns to allow for extraction of live cartridges from the chamber during unloading. Chamber markings (or additional chamber markings) may be acquired, particularly in blowback guns, during this phase as the swollen cartridge casing is expelled rearward out of the chamber.

Finally, the head of the cartridge casing is ultimately struck by the ejector, typically causing the casing to pivot around the extractor or simply to be knocked clear of the breechblock. With manually operated guns (e.g., bolt-action or lever-action rifles), an ejector mark may not be visible simply because of the greatly reduced force with which cartridge casings typically strike the ejector, as compared with semi- or fully automatic firearms. During their final exit, the cartridge casings may strike one or more areas around the margin of the ejection port and acquire additional marks as a consequence.

With some firearms this occurs with great regularity and reproducibility, and leaves an outstanding mark on the body of the cartridge casing or adjacent to its mouth. For these reasons, ejection port dings are often identifiable as having been created by a specific firearm. The fact that the casing is striking areas on the gun during ejection greatly affects the fired cartridge's ejection characteristics. These types of marks typically cannot be created except in an actual firing.

For normally generated marks on cartridges, the examiner should design a testing protocol that will isolate their source and production. This is important for a number of reasons. First, the examiner should be prepared to state whether the fired cartridge appears to have been *normally* chambered, fired, extracted, and ejected. Second, any atypical or foreign marks deserve to be explained since they may be important and may relate to some nonstandard use of the firearm or to some misadventure such as restricted or retarded slide travel.

A situation where this might be important is a purported struggle over a gun. A weak hold with some recoil-operated guns, for example, may reduce the slide travel and result in a weak strike by the ejector, with a corresponding reduction in ejection distance and/or direction. This *may* occur in awkward holds on a pistol with self-inflicted shootings or accidental discharges during unsafe handling. A suggested laboratory protocol is as follows:

1. Obtain cartridges of the same brand and type as those involved in the incident. Disassemble an evidence cartridge and one of the reference cartridges to ensure that powder morphology and quantity are in agreement. If available and of sufficient quantity, use evidence ammunition for testing. As an alternative to disassembly, a volley of at least a few shots of both evidence and exemplar ammunition should be fired together to determine if the pattern is affected by the difference.
2. Examine and select cartridges free of any preexisting marks that might later be confused as having been produced during the cycle of loading, firing, extraction, and ejection.
3. To examine magazine lip marks, and if the firearm uses a detachable magazine, load some of these cartridges in the magazine and then, with a nondefacing tool such as a pencil eraser, strip them out of the magazine by pushing against the head at the 12 o'clock position. As each cartridge comes up to the top of the magazine, place a suitable index mark on it so the source and position of any magazine lip marks can be ascertained.
4. To examine chambering marks from the feeding process, chamber a few cartridges using the full-forward force of the slide, but remove them gently from the chamber so that feed ramp marks, slide scuff marks, chamber marks from the loading process, and extractor marks from the initial phase of this process can be isolated. It may be useful to do this by inserting the magazine with the slide locked back, as opposed to retracting the slide over a previously inserted magazine containing cartridges. A slide drag mark can only occur with the latter method. Its presence or absence may be important when intercomparing cartridge cases from a multishot incident.
5. Insert a cartridge in the chamber by hand and close the action to look for any extractor override marks. It may be desirable to vigorously cycle several live cartridges through the gun's action to see if, by this means, a visible ejector mark can be left in the head of a live cartridge. This should be done with the utmost care, with the gun pointed downrange. It is also advisable to keep one's hand clear of the ejection port in case some malfunction or alteration allows the ejector to strike the primer and possibly discharge the cartridge. A live cartridge, with its projectile and propellant charge, is much heavier and possesses more momentum than a fired cartridge casing. For this reason, live cartridges cycled through guns at shooting scenes may acquire an ejector mark. This may be of value for live cartridges found at a scene or in verifying that an ejector mark in a fired cartridge is indeed the consequence of discharge and not some previous cycling through the gun's mechanism.
6. Obtain test-fired cartridge casings using a normal or firm hold, making provisions to capture them before they impact hard surfaces.
7. Obtain test-fired cartridges with any alternate holds deemed appropriate or germane to the incident under investigation. Capture them in the same manner and compare the markings with the previous cartridges.

8. If appropriate, obtain test-fired cartridges from semiautomatic pistols with the slide delayed or restricted. This can be accomplished by wrapping multiple rubber bands around the slide and frame. The additional force for slide retraction can be measured with a force gauge.

An often important factor to consider is the number of cartridges that were in the firearm at the time of the shooting. When setting up for a test firing, load the gun to the same load condition as involved in the incident (if known). While this rarely makes a practical difference in how cartridge casings are ejected, it is possible that the amount of pressure exerted on a casing being ejected by cartridges remaining in the magazine will affect the pattern. This is highly dependent on whether the particular mechanism of the gun allows the top cartridge to touch the departing casing, but by testing the firearm in the same condition it was in during the incident, this factor is easily accounted for.

For example, a law enforcement officer's training will typically dictate that his handgun be loaded to the fullest possible condition. Thus, a full-size Smith & Wesson M&P9 pistol will be loaded to 17 + 1, meaning seventeen cartridges in the magazine and one in the chamber. However, a shotgun or urban rifle carried in a car or trunk will commonly be in a "cruiser carry" condition, meaning that the chamber is left empty but the magazine is fully loaded. Attention to the loading configuration of an officer's gun is one of the very few saving graces in investigations of officer-involved shootings (OISs), as compared to investigations of more "everyday" shootings.

That having been said, we have come across many instances where certain officers are not as conscientious as they should be when carrying a firearm. We have seen underloaded magazines, the wrong ammunition, or firearms in poor or inoperable condition. In cases like these, a thorough review of statements, depositions, and scene notes is critical. As mentioned in other chapters, proper, thorough photography of involved firearms and note taking at a scene are crucial to a good investigation.

When considering the number of times to test-fire a firearm in an ejection pattern test, there is no set standard; however, the investigator should place himself on as firm a statistical footing as possible. Our common rule of thumb is to replicate the scenario of the shooting a *minimum* of 10 times. In other words, if the previously mentioned M&P9 shooter started off with a 17 + 1 load condition, and fired 3 shots in the event, it would be wise to fire the gun from this condition 3 times, then reload to the 17 + 1 condition. This should be repeated another 9 times for a total of 30 shots fired.

The investigator would be wise to remember that, from a statistical standpoint, the number of fired cartridge casings recovered at a scene should have some bearing on his confidence in the firearm.

In the case of a stationary shooter, for example, a cluster of 10 fired casings holds more weight in positioning a shooter in a scene than a single fired casing, because the cluster allows for an evaluation of the spread, or uncertainty, for that gun-ammunition combination. A single casing should not hold as much weight, not only because the amount of deviation for the gun-ammo combination cannot be accounted for but also because a single casing is easier to move (by responding officers, medical personnel, etc.) than an entire cluster. Following this logic, a string of 15 cartridge casings over a span of 60+ feet cannot realistically be accounted for by accidental kicking. A scenario such as this is indicative of a shooter in motion.

LABORATORY EXAMINATION OF EJECTED CARTRIDGE CASES

Insofar as questions and issues regarding cartridge case location and ejection patterns are concerned, the laboratory examination of fired cartridge cases should include the following:

- Inspection of the interior of the cartridge case for foreign debris (dirt, sand, water spots, spiderwebs, etc.) in order to address the issue of “freshness” or signs of exposure to environmental conditions.
- Inspection and description of the exterior of the cartridge case for adhering foreign debris (dirt, mud, sand, water spots, stains, etc.) and surface shine versus tarnish.
- Checking for any out of roundness of the case mouth or case body, which might be indicative of post-fire crushing.
- Inspection for any abrasive or impactive effects with nonfirearm-related surfaces. (With impacts on concrete and asphalt, the rim and/or the mouth of the cartridge case typically receives one or more rough dings or indentations, often with small particles of embedded mineral material, in these areas).
- Examination of any gouged or striated areas on the case wall that are not firearm-related. (from, say, the case being kicked while resting on a hard surface or being run over by an automobile, either of which tends to leave characteristic damage in this area).
- Assessment of any other form of adhering trace evidence such as paint, plaster, or stucco that might be associated with a surface the cartridge case impacted after discharge.

Documentation of any of these phenomena by sketches and/or photography is important, particularly in situations where trace evidence is seen adhering to the cartridge case because this evidence can easily be dislodged during subsequent handling and examination.

General Protocol for Ejection Pattern Testing

Test-firing the actual firearm with the same type of ammunition in an open area with a prearranged coordinate system will be necessary. Both circular and Cartesian (rectangular) coordinates have been used for this purpose. We routinely use the Cartesian coordinate system, with the intersection of the x -axis and y -axis directly below the firearm’s muzzle or ejection port and the y -axis aligned with the barrel. The use of the muzzle is usually preferable because it is typically the same reference point used in gunshot residue determinations.

Additionally, the cartridge casing locations can be measured to the nearest half foot. Documentation to the nearest inch is unnecessary given the level of accuracy that will be attributed to the final conclusion. Once again, the fact is that a conclusion of firearm/shooter location based on ejection patterning is not going to have the accuracy attributed to trajectory assessments.

Multiple metal tape measures are laid out on the surface to form the x/y -axis and to provide a grid for later measurements. The proper positioning of the gun relative to the coordinate system can be accomplished by dropping a plumb line from the trigger guard or other suitable location to the designated spot on the surface. Alternatively, a tripod can be set up so that the gun can be held at the appropriate location. A preselected aiming point should be established to achieve the desired vertical angle. For example, if the shooting event is

believed to have involved a 45-degree downward shot or shots, an aim point that yields a downward 45-degree barrel angle should be employed.

For most shooting events, an aim point yielding a horizontal (0-degree) barrel angle would be used. Gun height or the shooter's position (prone, kneeling, or standing), gun rotation, and possibly even the nature of the hold on the gun may need to be considered and varied to properly evaluate the implications of cartridge casing location(s) at a shooting scene. Once again, it is important to realize that given the accuracy of ejection patterning, differences in results from variables typically come from drastic, not subtle, changes in setup.

The further study described here could be used as an experimental model for case evaluation. Several firearms were chosen based on their relatively unique ejection characteristics. A Glock 27 was chosen as a classic example of right and rear ejection. An '08 Luger was chosen for its 12 o'clock extractor and 6 o'clock ejector. (This configuration typically sends fired cartridge casings up and directly over a shooter's head.) A Walther P38 was introduced because the ejection pattern is reversed from the classical pattern: The ejector and extractor are on opposite sides from "normal," a configuration that disperses cartridge casings to the left of the gun under typical circumstances.

Test firings were conducted in five pitch variations. Straight downward (-90 degrees; Figure 14.4(a)), downward at a -45 -degree angle (Figure 14.4(b)), horizontally (normal orientation; Figure 14.4(c)), and directly upward ($+90$ degrees; Figure 14.4(d)). Figures 14.4(e), (f), and (g) show results of the tests, including one at an upward, 45-degree angle. A forklift was employed to allow the shooter's legs a degree of safety for the downward shots and to hold a Kevlar-filled capture box for the upward shots.

The overall lesson to be learned from the evaluation of these data is that the most expected result of a tipped-down muzzle is the more forward ejection of cartridge casings. Conversely, a significant rise of the muzzle tends to bring the pattern back toward the feet of the shooter.

The nature and behavior of the surface on which the evidence cartridge casing(s) falls is yet another consideration. A cartridge casing falling on smooth sand will remain at its initial impact site, but the same casing landing on concrete will seldom, if ever, do so. The cylindrical shape of cartridge casings, their displaced centers of gravity, and their propensity to rebound from hard surfaces—all of these factors, with most surfaces, combine to send the casings off from the initial impact site in various directions.

The fired cartridge casings themselves emerge from the ejection port of the gun with a tumbling motion, and at departure angles and velocities that can vary slightly from shot to shot. The net effect is that a series of fired cartridge casings will land in an *area*, but not a fixed spot. The size, shape, and location of this area become the subject of ejection pattern testing.

The reproducibility of the ejection pattern for a particular gun-ammunition combination is illustrated in Figure 14.5, an aerial view for three consecutive cartridge casing ejection patterns for a 9mm Model 92F Beretta pistol fired over a nonresilient surface (uncut grass). Note the height change for Group 3 and its minimal effect on ejection pattern for this particular gun-ammunition combination.

Figure 14.6 shows a more complicated pattern for a .40 S&W pistol fired over level asphalt. The dashed lines represent the path from the initial impact point with the asphalt (*diamonds*) to their final resting positions (*circles*). In most investigations the final position of rest is the



FIGURE 14.4 (a) With the firearm still over the x/y -axis, a downward angle of 90 degrees is attained. (b) Downward angle of 45 degrees while the firearm is oriented over the x/y -axis. (c) Shooting under “normal” conditions.



FIGURE 14.4 (d) As viewed along the y -axis, test firing with the firearm in a $+90$ -degree (straight-up) orientation.

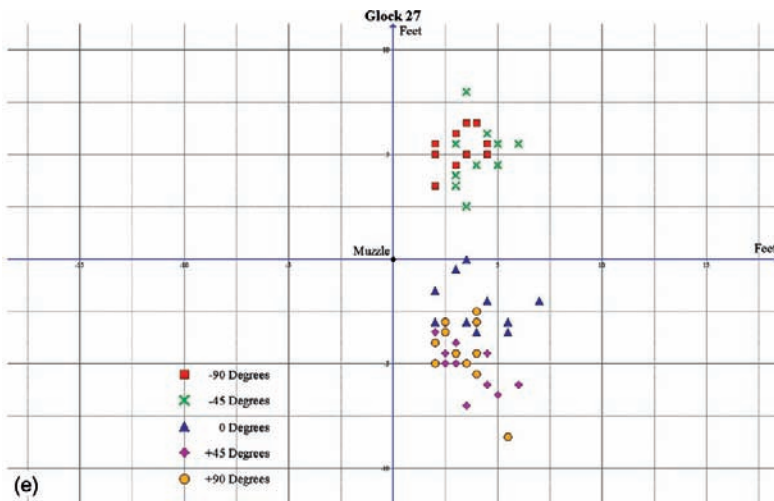
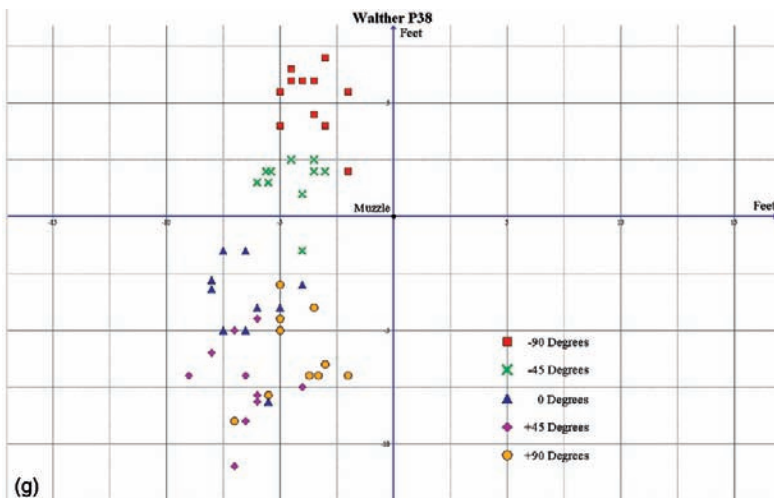
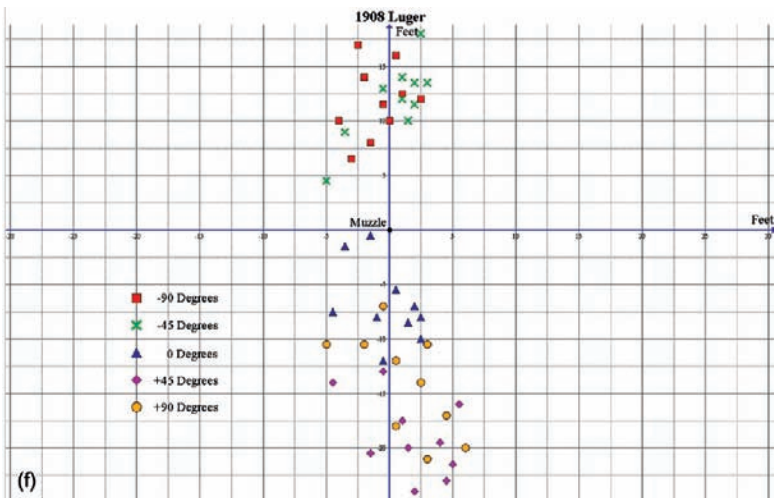


FIGURE 14.4 (e) Ejection pattern resulting in various orientations for a Glock 27. (f) Ejection pattern resulting in various orientations for an '08 Luger. (g) Ejection pattern resulting in various orientations for a Walther P38.



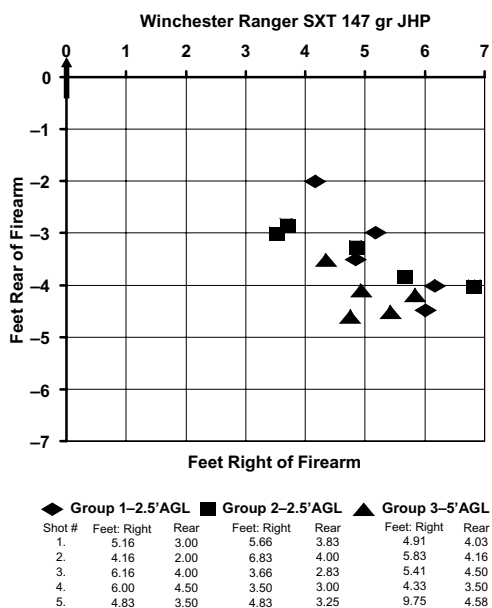


FIGURE 14.5 Reproducibility of a cartridge case ejection pattern.

This plan view shows three consecutive cartridge case ejection patterns for a 9 mm Beretta pistol fired over a non-resilient surface (uncut grass). The gun position is at the 0/0-axis intercept point, with the arrow indicating the direction of fire. Note the height change for Group 3 and its minimal effect on the ejection pattern for this particular gun–ammunition combination.

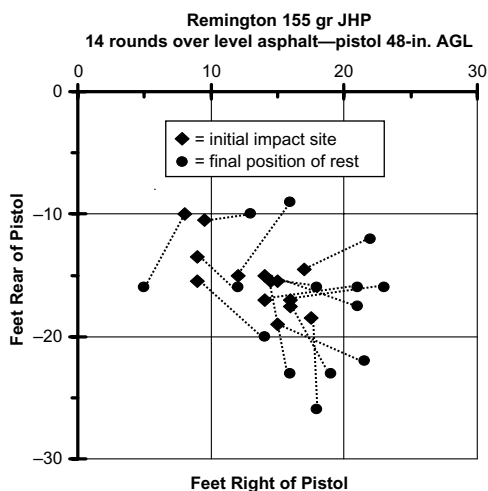


FIGURE 14.6 Cartridge case ejection pattern over a hard surface.

This diagram shows the pattern for a .40 S&W pistol fired over level asphalt and the effect of impact with a hard and somewhat uneven surface. The gun position is at the 0/0-axis intercept point. All of the fired cartridges were ejected to the right and rear of the pistol when fired in the normal configuration and with the barrel parallel to the substrate. The dashed lines represent the path from the initial impact point with the asphalt (*diamonds*) to the final positions of rest (*circles*).

pattern in which we are interested, but a study of this type is useful to appreciate and understand post-impact behavior.

An assistant will be needed in such a study to promptly identify and mark the initial impact site after each shot. This must be followed by a means of associating the particular cartridge casing with the specific impact site. The assistant can also provide information on the typical heights (if any) to which the ejected cartridge casings rise above the level of the gun. This can be important if there is the possibility or question of a fired cartridge casing passing over a fence or the roof of a car before landing on the ground.

Setting up a video camera at the same height of the gun, and at an appropriate position and distance behind it, can be useful in several ways. When properly positioned, the camera can record the flight characteristics as well as the behavior of the cartridges after ground impact. If photography of the final pattern of ejected cartridge casings is contemplated, the casings' positions should be identified with suitable markers. Once the markers are in place, at least one photograph should be taken from behind the pattern, with the shooting position in the field of view, and another should be taken with a profile view of the pattern and shooting position. (See Figures 14.7(a) and (b).)

Figure 14.8 (page 260) shows the effect of pointing the particular test firearm downward at a 45-degree angle compared to the same pistol fired parallel to the terrain. The general ejection characteristics of most semiautomatic pistols are either right or right and rear. In these situations, when such a pistol is pointed down, the rearward component is shortened with the result that the fired cartridge casings impact the surface further and further forward as the downward angle is steepened.

Additional study of how pitch (up and down) variations affect ejection patterning can be carried out with several types of firearms.

Cartridge Casings Ejected from Moving Vehicles and/or Firearms

The behavior of various cartridge casings ejected from moving vehicles traveling over common asphalt at speeds ranging from 10 to 40 mph was studied. As one might expect, the increasing speed of the vehicle increases the scatter of the casings and continues to move their final resting place further and further away from the launch or ejection point in the direction of the vehicle's travel.

Microscopic examination of the brass cartridge casings showed increasing damage with increasing vehicle speed in the form of multiple dings. Increased vehicle speed also corresponded to an increasing number of sites of embedded mineral material from repeated impacts with exposed stones in the asphaltic concrete. This impact damage quickly exceeded what was found with an ejection over the same surface from a stationary position.

With adequate testing it may be possible to set some limits on the speed of moving vehicles from which shots are known to have been fired based on the distribution of the fired cartridge casings relative to the trajectories of the shots and the damage the casings have sustained.

Movement of the firearm itself can cause a difference in the final rest locations of cartridge casings. This may be encountered when a shooter thrusts a gun forward or pulls it rearward during the firing cycle. As an example, a Walther PPK, .380 Automatic pistol was fired in a stationary, normal orientation and then fired repeatedly under two "in motion" scenarios. The first was a simple thrust-forward action; the second, a strong forward thrust.



FIGURE 14.7 Photographs of two cartridge case ejection patterns that allow one to better visualize them.



- (a) This photograph shows a profile view of the pattern for a 9 mm pistol fired over level ground (coarse sand). Numbered markers have been placed over each of the fired cartridge cases. The tape measures provide a coordinate system and a means of measuring the position of each cartridge case relative to the point immediately below the pistol's ejection port. The tripod is used as a reference point for the positioning and repositioning of the gun for each shot. The shooter's hands are barely touching the top of the tripod as each shot is fired. A plumb bob and line of a selected length suspended from the shooting hand and oriented over the 0/0-axis point can also be used for this purpose.
- (b) This photograph shows the same pattern with the camera positioned in front of and slightly to the right of the shooter. The numbered markers for these 10 shots have been turned to face the camera. A view from behind the gun and shooter accomplishes the same end.

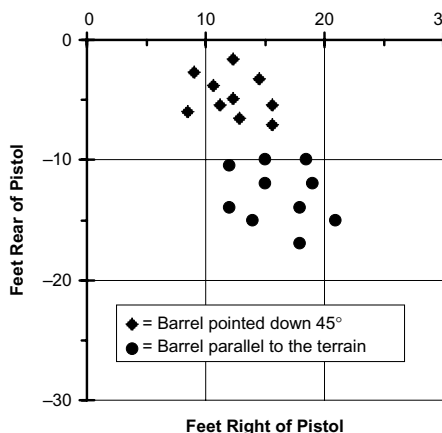


FIGURE 14.8 Cartridge case ejection pattern: The effect of vertical angle changes for a .40-caliber Glock fired over coarse, level sand with Winchester 180-gr JHP ammunition.

This pistol was fired 10 times with a conventional grasp and with the barrel 48 inches above and parallel to the terrain. An additional 10 rounds were discharged with the pistol pointed down at a 45-degree angle and a height above ground level of 32 inches. These results are typical for most right-rear ejecting guns in that a downward shooting angle moves the pattern of ejected cartridge cases forward.

As shown in Figure 14.9, the forward motion of the gun was imparted to the casings, which traveled between 2 and 10 feet further forward than they otherwise would have under normal circumstances.

Additional Considerations

To cycle properly, recoil-operated guns need to be held with a reasonably firm grasp. During the discharge process, the slide and barrel recoil and move rearward together for a short distance, and subsequently unlock while the frame is secured in the shooter's hand or hands. A poor or loose grip on some recoil-operated pistols can affect the extraction and ejection process to the point of causing a stoppage or jam. A very loose grip can altogether prevent the casing from being extracted from the chamber in some pistols. Although it might seem unlikely that anyone would hold and fire a gun with such a hold, it may be necessary to evaluate this potential variable in certain cases.

In some semiautomatic firearms the position and/or force exerted on the extracted cartridge case by the top cartridge in the magazine can have an effect on the subsequent ejection. This can often be seen in AK-47- and SKS-type firearms. The cartridges in these magazines are staggered so that the top cartridge is alternating between left and right. The result may be seen in alternating paths of the ejected cartridges.

Likewise, the force acting on the top cartridge in the magazine may play a role in the ejection of a fired cartridge. When a magazine is nearly full, the upward force on the top cartridge is much greater than on the last cartridge. This *may* have an effect on the ejection of the fired cartridge, which can easily be evaluated during test firing. The easier approach is to design the ejection pattern tests around the facts of the case. If the shooter is known to have fired four shots starting with a fully loaded magazine, then conduct the ejection tests in the same manner.

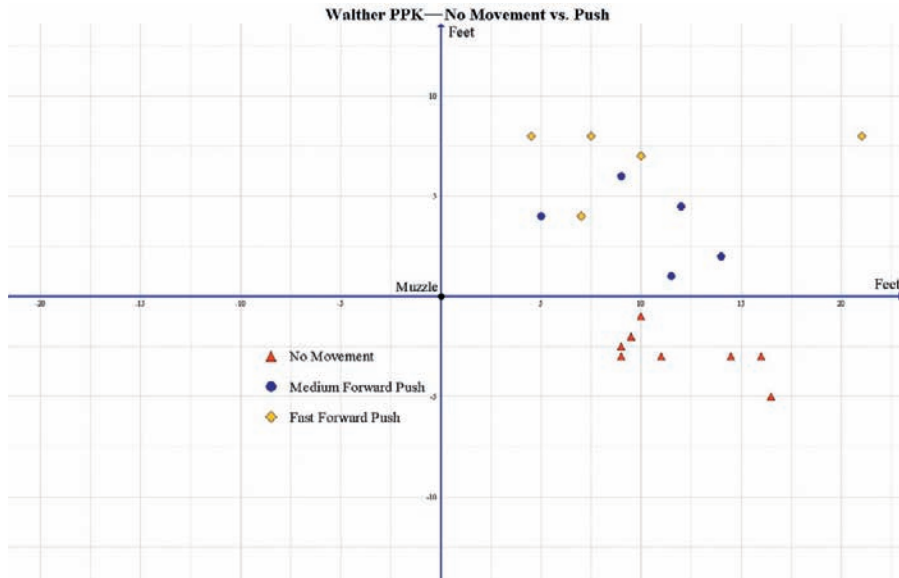


FIGURE 14.9 Comparison of ejected cartridge casing locations in stationary versus “in motion” scenarios.

Whether or not the firearm was canted can be another issue. Largely as a result of movies, the rotation of a firearm either right or left has become a popular cross-examination question at trial. In general, if a normally right-ejecting pistol is rotated 90 degrees to the left, pointing the ejection port skyward, casings will tend to travel upward and to the pistol’s left. Rotating the pistol to the right, pointing the ejection port to the ground, will tend to leave casings almost at the shooter’s feet.

Proper training in gun handling and shooting position requires the grip to be in a vertical orientation for proper sight alignment. However, just because it is improper to cant a firearm to the right or to the left does not prevent a shooter from doing so. If this issue is raised and is deemed to be of concern, then it too must be added to the list of variables to evaluate in any ejection pattern testing. If the shooter is cooperative, the question of canting needs to be put to him or her in a neutral fashion. Interview questions such as

- Could you please demonstrate your best recollection of how you were holding the pistol when you fired? [Photograph this position.]
- Could you demonstrate how you believe you were standing at the moment you fired?
- What is the highest you believe you could have been holding the gun at the time of the shot and the lowest? [Get measurements of the height of the gun above the surface.]
- How were you trained to hold and shoot this pistol?

There are, no doubt, additional questions that deserve to be asked of the shooter depending on the facts and possible issues in the particular case, but these can serve as a starting point.

MANUALLY OPERATED FIREARMS

The techniques described in this chapter are *not* necessarily applicable to mechanically operated firearms such as bolt-action and lever-action rifles, revolvers, pump/break-open shotguns, and single-shot pistols. With these and similar firearms, the location of the fired cartridge casing only provides some insight into where the shooter removed it from the gun. This location may or may not relate to the shooting position.

SUMMARY AND CONCLUDING COMMENTS

It must be said that of all the matters investigated and evaluated in shooting incidents, the interpretation of cartridge casing location and ejection is fraught with the greatest uncertainty. This is meant as a strong word of caution and not as a statement of futility. Despite the numerous variables, and recognizing that some of these are beyond our ability to know, we can often state with reasonable certainty where the semiautomatic pistol, rifle, or shotgun was *not* fired. The same holds true for fully automatic firearms. This is in keeping with the approach employed in the *scientific method*—that is, ruling out certain hypotheses. Consider the following:

- A cartridge casing can only be ejected so far by the gun that fired it.
- The design of the particular gun sets limits on the direction in which the fired cartridge case must emerge from it.
- While it is true that the performance of the ammunition may play a significant role in the extraction and ejection of fired cartridge casings, commercial ammunition is typically a highly refined and consistent product.

Subsequent laboratory inspection of evidence and test-fired cartridge casings can provide considerable information about the actual performance of the evidence cartridges during discharge, extraction, and ejection.

With semiautomatic and fully automatic firearms, cartridge casing location, as an expression of the shooter's approximate location, can be important in evaluating various accounts and theories related to a shooting incident. The accuracy of such determinations increases with an increase in the number of shots fired and/or trajectory information as a consequence of perforating bullet strikes to relatively fixed objects at the scene.

For example, two compact groups of pristine, undamaged cartridge casings, all fired by the same semiautomatic pistol, at two very different locations indicate a change in the shooter's position. If some of these shots have struck and perforated fixed objects, such as a wooden fence and then a nearby building wall, considerable improvement in establishing the shooter's location will be realized by integrating the trajectory information with a cartridge casing ejection pattern.

Trace evidence adhering to, or embedded in, recovered cartridge casings can provide very useful, and sometimes critical, information in certain instances, yet it is often overlooked.

Shots fired from moving vehicles may have special value or importance. With sufficient testing over the same, or comparable, surface, reasonable inferences as to the speed of a vehicle from which one or more shots are believed to have been fired can be drawn from the

location of the cartridge casings and the degree of impact damage they sustained prior to coming to rest. Trajectory information from the scene, if available, will greatly enhance the accuracy of such an evaluation.

Post-shooting incident damage to expended cartridge casings as a result of being stepped on or run over by vehicles is usually apparent and distinguishable from the small sites of abrasive damage around the rim or case mouth acquired by impact with hard surfaces such as concrete or asphalt.

Markings on cartridge casings produced by the firearm and/or the shooter's loading practices *may* allow the *first* shot to be discriminated from subsequent shots. This would be very significant in a situation where the fired cartridge casings showed obvious movement by the shooter (e.g., either advancing or retreating as he fired).

CHAPTER KNOWLEDGE

- Only a few types of firearm mechanisms were addressed in this chapter. How many other mechanisms can you think of, and how would they affect the meaning of an ejection pattern at a shooting incident scene?
- What steps can you, or would you, take while investigating a shooting incident to make sure trace evidence on a fired cartridge casing is preserved properly?
- In scientific investigation, the concepts of reproducibility and certainty are common. If a shooting incident involved a total of 10 shots fired from a particular gun in one location, how many test shots would you fire in your ejection pattern testing? Can you defend this number statistically or empirically?

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The Shooting of Motor Vehicles

INTRODUCTION

Automobiles (and most other vehicles, including trucks, trailers, and mobile homes) present special reconstructive problems. The materials that they are constructed with comprise a wide variety of surfaces susceptible to bullet impact, including the following:

- Frangible materials such as the laminated glass in windshields and tempered glass in side and rear windows
- Malleable surfaces (sheet metal)
- Heavy, unyielding metal structures (support members, frame, engine, axles, etc.)
- Various composites
- Soft materials (plastic, fabric, rubber moldings, insulation)
- Tires
- Painted and unpainted surfaces

Each material responds in a unique way to impacting projectiles. The varied shapes and compound curvatures common in automobiles add another complicating factor when struck by bullets.

Vehicles are often in motion and/or not on level surfaces when struck. The surface on which they come to rest may differ substantially from the surface on which they were struck by one or more projectiles. In some cases it may not be possible to determine the exact location or orientation of a vehicle when it was struck by gunfire. The positions of doors and/or windows may change during or after a shooting incident.

Other changes such as the loss of shattered glass from the struck side and/or rear windows may occur after the actual shooting. Cracks in one or both layers of laminated windshield glass often continue to propagate during the post-incident interval because of stresses, movement of the vehicle, or other forces and events. Tires may deflate slowly after being shot and go flat at some location other than where the shooting incident took place.

Finally, vehicles are often moved from the shooting scene before they can be examined for the purpose of shooting reconstruction. In cases where the vehicle was stationary when

shot and then moved to an examination bay, a thorough review of any and all photographs and videotapes of the vehicle at the scene may allow questions to be answered regarding its orientation at the time of the shooting or the location of bullet holes in tempered glass that has since fallen out.

These matters may seem to make the whole question of vehicle shooting reconstruction a daunting or even a futile endeavor. There is much that can be done, however, as long as the examiner keeps these matters in mind as the work progresses and he or she adheres to the fundamental principles of reconstruction articulated in Chapter 10, on trajectory principles.

VEHICLES AT A SCENE

It is not always likely that a shot vehicle is going to be left at a scene sufficiently long to carry out *all* of the measurements that one might desire. If it is to be moved, its location and orientation at the scene should be documented by measurements and photographs. The photographs should include straight-on front, rear, and side views and should incorporate a known frame of reference such as a plumb line or surveyor's rod positioned in the vertical plane so that any tilt or listing of the vehicle at the scene can later be determined. This is of particular importance if the vehicle was shot at this location.

Alternatively, an inclinometer can be placed on selected sites such as the edge of the front and back windows, the center of the hood and trunk; the particular angles can then be noted and each setup photographed. If there has been a failure to do this, it may be possible to locate one or more fixed references in the scene photographs. In this situation one will need to return to the scene, measure the actual vertical or horizontal angle formed by the surrogate reference feature (e.g., the edge of a building, a telephone pole), and use the feature to estimate any desired angles for the evidence vehicle in the scene photographs.

During the original scene processing, the positions of the tires should be marked in some way so that they can later be repositioned in the examination bay or other suitable area. Stripes of bright fluorescent spray paint on the sidewalls of each tire that continue down onto the roadway are useful for this purpose. They will usually survive on paved surfaces for days to months should the need arise to return and reposition the vehicle at the scene.

Data regarding the roadway, parking lot, or any other surface occupied by the vehicle when shot should be gathered at some point before any significant changes (e.g., resurfacing) take place. This may require the assistance of a surveyor or someone from the streets or highway department, or it may be as simple as taking a few inclinometer measurements or checking several representative areas with a carpenter's level. If the involved vehicle was in motion during the incident, the assistance of a qualified expert in accident reconstruction may be appropriate to address questions about speed, acceleration, or deceleration.

In a few instances we have requested videotaping of the actual vehicle driven through the shooting zone at differing speeds so its natural movements can be later studied in a frame-by-frame manner.

If an injured or deceased subject has been removed from any seat that is adjustable, its position should *not* be altered until sufficient documentation has been completed. Preferably, the seat will be repositionable. Prompt inquiry of any paramedics involved should be made regarding any changes they made in the seat or seatback positions. These concerns

also apply to any adjustable windows in the vehicle. Seat and window positions should be included in the scene photographs. It is suggested that strips of tamper-proof evidence tape or masking tape be placed over these adjustments in such a way that any changes in the seat or window positions would disturb the tape.

Tempered-glass rear and side windows that have been shattered but are still largely in place must be thoroughly photographed with a suitable scale so the approximate center point of any bullet holes can be determined. Concerted efforts should be made to secure the glass in place as much as possible as soon as photo-documentation is complete. Both sides of the shattered glass should be reinforced with strips of wide, clear tape. Some scene investigators use sheets of clear, adhesive film for this purpose. Neither technique will guarantee that the shattered window will survive transport from the scene to the impound area or laboratory, which is why scene documentation is of critical importance.

Several determinations need to be made in instances where the tempered glass in side windows appears to be totally missing as a result of one or more projectile strikes. The interior of the vehicle and the scene should be searched in an effort to find any portions of the window that have surviving radial fractures and flaking near one end (from cone fracturing). These phenomena are associated with the first strike to the glass.

The conical spalling, beveling, or flaking effect will allow the direction of fire to be established after the laboratory determines which surface represents the exterior or interior side of the glass. The rubber molding at the top of the window frame should also be carefully examined for any trapped pieces of tempered glass, which will establish the window as being in the up (closed) position when the window was shattered.

Any glass fragments in this location should be photographed, then carefully removed and marked in some way that shows which surface was the exterior and which the interior side of the fragment. In the absence of such fragments, some further effort will be necessary. Before the vehicle is released and after any other reconstructive efforts have been completed on the door that contained the shattered window, the interior door panel should be removed or loosened sufficiently to see and photograph the position of the window carrier, which will invariably hold some remaining glass. The interior surface of several representative pieces of this glass should be marked in some way and then removed and impounded for submission to the laboratory. Without these reference fragments, it may be impossible to determine the direction of fire.

At this point the reader might find the "Vehicle Data" checklist useful (see the Appendix). It will serve as a guide and reminder for documenting matters that may not seem important at the onset of an investigation but that have a habit of becoming important later. Examples include the position of the driver's seat, the position(s) of the side windows, the position of the parking brake, and the position of the shifting lever.

Frames of Reference and "Squaring" the Vehicle

The usual frames of reference outlined in Chapter 10 are not particularly useful with objects that move, such as vehicles. Various fixed reference points on the vehicle itself can and should be used, including trim, moldings, hood centerlines, and door edges. For example, an entry hole in the driver's door might be described as *"Eight inches back (to the rear) from the front edge of the driver's door and 10 inches down from the lower edge of the driver's window sill."*

These natural reference lines in a vehicle should be integrated into any subsequent photographs depicting reconstructed projectile paths.

At some point the vehicle's height above ground level should be measured, but it must be recognized that this can change with vehicle loading and movement. Such potential changes can be evaluated later. Nonetheless, the location of a bullet hole or impact site described by identifiable and fixed reference points can be reestablished at any future time on the repaired vehicle or a comparable vehicle of the same make, model, and year and equipped with the same size tires.

Every vehicle can be divided into natural planes such as a front-to-rear axis, a vertical axis, and the plane across its width. These can be useful in describing the general path of a striking projectile with the vehicle viewed as a box or, more correctly, a 3-dimensional rectangle. A technique called "boxing" or "squaring" naturally arises out of viewing the vehicle as a rectangle. It is used when examining a bullet-struck vehicle in a subsequent controlled environment and on a smooth, level surface.

The vehicle is first leveled on a flat surface that provides sufficient working space on all four sides. Housekeeping matters such as the height of certain features (e.g., top of the roof, driver's window sill, driver's side rocker panel) can be measured at any time, although they may not be particularly relevant. Likewise, any height changes due to driver and/or passenger weights as well as any roll or pitch changes can be determined with the vehicle on this level reference surface.

Let us imagine a vehicle that has projectile strikes entering the front and driver's side. Two sturdy tripods with a taut string line between them are positioned a short distance forward and aft of the car so that the string just touches and parallels the driver's side. Figure 15.1(a) demonstrates this in a class environment. Figure 15.1(b) shows a downward view with trajectory rod crossing under the "squared car" reference line. Figure 15.1(c) shows how the protractor is established on the reference line string while a plumb bob is used to measure the azimuth angle on the gradations present on the zero-edge protractor.

Two more tripods with a taut string line can be positioned across the front of the car and at a right angle to the first string line. This is done particularly when trajectories cross the front or rear of the vehicle. The tripods are positioned so that the string line just touches or is immediately over the forward-most feature of the car. It may be desirable to do the same thing at the rear of the vehicle if for no other reason than to establish the size of the "box" that will represent the car. We now have a coordinate system with which we can define and measure azimuth angles as well as describe impact sites.

The reference point (RP) in this example will be the intersection of the two string lines at the left front of the vehicle. The earlier example of a bullet hole that was found to be 8 inches back from the front edge of the driver's door and 10 inches down from the lower edge of the window sill now has an additional identity in this new coordinate system. It is determined to be 60 inches to the rear of the RP and 32 inches above the flat, level surface upon which the vehicle is standing.

A properly inserted and positioned trajectory rod through the driver's door is photographed from directly above the intersection of the probe and the string line. From this the azimuth angle is determined. The vertical component is measured as described in Chapter 10 using the photographic method with a plumb line, an inclinometer, or both. This same probe with an attached and co-aligned laser can be used to evaluate possible, improbable,



FIGURE 15.1 (a) Two tripods hold taut a string along the side of the vehicle being examined, “squaring” up the curved side into an easily manageable reference line. (b) For azimuth measurements, the crossing of the reference line and trajectory rod is the correct location for a measurement. (c) A plumb bob can be used to efficiently correct for any variation in height between the reference line and the probe.

and even impossible gun heights and to recheck both azimuth and vertical angle components of the bullet’s approach to the “box.”

In cases where a bullet has impacted near the vehicle’s centerline, it may be desirable to run a string up and over the vehicle from front to back. Most cars and trucks have emblems, key holes, or other manufacturing characteristics that help align the string properly. Once the string is in place, rods that cross over this line can be measured relative to it. Particularly when it may be unwieldy or impossible to extend a steep trajectory probe, the centerline technique is appropriate.

Yet another method of squaring the car involves the use of probes themselves to establish a constant side of the “box.” In Figure 15.2, we can see a yellow rod representing the side



FIGURE 15.2 The yellow probe serves as a reference line, while a stainless steel rod represents the bullet's path into the vehicle.

of the car. It is taped to this rather square vehicle's side in an area that corresponds to the side of the "box" that is of interest. In the image, a silver welding rod represents the bullet's path. From this view directly above the intersection of the trajectory rod and reference line, an azimuth measurement can be made.

Shots into the front of the vehicle, into the hood, and into the windshield are referenced and measured relative to the line across the front. This "box" with the trajectories for each shot can now be integrated with diagrams and various views of the actual scene. The "box" can be pitched up or down, or rolled to one side or the other, and the trajectories go with it. This is best done with a computer program and a model of the scene, into which the pertinent information regarding vehicle size ("box" size) and associated trajectories can be illustrated in any view.

PROJECTILE STRIKES

The general properties and behavior of bullets striking sheet metal, glass, rubber, and plastic were presented in other chapters. Now we have all of these materials and more in motor vehicles, arranged in varied shapes and ever-changing angles. It must be recognized that this can make the impact sites from two shots fired from the same position and along very similar flight paths look very different. For example, a grazing strike to the hood of a car and a perforating shot into the front fender could be the consequence of two shots fired from the same location that differ by only 6 inches in the heights of their pre-impact flight paths. The sudden changes in shape and contour, along with variations in underlying support structures, can also affect the amount and nature of any deflection experienced by the bullet. Complicating factors such as these may once again create the need for some subsequent empirical testing on an exemplar vehicle.

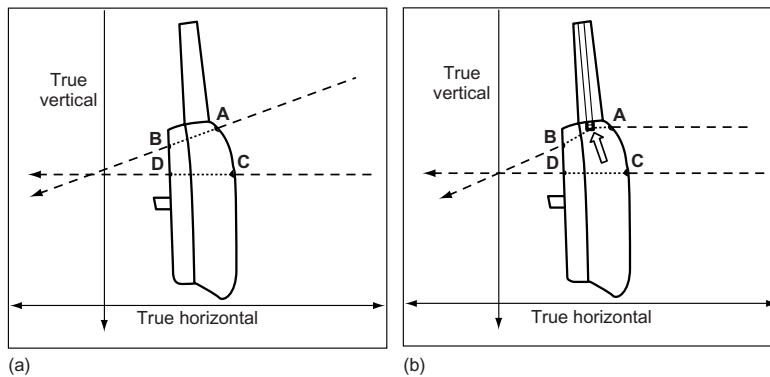


FIGURE 15.3 (a) Cross-sectional view of probes passed through two perforating shots to the driver's door of a vehicle. (b) Cross-sectional view of the actual paths of two perforating shots to the driver's door of a vehicle.

- (a) This drawing illustrates the danger of assuming that the distance between entrance and exit holes represents a straight line. Probes passed through A–B and C–D may, at first, seem reasonable until the internal components of the car door are carefully inspected. It is found that the bullet that produced entry hole A struck the metal carrier for the driver's window, after which it was deflected downward and exited at B; see Figure 15.3(b). Note the substantial differences in the back-extrapolated vertical angles for these two shots into the car door.
- (b) This is a cross section of the door shown in Figure 15.3(a). The raised driver's window and carrier have been added to the figure after a careful inspection of the internal components revealed that the bullet that produced entry hole A struck the metal carrier for the driver's window (*arrow*) after which it was deflected downward and exited at B. The correct representation of the pre-impact flight path for strike A is represented by the path from the entry hole (A) to the impact site in the window carrier. Note the substantial differences in the plane of the sheet metal at entry points A and C relative to each bullet's flight path. This can easily produce entry holes of different shapes, even though the multiple shots strike the vehicle along near-identical flight paths. The nature of the impact damage to the bullets recovered from the driver's body should allow them to be associated with their respective impact sites in the driver's door.

Perforating Projectiles

The tracking of a perforating projectile can be difficult because of the various internal structures and components in vehicles. It may be necessary to cut viewing windows in sheet metal surfaces and ultimately disassemble door panels to make sure that there was not some internal structure hit that caused a change in the bullet's direction.

Consider the situation illustrated in Figures 15.3(a) and (b), where two entry bullet holes are found in the exterior of the driver's door and two exit holes are subsequently noted in the interior door panel. The roundness or out of roundness of bullet holes in automotive sheet metal provides only a very general notion of incident angle (see Figure 15.4), so passing trajectory rods through these holes and along the tracks illustrated by lines A–B and C–D might seem reasonable and appropriate. This results in widely divergent azimuth and vertical angles between these two shots, yet the police officer-shooter claims that he fired two rapid shots from a single location and stance about 10 feet out from the side of the vehicle.

The officer also claims that he did this when the driver made a rapid, noncompliant movement as he approached the stationary vehicle. If these divergent angles are true representations of the two bullets' flight paths, then either the shooting officer moved between these two shots or the vehicle moved or both did.

A careful disassembly and inspection of the internal components of this door later reveals that a heavy cross member was struck by the bullet that entered at point A; the true path of this shot is as depicted earlier in Figure 15.3(b). The lessons here are that two points do not necessarily represent a straight line and that at some point the examiner needs to look inside complicated vehicle structures such as doors that have been penetrated or perforated by gunfire.

Sometimes the troublesome internal components in doors can be beneficial. The positions of important moveable components such as the operating rod or lever for the door handle, the door lock, or the window carrier may be struck by the bullet. Careful inspection of this damage and its spatial relationship to the responsible bullet's path may answer questions such as: *Was the driver in the process of opening the door when the shot was fired?* or *What position was the shattered window in when the shot occurred?* Other moveable components (e.g., steering column, steering wheel, tires, wheels, and/or drive shaft) may provide useful and otherwise overlooked clues when struck by bullets.

The task of trajectory reconstruction is relatively easy if one is lucky enough to be dealing with a vehicle that was shot while at rest and there is ample time to carefully reconstruct the trajectories of the bullet strikes to it. This is accomplished by one or more of the techniques described in the Chapter 10. The reconstructed trajectories can be related to the usual vertical and horizontal frames of reference and the associated scene. Included and excluded positions for the shots naturally flow from this situation. With vehicles that have been moved from the scene or that were moving when shot, the work becomes more difficult. This is the more common situation for which the "squaring" technique was developed.

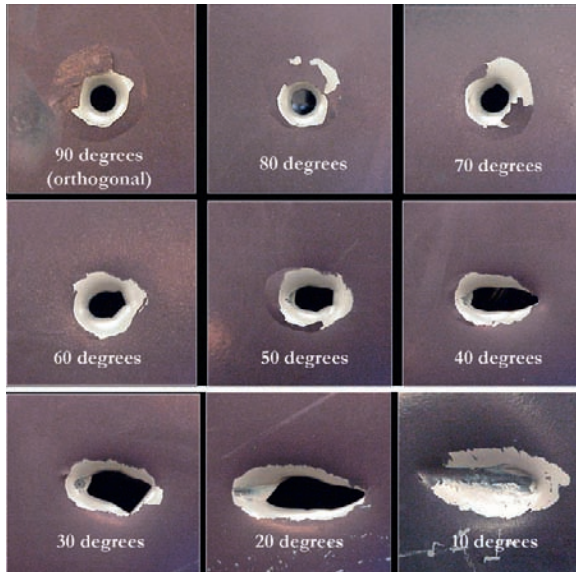


FIGURE 15.4 Appearance of entry bullet holes in automotive sheet metal at various incident angles.

These bullet holes in automotive sheet metal were produced with 147-gr Federal Hydra-Shok bullets fired at the indicated incident angles with a Model 39 S&W 9 mm pistol. As can be seen, the shape of the holes between 70 and 90 degrees are essentially round, making the location of subsequent impact points within the vehicle of critical importance in defining the pre-impact flight path of the bullet. (Photos and test shots courtesy of Michael Haag.)

Penetrating Projectiles

It is often the case that bullets enter a motor vehicle and do not exit. Sheet metal or one panel of glass is relatively easy to perforate, but the numerous major heavy metal structures inside doors and in other locations will defeat many small arms projectiles, particularly pistol bullets. This is quite like the example in an earlier chapter in which a bullet enters a wall but does not exit.

After the bullet hole has been located, appropriately measured and documented, a bore-scope with an integral illumination system may be useful in locating the next impact site or even the bullet itself. However, we still need to properly position a trajectory rod or laser and the bullet must ultimately be recovered if at all possible.

We prefer the “viewing window” approach to both trajectory reconstruction and bullet recovery. Not using it can lead to one of the most common errors when tracking a bullet’s path through a vehicle: an investigator’s assumption that the bullet passed directly from the primary entrance to the visible exit, which does not account for any possible internal structures that were hit. Even more important, this incorrect assumption does not account for the potential *deflection* that was created by the intermediate impact.

Examine Figure 15.5, and try to determine where the 45 CAP caliber bullet impacted the inside of the car door. The shallow angle impact is just to the left of the oval hole in the sheet metal. Without a clear view, this impact might easily be missed. A viewing window may be created by removing panels or by using cutting wheels to peel back the sheet metal of

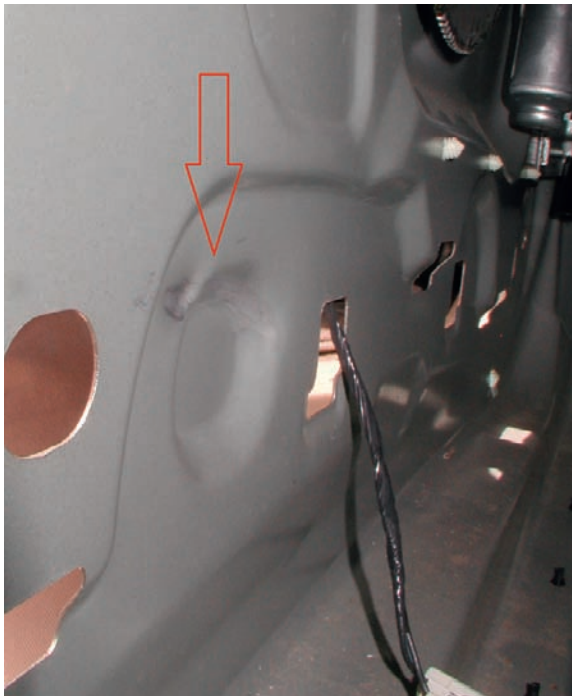


FIGURE 15.5 A subtle impact on the inside of a car door.



FIGURE 15.6 Primary perforation of the vehicle is the hole to the right of the square viewing window cut out with a cutting wheel. Because the trajectory travels from right to left as viewed, the window allows easy examination of any potential secondary impacts inside the door without altering the original bullet hole.

the car body. Any criticism of such methods with regard to *spoliation* should be met aggressively with the argument that failure to visualize such characteristics risks the integrity of the investigation and its conclusions. Additionally, as investigators and forensic scientists, we make every reasonable attempt to preserve evidence exactly as it is found, but unless we work with and on the evidence, we cannot make conclusions that are relevant and correct.

Creating these windows is somewhat labor-intensive; however, pulling off door panels and other similar components can disturb the geometry of certain bullet-struck sites within them, meaning that one cannot be certain that the sites will be in the same position when the panel is replaced and reconstruction efforts are renewed.

A high-speed electric Dremel tool or a cutting wheel is used to slowly and carefully cut a combined viewing window and access panel in sheet metal. Just as before, the window can be adjacent to the bullet hole or it can include the bullet hole itself. Figure 15.6 gives the reader an idea of how a bullet's perforation of the exterior of a vehicle (hole to the right) can be tracked confidently by cutting a section of metal away along its expected path. With this rectangular portion removed, the secondary impact is easily visible on the underlying structure.

If the struck surface possesses significant curvature so that crossed strings will *not* occupy the position of the bullet hole once the panel is cut, an alternative is recommended if the excised panel includes the bullet hole. The excised panel is placed on a copy machine with the area of the bullet hole in contact with the copier's platform. Clear plastic transparency film is used rather than paper. The result will be a plastic sheet with the outline of the bullet hole visible as well as the outline of the edges of the panel.

The transparency can be matched back to the excised area and taped in place. An externally mounted laser is positioned and adjusted until the beam passes through the *copy* of the bullet hole and onto the internal impact site or the embedded bullet. A digital inclinometer can be placed on the laser (if it is suitably constructed) or carefully shuttled in under the laser beam to read off the vertical component of the angle.

The azimuth angle can likewise be determined in several ways, all of which are virtually the same as described in Chapter 10. The examiner need only apply a little forethought and

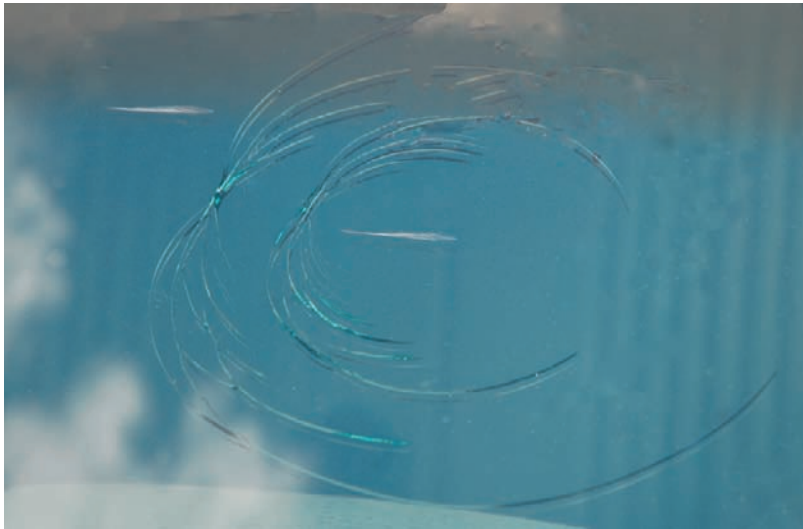


FIGURE 15.7 Two ricochets on the surface of a windshield, only one of which left any cracks.

planning to measure or calculate the angular components of the bullet's pre-impact flight path relative to the appropriate axis of the "box" representing the car.

Ricochet Marks, Graze Marks, and Nonpenetrating Strikes

Ricochet and graze marks can occur on any vehicle surface and can sometimes be exceedingly difficult to locate. A soft lead bullet, or even a slow jacketed bullet, traversing the windshield or side window can leave a "Chisum trail" without cracking the glass (see Figure 15.7).

A graze mark across the hood may produce only a 1- to 2-inch blemish in the paint. Further evaluation will require a test for copper and lead by the transfer technique. Direct strikes into very heavy structures such as thick steel bumpers, wheels, or axles may result in heavy bullet fragmentation. In these cases, patterns of copper and lead transfers and especially lead splash can establish the mark as bullet-caused. The use of lead splash to obtain useful information on direction must be approached very cautiously here. Any curvature in the struck surface stands to play a major role in the direction taken by spattered and vaporized lead.

SUMMARY AND CONCLUDING COMMENTS

Vehicles present special challenges for recognizing, identifying, and reconstructing projectile damage to them. Their wide variety of materials and complex shapes and surfaces greatly increase the difficulty in reconstructing the direction or sequence of projectile strikes. Shots fired inside dwellings and buildings have the advantage that struck surfaces are usually static and often consist of relatively flat surfaces that make natural planes of reference.

Vehicles, on the other hand, are often moving when struck by gunfire or are moved to some other location shortly afterward.

All of these factors require more diligence and effort during the vehicle's examination. The technique of squaring the vehicle while on a flat and level surface provides a useful frame of reference for back-extrapolation to the scene. The behavior of most of the materials in vehicles and their interaction with projectiles can be studied using techniques covered in other chapters. The pertinent ballistic phenomena described in those chapters were sheet metal behavior during bullet penetration and perforation, pinch points, lead-in marks, fracture lines in painted metal surfaces, laminated and tempered glass, sequence of shots through tempered glass, bullet holes in tires, and strikes in plastic bedliners in trucks.

CHAPTER KNOWLEDGE

- The next time you are in a vehicle, count the number of different materials you see. How would you expect each to behave when struck by a pistol bullet or a rifle bullet?
- If there was a *steeply* downward trajectory into the center of the trunk of a vehicle, what references would you use in the determination of an azimuth component?
- An unusual type of paint is found on a vehicle involved in a homicide investigation. How would you determine its behavior when struck by bullets?
- Would deflection through windshields be different if the glass was supported by the car, or supported by a loose jig apparatus? How would you find out?

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Shotgun Shootings and Evidence

INTRODUCTION

Shotguns present special challenges to crime scene investigators, medical examiners, and firearms examiners. This is largely due to the great variety and complexity of this ammunition compared to bulleted cartridges.

There are numerous types of wads, shot collars, shotcups, and buffering materials, as well as many sizes and compositions of shot available for shotguns. Figures 16.1, 16.2, and 16.3 provide three examples. The two most common types of shotshell mouth are shown in Figure 16.4. The white plastic shotshell on the left has a roll crimp; the red shotshell on the right has a star crimp. All of the items shown in these photographs have important evidentiary and reconstructive value. They also have their own ballistic properties that can play a vital role in establishing the distance from which the shot was fired and the location of the shooter at the moment of discharge.

One of the frustrating aspects of shotgun shootings is that it is very seldom possible to identify shot pellets as having been fired from a particular gun. There are rare exceptions



FIGURE 16.1 A 20-gauge shotshell and its fired components.



FIGURE 16.2 Sectioned 12-gauge shotgun shell containing #8 shot.

Figures 16.1 and 16.2 show several common types of wadding in contemporary shotshells. Multiple cardboard or fibrous wads may be in a single shotshell such as the 20-gauge shell depicted in Figure 16.1. The upper wad will take up impressions of the pellets during discharge, as will the plastic shot collar unique to certain Winchester shells. The sectioned shell in Figure 16.2 contains a one-piece plastic shotcup in which the pellets are nested. Two of the four petals of this shotcup can be seen in this figure.

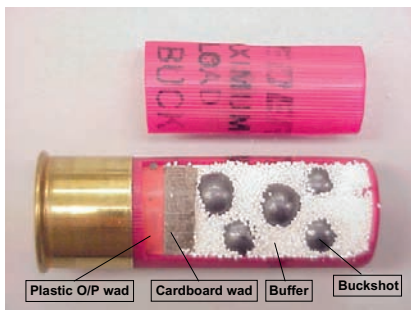


FIGURE 16.3 Sectioned standard Federal brand 12-gauge shotgun shell containing 00 buckshot.

Shown is a typical American buckshot load with plastic buffering material filling the spaces between the individual pellets. This particular shell contains both plastic and fiber wads. All of these components emerge from the muzzle of the gun and have exterior ballistic properties of reconstructive value.



FIGURE 16.4 Two of the most common crimps found on shotgun shells: Roll crimp (*left*) and star crimp (*right*).

when large shot (buckshot) loaded in old-style shotshells is used and the sides of the pellets rub against the bore during discharge (see Figures 16.3 and 16.5). Fired shotshells, on the other hand, can often be matched back to the responsible gun using the same principles employed for bullet cartridges: firing pin impression, breechface signature, and so forth.

The printed information on the side of an expended shotshell often provides the size of the shot, the amount of shot, and the purpose of the load. This information can lead to other facts about the ammunition. For example, a trap load and a field load with the same size

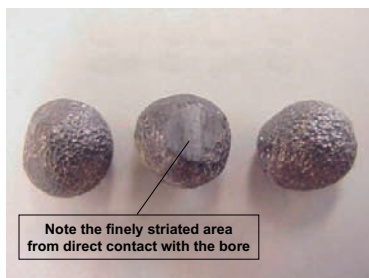


FIGURE 16.5 Fired 00 buckshot pellets from a buffered shell recovered from loose Kevlar at 30 yards, 20-in. cylinder bore 12 ga.

These three fired 00 buckshot pellets show the characteristic “orange peel” imprint of the plastic buffering material acquired during discharge. One of these pellets has been oriented to show the area where it contacted the bore of the gun. This mark establishes the pellet as having come from a shell like that in Figure 16.3 as opposed to a shell employing a shotcup (such as shown in Figure 16.2), where the pellets are prevented from contacting the bore of the gun.

shot and made by the same manufacturer will have different types of wadding or shotcups in them. Some American shotshells contain fine plastic granules mixed with the shot to act as buffering material.

All of these components (wads, shot, shotcups, and plastic buffer) emerge from the muzzle on discharge and all have useful exterior and terminal ballistic properties. When conducting range determinations based on pellet pattern diameter, the most important factors to consider are ammunition, barrel type and length, and choke.

SHOTGUN DESIGN AND NOMENCLATURE

Shotguns may be semiautomatic, pump action, lever action, or bolt action, or of a break-open design. Many semiautomatic and pump action guns allow for quick removal and replacement of the barrels for different hunting and sporting purposes, so this should be kept in mind. Break-open designs are used in single-shot and double-barreled guns. Double-barreled guns are manufactured with their barrels side by side or over and under. The bores of shotgun barrels are normally smooth (unrifled), but special-purpose barrels with rifling are available. These are usually associated with deer hunting in the Eastern United States or are used in special law enforcement applications.

The performance of these guns with shot cartridges is radically different from that of the same gun with a conventional smooth bore. This rifled barrel factor is one that investigators should bear in mind when no information is available about the firearm used in a shooting. At the same distance from the muzzle, with the same ammunition, the diameter of a pattern from a rifled barrel shotgun can easily be three times the pattern diameter from a smooth bore shotgun.

Figures 16.6(a) and (b) show how drastic this variation can be. The two shots shown were fired from the same gun, with the same barrel length and cylinder bore choke, and each shot was set up with a muzzle-to-target distance of 10 feet. Additionally, the ammunition fired was consistently Federal, 12 gauge, 2 3/4-in. shotshells loaded with 1 1/2 ounces of BB shot. For the reader’s reference, each of these figures has the same 15-cm scale in view.

The key factor and variable changed in the figures is the rifled barrel. The larger pattern was created with an 18-in. rifled barrel in place; the smaller pattern, with a smooth bore

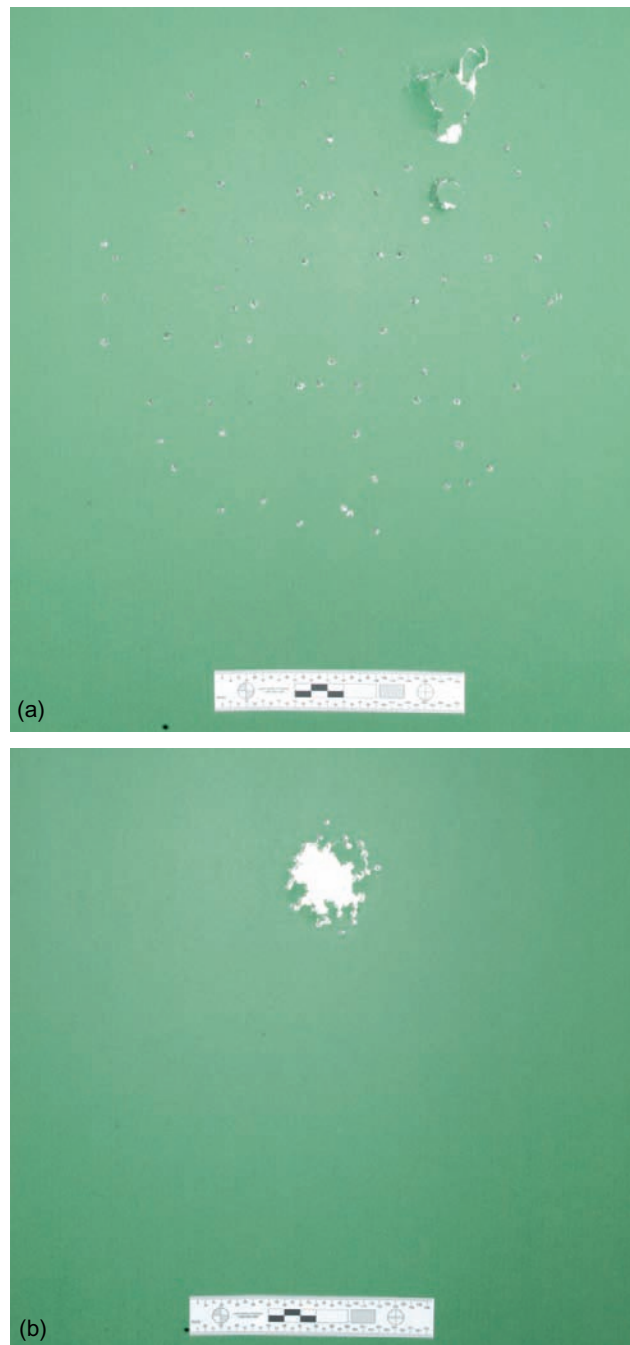


FIGURE 16.6 (a) Shown with a 15-cm scale, this pattern was fired from a rifled shotgun barrel. (b) With the same 15-cm scale in view, this pattern was fired with the same ammunition, same receiver, and at the same distance as in (a), but with a smooth bore barrel.

18-in. barrel. It should be immediately obvious that unless we know something about the shotgun used in the incident we are investigating, field determinations of the distance from muzzle to target should be heavily restrained.

Considering the potential for two law enforcement officers to be firing from the same distance, one with a rifled shotgun and the other with a smooth bore shotgun, the inclusion of the type of shotgun barrel in the number of variables examined is important now and will be more important in the future as the number of rifled barrels in use increases.

There is some hope for the astute shooting incident reconstructionist in determining if the shotgun used had a rifled barrel. A close examination of any wads recovered will tell the tale. The two 12 gauge wads shown in Figures 16.7(a) and (b) are the same brand and model, and loaded with the same shot charge, but were fired from rifled and smooth bore shotguns.

The muzzles of the more common smooth bore guns may possess a certain amount of constriction. This is called “choke,” and its function is to tighten the flight pattern of shot for certain hunting applications. Note that the amount of choke is often different between the two barrels of double-barreled shotguns. Moreover, some shotguns have a replaceable choke that is threaded into the muzzle of the barrel, while others may have adjustable chokes. Since the type and amount of choke affects pattern size, it is of critical importance that no changes be made to any adjustable choke present on an impounded gun. We recommend marking the position of any adjustable choke in some noninvasive manner.

Shotguns were developed for small-game hunting (ducks, quail, rabbits, etc.), although special-purpose loads are available for deer hunting (buckshot and solid slug) as well as personal protection, law enforcement, and military purposes. Less lethal munitions using shotshells containing “bean-bags,” rubber shot, and chemical munitions are a relatively recent development in shotgun ammunition. An image of a common “less lethal” drag-stabilized sock is shown in Figure 16.8. This particular example was fired from a rifled shotgun barrel against the side of a car door. Note the circular or doughnut like impact impression as a result of the rifling and related centrifugal force.

For traditional small game hunting the shells are loaded with selected sizes of spherical lead shot hardened with antimony. The large caliber lead spheres used in buckshot loads are usually composed of plain lead, although they may possess an exterior plating of copper or nickel. The various sizes of shot were developed for different types of game. The various sizes and weights of shot were discussed and illustrated in Chapter 3, in the section

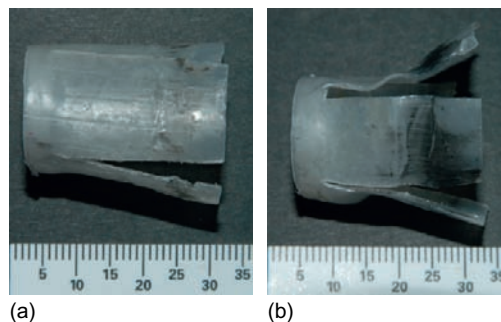


FIGURE 16.7 (a) A 12-gauge plastic shotcup fired through a rifled barrel. (b) Same brand 12-gauge shotcup but fired through a smooth bore barrel.

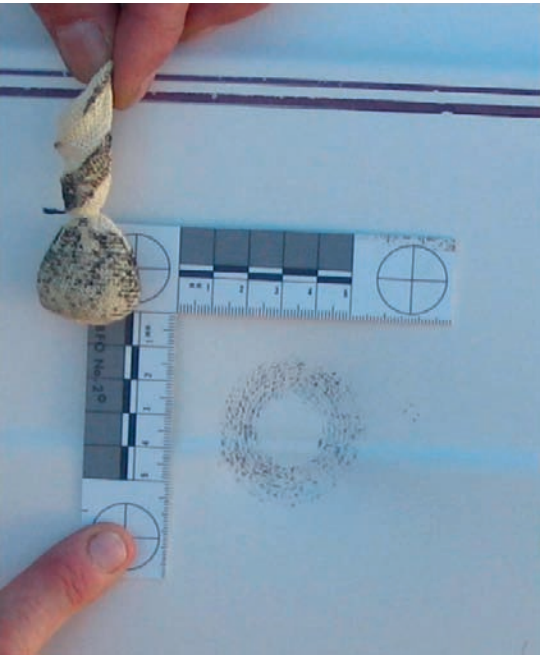


FIGURE 16.8 “Spun” 12-gauge drag-stabilized sock impact on a car door.

TABLE 16.1 Shotgun Gauges and Bore Diameters

10 gauge 0.775 in. (19.6mm)	20 gauge 0.615 in. (15.6mm)
12 gauge 0.730 in. (18.5mm)	28 gauge 0.550 in. (14.0mm)
16 gauge 0.670 in. (17.0mm)	410 gauge* 0.410 in. (10.4mm)

*Not a true gauge.

“The Worth of Weight” and Table 3.1. High-flying geese with their thick layer of feathers, for example, require larger size shot than a rabbit that breaks and runs from under foot.

Traditional shotgun pellets were made of lead, but presently they may be made of steel, tungsten, or bismuth, as well as composites of steel and tungsten. These developments are the consequence of concerns regarding lead contamination of lakes and waterfowl areas. The size of the bore in shotguns is expressed in terms of *gauge*. The actual bore diameters for shotguns are given in Table 16.1. The four most common gauges are set in italics.

CHOKE AND PATTERNING

As previously pointed out, many shotgun barrels will have some amount of choke present at the muzzle. Chokes may be categorized in three ways:

- *Fixed*: These are made as an integral part of the barrel and cannot be readily changed except by a gunsmith, and any alteration is considered permanent.

TABLE 16.2 Choke Constriction

Choke (12-gauge)	Muzzle Diameter (in.)	Constriction (in.)
Cylinder	0.730	0.000
Improved cylinder	0.721	0.009
Modified	0.712	0.018
Full	0.694	0.036

- *Interchangeable*: These can be of the “screw on” or “screw in” style recessed into the barrel. To change the degree of constriction you simply remove and replace the collet with a choke of a different diameter.
- *Adjustable*: This style of choke is adjustable throughout a range by turning a sleeve, which collapses or allows a collet to expand, thus changing the diameter. Take care at the scene to ensure that the choke’s setting is documented and protected.

In fixed and interchangeable chokes, the constriction is usually described as *full*, *modified*, *improved cylinder*, or *cylinder*, with the last one being somewhat of a misnomer since it involves no constriction. The term *cylinder bore* may also be used for this type. The type of choke machined into a shotgun barrel is usually marked somewhere on the barrel, but it may be in some codified form and not immediately understandable. Special, inexpensive gauges made for gunsmiths will quickly determine the type of choke present if any, but careful laboratory measurement of the inside diameter at the muzzle will resolve the question.

An inspection of Table 16.2 for a 12-gauge shotgun with a bore diameter of 0.730 inches should give the reader some idea of the amount of constriction for the various amounts of choke.

SHOT CHARGES AND DRAM EQUIVALENTS

The numbering system for shot pellets, their diameters, and the weights for individual pellets were discussed in Chapter 3, but the *number* of pellets in a given shotshell is a separate matter. The total weight of a shot charge is given in ounces for American shotshells. In addition to the weight of the shot charge, the manufacturers’ markings on the sides of most shotshells usually include the size of the shot and a dram-equivalent value that relates to the velocity of the particular load. The total number of pellets in a particular loading of shell will be determined by the size of the pellets and the charge weight.

Table 16.3 gives the approximate number of pellets per shell for lead shot sizes #2 through #9. The exact number will vary slightly depending on the alloy content and slight variations in pellet diameter. Different charges of shot are available in different product lines in the same gauge and from the same manufacturer. A 12-gauge target shell may only contain 1 ounce of #8 shot, but a heavy field load from the same manufacturer may contain 1 1/4 ounce of the same size of shot. Table 16.3 reveals that there are approximately 410 pellets in the 1-ounce load and 513 pellets in the 1 1/4-ounce load of #8 shot. This example illustrates the importance of counting the total number of pellet impacts when it is reasonably certain that the entire shot charge is represented at the scene of a shotgun shooting.

TABLE 16.3 Lead Shot Pellets per Shell in U.S. Sizes

Shot Charge (oz)	#2	#4	#5	#6	#7½	#8	#8½	#9
1/2	45	67	85	112	175	205	242	292
3/8	67	101	127	168	262	308	363	439
7/8	79	118	149	197	306	359	425	512
1	90	135	170	225	350	410	485	585
1 1/8	101	152	191	253	393	461	545	658
1 1/4	112	169	213	281	437	513	605	731
1 3/8	124	186	234	309	481	564	665	804
1 1/2	135	202	255	337	525	615	730	877
1 5/8	146	220	276	366	569	666	790	951
1 7/8	169	253	319	422	656	769	850	1097
2	180	270	340	450	700	820	910	1170

WADS AND SHOTCUPS

Examples of contemporary shotshells were illustrated earlier in Figures 16.1, 16.2, and 16.3. The several types of wads and one shotcup shown in these figures all serve the same purpose—namely, to seal off the powder gases from the shot charge and to drive the shot out the barrel. The class characteristics of these components are of special importance in determining the gauge of the responsible gun and the brand of the ammunition; in addition, they have useful exterior ballistic properties. At very close range (inches to perhaps several feet) they will follow the shot charge into any gunshot wound.

The pellets in the shot charge will still be very close together, resulting in a single, large entry hole or wound followed by “billiard-balling” of the pellets inside the body. As the range increases these wads or shotcups typically fall out of alignment with the shot charge and strike to one side of the entry wound. They still have sufficient velocity and energy to produce satellite wounds on the body and defects in any clothing.

In cases where only a plastic wad is recovered, it may be possible to get an estimate of the size of shot that was loaded in the shotshell. During the acceleration process of the overpowder wad into the shot charge, impressions of the pellets themselves are left in the soft plastic cups. These can be observed both on the inside of the petals and on the inner base portion of the cup. While it may not be prudent to attempt to determine the difference between a #7 1/2 and a #8 shot charge, Figure 16.9 shows how drastic the impression size will be when comparing a #8 shot (on the left) and #2 shot (on the right).

Another useful manufacturing characteristic related to plastic shotcups is the thickness of the plastic itself. In order to protect steel barrels from steel shot, the wads for these harder pellet loads are drastically thicker than their lead pellet-bearing counterparts. The astute investigator with experience examining known samples of each can pick up on these differences at a scene.

Another very interesting and useful phenomenon associated with most shotcups is the fact that the petals open out during the very early phase of flight as they encounter air resistance.

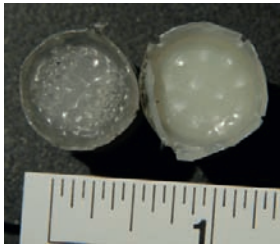


FIGURE 16.9 Interiors of two plastic shot cups. The one on the left held #8 shot; the one on the right held #2 shot.

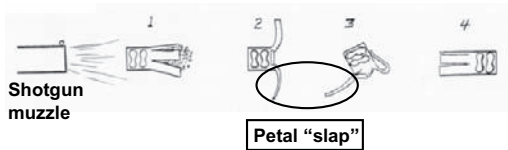


FIGURE 16.10 In-flight reversal of shot cups.

This drawing illustrates the four major phases of the exterior ballistic behavior of plastic shotcups fired from smooth bore guns. Within a few inches of the muzzle, the petals begin to open up as they encounter air resistance. At this stage the pellets are essentially en masse and still within the shotcup. Phase 2 shows the petals fully extended. Air resistance has slowed the shotcup sufficiently so that the pellets are fully separated from it. Because the center of gravity is toward the rear, the shotcup consistently rotates, as shown in phase 3. The velocity of a shotcup at phases 2 and 3 is on the order of 1000 fps; consequently, the extended petals typically produce an injury in living skin and leave a mark on most inanimate objects. This is called “petal slap” and is very useful in range-of-fire determinations because these events all occur within a few feet of the muzzle of the gun and in a very reproducible manner for the specific gun–ammunition combination. Phase 4 shows the final orientation of a shotcup in flight. This position may require 3 to 5 feet to achieve. However, the shotcup still has sufficient velocity and energy to produce an injury and sustain impact damage to its forward-flying base.

Shotcups of this general type are made by all U.S. shotshell manufacturers, and they all go through a cycle of opening, then reversing ends (due to air resistance and an aft center of gravity), and then quickly losing velocity because of their light weight.

The important phases of this cycle are illustrated in Figure 16.10. This opening and reversal cycle typically occurs in the first 3 to 4 feet of travel and has very important reconstructive value. At such close distances, the shot charge is still en masse and will produce a single entry defect. In this situation, muzzle-to-wound distance determinations based on the entry wound appearance, cannot usually distinguish between 12 inches, 18 inches, and 24 inches, for example. The impact marks and/or impact orientation of this type of one-piece plastic wad can often resolve distance determination questions over these separation distances. Reliably distinguishing a 12-inch standoff distance from a 24-inch standoff distance could mean the exclusion of a self-inflicted wound where the muzzle-to-wound distance, combined with the wound path and gun dimensions, precludes the victim from reaching the trigger.

One of the most useful and interesting marks produced by these shotcups occurs very early in their flight when one or more of the extended petals strikes the skin. This leaves a visible rectangular mark that we have named *petal slap*. Figure 16.11 is an example of petal slap for three shots fired from a distance of 20 inches with a cylinder bore 12-gauge shotgun.

Petal slap will usually occur immediately adjacent to the entry wound produced by the associated shot charge. It relates to range of fire for a particular gun–ammunition



FIGURE 16.11 Shotcup petal slap.

This photograph shows the results of and reproducibility for three shots fired into foamboard from a distance of 20 inches using a Remington Model 870 12-gauge shotgun with a 20-inch cylinder bore. At this distance the four petals of the plastic shotcups are fully extended for this particular gun–ammunition combination. The large holes produced by the 1 1/4-ounce #4 shot (approximately 170 pellets) clearly show that the shot charge is still en masse at this distance. This would also be true for all distances less than 20 inches. The behavior of the shotcups and particularly the shotcup petals would be significantly different at lesser distances and thereby provide a useful means of estimating the separation distance between muzzle and entry wound or site.

combination. Petal slap marks can also be seen or detected in clothing. The sodium rhodizate test for lead will often raise them if lead shot was in the wad's cup. The center-to-center distances of the imprints of the shot pellets in the interior of recovered wads or shotcups can provide useful information on shot size.

There is a notable exception to this in-flight reversal behavior for shotcups. When fired from *rifled* barrels, they have repeatedly been observed to remain in a forward orientation with the petals extended. This is the consequence of spin stabilization from the rifling sufficient to overcome the overturning moment caused by the aft center of gravity. This results in an increase in the distances over which the shotcups can produce petal slap but also reduces their overall range of flight. Careful examination of recovered shotcups fired from rifled barrels will reveal the presence of rifling marks.

The shotcup itself may also have a significant effect on pellet pattern size. No doubt, manufacturers of shotgun ammunition are continually designing improved or special-purpose shot cups. The shooting scene reconstructionist should be aware of new products on the market to evaluate the impact of these changes on the physical evidence observed at scenes. One good example of this can be seen in a comparison of a standard law enforcement 00 buck load with a newer, common type of plastic wad.

Figure 16.12(a) shows an older, two-piece design. On the left is the overpowder portion; on the right is a 4-petaled shotcup. Figure 16.12(b) shows a one-piece, thick plastic cylinder with no petals. In this fired example, the over powder side is to the right and is flanged outward similarly to air brakes because of the propellant gases at the time of emergence from the muzzle. As the cylindrical wad travels downrange, there is no opening of petals to begin the spread of the shot column; instead, the air brakes act as the decelerating force. The end result is that the pellets are not “released” to their own flight paths until much later. This of course results in a much tighter pellet pattern at greater ranges when compared to a more conventional shotcup.

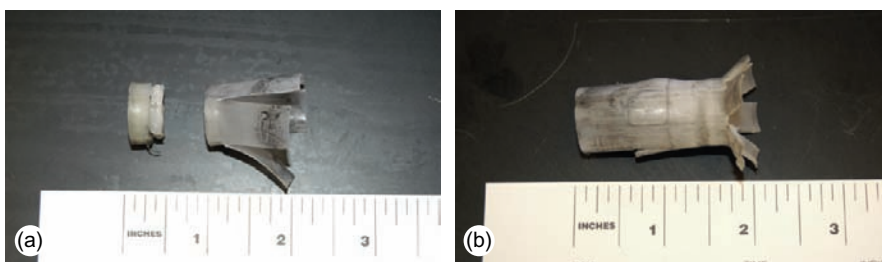


FIGURE 16.12 (a) Classic two-piece wad design. (b) Newer single-piece, thick plastic design.



FIGURE 16.13 With a 12-inch scale in view, the difference in pattern size when the distance is kept the same and only the altered ammunition is apparent.

Figure 16.13 shows three shots per ammunition type at a consistent distance of 5 yards from the muzzle. Clearly, any investigator who does not consider the type of wad in the ammunition as a major factor in pattern size could arrive at an erroneous conclusion. Without the appropriate information, conclusions about range of fire based on pellet pattern diameter should be extremely conservative.

POWDER, GUNSHOT RESIDUES, AND BUFFER MATERIAL

Traditional gunshot residues (GSRs) in the form of soot and partially consumed powder particles are often seen at close ranges of inches to a few feet. These residual materials have the same evidentiary and reconstructive value as GSRs (see Chapter 6). All of the physical forms of smokeless powder described in that chapter, with the exception of tubular powder, have been used in shotshells.

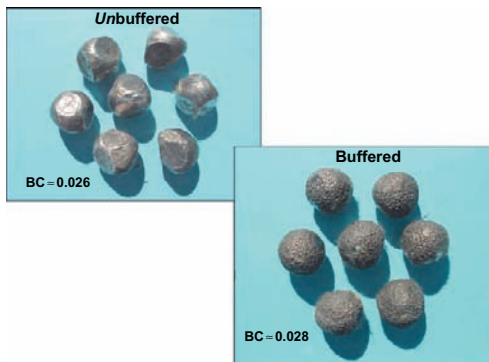


FIGURE 16.14 00 buckshot from buffered and unbuffered 12-gauge shotshells.

The flat spots on the lead pellets fired from an unbuffered shell occurred during discharge and not as a consequence of any downrange impact. Without the particles of plastic buffering material (refer to Figure 16.3) between the pellets in the unfired shell, the very high accelerative forces during discharge deform the soft lead pellets. The “orange peel” texture on the relatively undeformed buckshot pellets at the lower right is caused by the same high accelerative forces of discharge that, in this situation, produced impressions of the buffering material in the surface of the pellets and minimized their deformation.

The approximate ballistic coefficients for these 33 caliber, 53-gr lead projectiles derived from Doppler radar tracks and tests with an Oehler M43 system are also shown in this figure.

Many American shotshells also contain a granulated plastic material that fills the air spaces between the individual pellets (refer to Figure 16.3). This material is usually white and composed of either polypropylene or polyethylene. Its purpose is to reduce the deformation of the spherical lead pellets that normally occurs during the very high accelerative forces emitted during discharge. The shape, size, and composition of this buffering material are related to the brand of ammunition. It behaves very much like unburned powder and will produce very conspicuous stippling of the skin around close-range entry wounds.

Just as with powder stippling patterns, the patterns from this buffering material can be used to estimate range of fire in close-proximity shotgun wounds involving this type of ammunition. The material also produces an orange peel texture on fired buckshot pellets. Buckshot from unbuffered shells will have obvious flat spots (acquired during discharge) on their surfaces but *none* of the orange peel texture.

The two effects can be seen in Figure 16.14. Consider the implications if the medical examiner removed pellets of both types from a purported victim of an accidental shooting. The presence of pellets from a buffered and an unbuffered shotshell means that at least two shots were fired.

THE EXTERIOR BALLISTICS OF SHOTGUN PELLETS

As the muzzle-to-victim separation distance increases, the diameter of the pellet pattern increases and the margins of the entry wound now show scalloping. With a little more distance, satellite injuries from individual pellets appear outside the main entry wound. Finally, distances are reached at which the pellets have separated sufficiently that they create individual injuries or impact sites on inanimate objects. If the incident angle of a

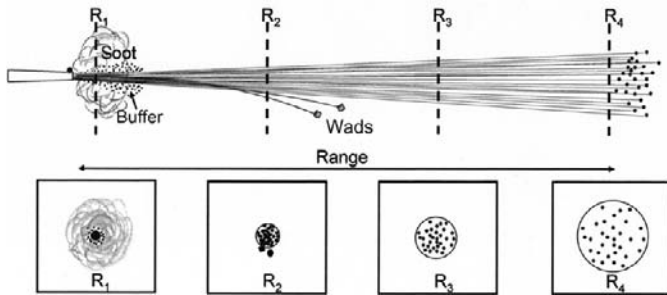


FIGURE 16.15 Witness panel pellet pattern versus range.

This illustration depicts the general behavior of the pellets, wads, buffering material, and GSR for a shotgun discharge. The vertical dashed lines represent witness panels placed at four selected distances from the muzzle of the shotgun. The lower squares show idealized results at these four ranges. At distance R_1 , soot, powder residues, and buffering material are deposited on the witness panel. Stippling of skin and other surfaces can be expected at such close range (inches to perhaps 2 feet). The pellets are en masse at these standoff distances and produce a single, large entry hole through which the wads or shotcup also pass. Distance R_2 is beyond the reach of GSR and the buffering material. The pellets have now separated sufficiently to create individual holes in the witness panel.

The two wads in this illustration have deviated to the point where they create satellite holes outside the pellet pattern. The pellet pattern in this and the remaining panels (R_3 and R_4) can be enclosed within a circle of minimum diameter. A plot of range versus average minimum pellet pattern diameter for a series of shots at selected distances will typically produce a straight line for buckshot and the larger sizes of shot over distances normally encountered in casework. The very small sizes of shot will often produce a plot of pattern diameter versus range with a slight upward curvature.

shotgun discharge is orthogonal, the pellet pattern will usually occupy a circular area the diameter of which is range dependent. This is illustrated in Figure 16.15.

The size of the pattern at any point along the discharge path is largely controlled by choke. Gauge and barrel length have very little effect on pattern unless one is dealing with a very short, sawed-off barrel. In this situation, the pellet pattern is often “blown” or disrupted by excessively high pressures at the muzzle as the pellets emerge.

Another useful phenomenon occurs with substantially sawed-off barrels when the fired shell contains a shotcup rather than cardboard wadding. The bottom skirt of the shotcup will either be everted or blown away by these high-pressure gases as it exits the muzzle.

The most common and accepted practice for determining distance is to carry out a series of shots with the gun and ammunition at selected distances and then measure the minimum diameters of the circles that include all of the pellets in each shot. A graph is then prepared from these test firings that shows the relationship between average pattern diameter and range of fire. The validity and reliability of this graph and the uncertainty limits associated with it depend on the number of shots fired at each distance. Although there is no set requirement for the number of shots at each distance, the person preparing and interpreting the results must be able to describe his procedure and provide confidence limits.

An additional consideration is the evidence pattern itself. If one has an evidence pattern that fits nicely within a 3-inch circle, there is no need to fire more than one shot at 25 feet, at which distance the pattern is many times this size. For most sizes of shot over relatively short distances such as 30 to 40 feet or fewer, the relationship between average pattern diameter and range is linear. With the smaller sizes of shot such as #8 and #9 and/or substantial increases in

distance, the plot of pattern diameter versus distance may curve slightly upward. This is due to a combination of two factors.

The spread of the pellets away from the center point of the pattern occurs at an essentially constant rate based on *time*. We have measured this lateral spread on several occasions and it is on the order of 10 to 12 feet per second. Because of the very poor ballistic coefficients of shotgun pellets, the *forward* movement of the same group of pellets decelerates *very rapidly* from its initial muzzle velocity of about 1300 fps.

The plot of average pellet pattern diameter is based on *distance*, not on the time of flight. With a constant rate of lateral spread, the pellets will move farther apart during the second half of a select distance than during the first half. This is because it takes a little more time to cover the distance between 25 and 50 feet than it takes to cover the distance between 0 to 25 feet.

Another consideration and potential difficulty is the presence of “flyers” in the evidence or test pattern. These are pellets that were probably deformed in some way and consequently strayed from the main group. This creates a quandary. Do we exclude these errant pellets? If yes, how do we make the decision that a pellet impact site is a flyer? One approach is simply to be consistent. If flyers are included in the determination of pattern diameter, this should be noted and they should be included for all test shots and the evidence pattern. The converse is also true.

An alternate solution to the problem of flyers is the *equivalent circle* method for pattern diameter determination. In this method a multisided polygon is created by drawing lines between all of the peripheral pellet strikes. The line segments are measured, added together, then divided by π to obtain the equivalent diameter of the circle having a circumference represented by sum of the line segments. This can be time-consuming, but it removes the subjective element associated with including or excluding flyers, and it minimizes the skewing effect of flyers when they are included in the minimum circle method.

The final result derived from a proper patterning of the evidence shotgun and ammunition involved in the shooting incident will be a range of distances. A typical report might read, “*Patterning of the evidence shotgun with the submitted ammunition and measurements of the pattern at the scene established a range of fire between 10 feet and 15 feet.*”

Nonorthogonal patterns on essentially flat surfaces produce an elliptical pattern whose minor axis is related to range of fire. The arcsine ($\sin^{-1}$) function on a pocket calculator can be used to determine the approximate incident angle following the division of the diameter of the minor axis by the major axis. This concept is illustrated in Figure 16.16.

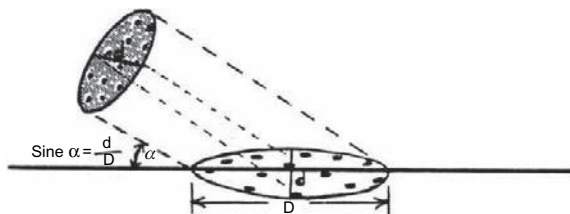


FIGURE 16.16 Nonorthogonal shot patterns at angles other than 90 degrees.

The discharge of a shotgun against a flat surface at incident angles other than orthogonal will produce an elliptical pattern much like that illustrated in this figure. The minimum diameter of this ellipse is related to the range of fire (as shown in Figure 16.15). The approximate angle of incidence can be calculated by dividing the minimum diameter by the maximum diameter of the elliptical pattern and then using the arcsine function to obtain the incident angle.

Some actual examples of this phenomenon are presented in Figures 16.17(a), (b), and (c). All of the shots were fired from 20 feet away, with a Remington, model 870 Police Magnum, 12-gauge, pump action shotgun with an 18-inch cylinder bore barrel. The ammunition used for each shot was Remington 12-gauge, 2 3/4-inch, loaded with 1 1/8 ounces of #8 lead shot.

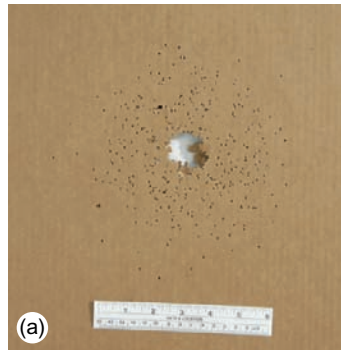


FIGURE 16.17 (a) Orthogonal shot pattern with 6-inch scale in view. (b) A 40-degree angle of intercept shot, with 6-inch scale in view. (c) A 15-degree angle of intercept shot, with 6-inch scale in view.

Careful examination of these images shows that the small diameter, or d , does not change as the pattern becomes more elliptical with shallower and shallower angles of impact. Using the scale provided in the figures, the reader can see that the numerical values of d are nominally 9 inches for each shot.

Only the D value, or long elliptical axis measurement, changes as these shots proceed from orthogonal to 40 degrees to 15 degrees. Measurement of these patterns followed by a trigonometric treatment using the inverse sine function provides the following calculated angles of impact respectively: 89, 31, and 14 degrees. Clearly this type of assessment will not provide the accuracy we hope to obtain from analysis using trajectory rods, but it does provide an avenue of investigation when other methods are not available.

From classical maximum-range computations and some actual test-firings, it can be seen that shotguns, particularly when loaded with the smaller sizes of shot, are very short-range firearms compared to rifles, which fire bullets that may travel more than a mile when fired at departure angles of 20 to 30 degrees. This is due to the very low ballistic coefficients for the shotgun's small, spherical projectiles.

We measured the ballistic coefficient for 00 buckshot with both Doppler radar and the Oehler M43 PBL system and obtained values on the order of 0.026 to 0.028. Steel air rifle BBs of 0.173-inch diameter yielded G_1 ballistic coefficient (BC) values of 0.009 to 0.010. By way of comparison, typical medium-caliber pistol bullets have BCs on the order of 0.16 to 0.20; modern rifle bullets have BCs as high as 0.50.

Some maximum-range values for several common shot sizes fired at sea level are as follows: #8: 240 yards; #6: 275 yards; #4: 300 yards; 4 buck: 480 yards; 00 buck: 610 yards. Actual firings and tracking with Doppler radar for several 00 buckshot loads gave maximum-range values of 618 and 639 yards at a site elevation of about 400 feet MSL and required departure angles of 25 to 30 degrees.

Maximum-range determinations such as these for shotguns are usually associated with potential injury causation when someone is claimed to have discharged a shotgun in someone's direction but the pellets failed to strike.

SUMMARY AND CONCLUDING COMMENTS

Although shot itself cannot normally be matched back to the gun that fired it, various class characteristic comparisons can be made between seized ammunition and fired components. These components can be numerous and varied and include shot size, wads, shot collars, shotcups, and buffer material if present. In some instances recovered shotcups and plastic over powder wads can be matched to the gun used when they have been sufficiently striated by the gun's bore.

In "no gun" cases, the gauge of the responsible gun and the brand of the shotshell can often be determined from recovered wads or shotcups. In some instances the amount and size of shot can also be determined from these components. Recovered pellets are of obvious importance, and a total pellet count in a complete pellet pattern can establish the weight of the shot charge.

It is, however, the relatively short-range ballistics of the shot, the wads, the shot collars, the shotcups, and any buffer material that are of great interest and value to the forensic

scientist or crime scene examiner attempting to reconstruct a shotgun shooting. The chemical composition and physical form of any plastic buffering material loaded in certain American shotshells have both brand identification and reconstructive value. This material can produce close-range stippling in skin much like unburned propellant particles and thereby can provide a means of estimating muzzle-to-wound distance.

The exterior ballistic behavior of all of these components can be related to range of fire as well as the vertical angle from which the particular shot originated. This information can be used to locate possible points of origin for the shot, additional physical evidence, and witnesses. If this physical evidence includes one or more fired shotshells, these can usually be matched to the gun used. Carefully conducted and evaluated test firings of the shotgun involved with the appropriate ammunition will permit the determination of the range of fire. This is useful in testing various explanations, theories, or accounts of the incident.

The four main variables to be evaluated when ensuring that test patterns are representative of the scenario being investigated are (1) ammunition type, (2) barrel length, (3) choke, and (4) barrel type.

CHAPTER KNOWLEDGE

- How would you expect a gunshot residue pattern to change if the barrel of a shotgun were cut from 24 inches down to 8 inches?
- What conclusions would you reach with regard to distance determination if the only piece of evidence you had was a pellet pattern and a few recovered pellets? What specific variables might limit your conclusions?
- Could you express the meaning of the following box labeling as it relates to the shotgun shell's loading: 3 DRAM EQ, 8 SHOT, 12 GA, 2 3/4 IN?

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Sound Levels of Gunshots, Supersonic Bullets, and Other Impulse Sounds

INTRODUCTION

The sound of gunshots is a common recollection of many witnesses at or near a shooting incident. On occasion, the sound of gunshots may also be captured by various recording devices and become a form of evidence to be submitted to the criminalist or firearms examiner in the crime laboratory. The passage of a supersonic bullet near an earwitness produces a substantial, high-intensity impulse sound that is sufficiently loud to occasionally be confused with a gunshot. These impulse sounds may be inadvertently recorded in certain circumstances. The intensities of such brief impulse sounds are very difficult to measure accurately, and there are only a very limited number of sound level meters capable of doing so.

Sound level meters allow a means of comparing the intensity of gunshot sounds under a variety of conditions as well as of evaluating the effectiveness of suppressors. With an appropriate experimental design, the meter can measure the sound levels of supersonic bullets apart from the report of the guns that fired them. For more than a century, firearms designers and manufacturers around the world have sought to minimize the sound levels of gunshots by various means, the most well known of which are so-called silencers or, more properly, suppressors.

THE NATURE OF GUNSHOTS AND THEIR MEASUREMENTS

Sound consists of very rapid and recurring pressure changes in the air as the result of some vibrating object. There are two general classes of sound: those that have a periodic (musical) character and those that are irregular, or aperiodic. We know this second type as noise. Noise can be continuous, intermittent, or very brief and loud as the result of an impact or explosion. This last type includes slamming doors, firecrackers, bursting toy

balloons, automobile backfires, and, of course, gunshots. In addition to the seemingly simple matter of a gunshot's amplitude (loudness), there are a number of parameters that are often uncertain in an actual shooting incident.

Parameters may include ammunition (bullet type and powder charge), the actual gun, gun position, and the presence of intermediate materials and barriers. Even if we later have accurate measurements of the evidence firearm (typically in the form of a peak decibel value under some standard test conditions) with the ammunition actually discharged in an incident, the results of such careful measurements still carry some difficulties for the forensic scientist who attempts to evaluate the recollections of earwitnesses or recorded gunshots.

These difficulties carry over into any attempts to apply these laboratory measurements to the actual shooting scene. The *direction* of the gunfire, the *position* of the listener or recording device, the *quality and capabilities* of the recording device, the possible *reflective or absorbent effects* of various intermediate objects and materials (houses, buildings, fences, trees, etc.)—all stand to have some effect on the impulse sound(s) at the listener's or the recording device's location.

The most troublesome aspect of the foregoing is that a good many of these parameters, which stand to affect an earwitness's judgment or a microphone's pickup of one or more gunshots, will not be fully known in an actual case situation. An excellent discussion of sound and noise, their nature and measurement, and the human response to both can be found in Brüel and Kjaer (see References).

This chapter focuses on the amplitude (peak decibel level) of gunshots, the measurement of decibel (dB) levels, the methodologies and equipment for measurement, firearms and ammunition variables, environmental variables, insight into the effectiveness of selected homemade and professionally made sound suppressors, and the peak dB levels of supersonic bullets at known standoff distances.

HUMAN EXPERIENCE AND WEIGHTED SCALES IN SOUND LEVEL METERS

At the tympanic membrane of the ear sudden pressure changes (associated with sound) are translated into nerve impulses that the brain interprets as sound. The number of pressure variations per second is called the frequency of sound and is measured in hertz. One hertz is one cycle per second. The tone of a given sound varies with the frequency. Although certain musical notes may be a pure tone (single frequency), the vast majority of sounds in our environment are made up of multiple simultaneous frequencies.

The audible frequency range for human hearing (in a young, healthy individual) is typically 20 to 15,000 Hz. By way of a familiar reference, the frequency of the first left-hand key on a properly tuned standard piano (A_0) is 27.5 Hz; middle A (just above middle C), 440 Hz; and the last right-hand key (C_8), 4186 Hz. The maximum sensitivity of human hearing occurs between 2000 and 5000 Hz. Stated another way, we are less able to hear very-low-frequency and very-high-frequency sounds possessing the same sound pressure level.

There are additional complicating factors. One is that the human ear is also less sensitive to impulse sounds such as gunshots that are less than one second in duration. Another is extremely high and low sound pressure levels. Because of our varying sensitivity to sound,

devices for measuring sound levels use weighting networks to alter meter sensitivity to compensate for human hearing acuteness at differing frequencies and sound pressure levels. These are the A and C scales available on most dB meters. The LIN scale (also called the Z scale) denotes the absence of any weighting. The A weighting scale has been traditionally used for gunshot measurements, but nothing prevents the forensic scientist equipped with a suitable sound level meter from using an alternate scale so long as the test conditions are recorded and later reported.

The C scale on most meters is more sensitive than the A scale in the lower-frequency region (less suppression below 1000 Hz) and has been recommended for very high sound levels. This has not been the practice historically but one can take readings in both modes. Any significant or substantial increase in C scale values would be due to a low-frequency component that was substantially suppressed in the A scale mode.

If the ammunition supply allows for it, measurements of multiple gunshots with all three scales can also be taken. An example will be presented later in this chapter.

Sound Pressure Levels and Their Measurement

The loudness of sounds is related to the amplitude of the pressure changes. These pressure changes are typically measured in dynes (a unit of force) per square centimeter. Sound pressure levels (SPLs) may also be expressed in microwatts of energy per square centimeter, or microPascals (μPa). The range of pressure changes perceived as sound by humans can range over a magnitude of a billion to one. This makes the preparation of a scalar system problematic for any attempts to illustrate the wide range of sound levels capable of being heard by the human ear. A logarithmic system is employed to solve this problem: the well-known decibel system. The basic unit for describing sound intensity levels is the Bel (named after Alexander Graham Bell) and the decibel.

There are 10 decibels (abbreviated dB) in a Bel. The starting or reference point for human hearing was somewhat arbitrarily chosen as that level below the human threshold of hearing, $0.0002 \text{ dynes/cm}^2$ ($20 \mu\text{Pa}$), and corresponds to the value of 0 in the logarithmic dB scale. The reader should note (and later remember) that a 0-dB level does *not* denote the total absence of sound. Rather, it is the designated threshold level for human hearing.

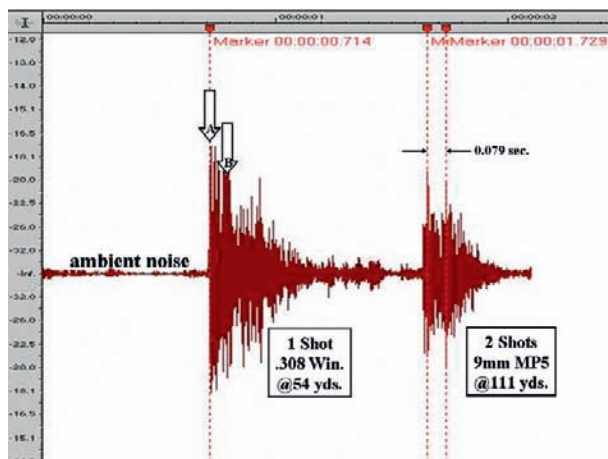
A careful inspection of the equation for deriving decibels from pressure measurements quickly reveals how the threshold value of $0.0002 \text{ dynes/cm}^2$ equates to a 0-dB level. A dB level of 140 is considered dangerous to hearing for a 1-noise impulse. This corresponds to a momentary pressure of 2000 dynes/cm^2 —a 10 million-fold increase over the previously cited human hearing threshold value.

Some representative sound level values have been excerpted from several sources and reproduced in Table 17.1. This table is not as useful as it might at first appear, for several reasons. For example, the standoff distances between source and detection device are not given for most of the entries, yet sound levels depreciate very rapidly with distance, as will be demonstrated later in this chapter (see page 308). Moreover, all of the listed sounds are of long duration; not impulse sounds such as gunshots. Nonetheless, they are presented here in an effort to provide the reader with some sense of dB levels for commonly encountered sounds.

Even with the relatively well-known decibel system, there remain some special problems associated with the measurement of the peak sound levels of gunshots. Most noteworthy

TABLE 17.1 Representative Sound Levels

Jackhammer (1 m)	150 dB
Riveting gun	130 dB
Jet takeoff (100 ft.)	130 dB
Chain saw	110 dB
Garbage disposal	80 dB
Vacuum cleaner	80 dB
Inside moving auto	70 dB
Normal conversation (3 ft.)	60 dB
Typical residence	45 dB
Whispering	20 dB
Mosquito in flight (10 ft.)	0 dB

**FIGURE 17.1** Sound Forge® spectrum of Channel 34 news videotape of three gunshots.

is their very rapid rise times, which are on the order of a few microseconds (millionths of a second). This is followed by decay times of about 10 milliseconds or more.

Figure 17.1 depicts a shot from a .308-caliber rifle followed by two gunshots from an MP5 9mm sub-machine gun recorded by a professional television camera and crew located 54 yards from the rifle and 111 yards from the MP5. The spectrum of the initial .308 shot shows the near instantaneous rise in sound pressure followed by its decay over a total time of about 0.4 seconds. The peak-to-peak time for the two shots from the MP5 directly relates to that firearm's cyclic rate of fire.

The high dB levels of gunshots (140 to 170dB(A) at 1 meter from the firearm) and the very rapid rise times means that few sound level measuring devices are capable of accurately detecting and measuring the peak values of such brief, intense sounds. Kramer (see References) used a Brüel & Kjaer (B&K) Model 2218 impulse sound level meter connected to a

B&K 1/4-in. Model 4135 microphone in an effort to measure the peak sound levels of several thousand gunshots immediately adjacent to the shooter's ear. For a particular gun-ammunition combination, he found that the reproducibility (precision) of the measurements was excellent, typically showing less than 1-dB standard deviation, and that 15 to 20 rounds were quite adequate to give a reliable picture of a gun and ammunition's peak sound pressure level.

Dr. Philip Dater (designer and manufacturer of an excellent line of firearm sound suppressors) uses a Larson-Davis Model 800B impulse sound level meter with a 1/4-in. random incident microphone to test the effectiveness of various sound suppressors under MIL-STD-1474C (8 March 1991).¹ This specification requires the measuring system to have a rise time of 20 microseconds or less. The "system" includes the microphone. If the microphone cannot respond to a pulse shorter than 100 microseconds (100 μ s), this dictates the performance of the system.

At the time of this writing, microphones and sound level meters that can adequately respond to the very rapid rise times of gunshots are the B&K 4136 and the Larson-Davis 2530 microphones and the B&K 2209 meter and several models manufactured by Larson-Davis (the 800B, the 831, and possibly the Larson-Davis LxT1). Unfortunately, the B&K 2209 was discontinued in 1980 and its manufacturer's subsequent units have 50- μ s rise times. The L-D 800B that we use has also been discontinued but used or refurbished L-D 800Bs can be found.

Kramer also studied the frequency distribution of various gunshots between 100 and 10,000 Hz and found that the peak values are at about 630 Hz. Although a broad area for the highest intensity typically occurs between 400 and 2500 Hz, there are distinct differences for some gun-ammunition combinations. A 22LR and a 22WRM in comparable barrel lengths gave peak dB values of 154 and 157, respectively (no standoff distance was given but is assumed to be the same for both firearms).

When one converts these logarithmic values to actual pressure values, this seemingly small difference of 3 dB amounts to a $1.4\times$ increase in the intensity (pressure level) of the sound for the 22WRM over the 22LR. This is undoubtedly hard for many to understand since we don't normally think or function well in the logarithmic world.

Table 17.2 should provide some insight into the relationship between decibel values and pressure values. It starts with the lowest level of sound intensity capable of being heard by the human ear: 0.0002 dynes/cm². From a brief study of this table it should become apparent that the use of the logarithmic decibel scale allows for compression of an extraordinary range of sound intensities (0.0002–20,000 dynes/cm² corresponds to a 100,000,000 increase). Some additional insight may be provided by the equation for the dB values, which starts with that for the Bel:

$$B = \log(P/P_0)^2$$

where P_0 is the threshold value of 0.0002 dynes/cm² and P is the pressure value for the particular sound intensity. The final equation for decibels can be written as

$$dB = 20 \log(P/P_0)$$

¹The current standard for dB measurements of gunshots is MIL-STD-1474D, released February 12, 1997.

TABLE 17.2 Decibel and Pressure Values

dB	Pressure dynes/cm ²
20	0.002
40	0.02
60	0.2
80	2.0
100	20.0
120	200.0
140	2000.0
160	20,000.0

Note: 1 dyne/cm² equals 0.1N/m² or 1.45×10^{-5} lbs/in.².

The first two entries in Table 17.2, 154 dB and 157 dB for the 22LR and the 22WRM provide a useful and simple example. Using the equation just described and solving for P, we have

$$154 = 20 \log(P/0.0002)$$

$$10,024 \text{ dynes/cm}^2 = P \text{ for the .22LR}$$

Carrying out the same computations for the 157-dB value (a 3-dB increase) yields a calculated pressure of 14,159 dynes/cm²—a value 1.41 times greater than the 154-dB value. For those interested in actual pressure levels, the dB equation of $20 \log(P/P_0)$ can also be rearranged to isolate the particular pressure value associated with a specific dB value. This gives

$$P \text{ (in dynes/cm}^2\text{)} = 0.0002 \times 10^{(\text{dB}/20)}$$

Precision versus Accuracy

Accuracy is the ability of a device to measure a true value. Precision is the repeatability of multiple measurements. From this it can be seen that accuracy is not possible without precision. On the other hand, it is possible to have very good precision but poor accuracy. This is analogous to target shooting. A rifle fired at a distant target might produce a very small 10-shot group (good precision), but this group is located at the 6 o'clock position with its center point 5 inches from the bullseye (poor accuracy).

Depending on the purpose of our measurements, an inability to obtain the “true” peak dB value is not necessarily fatal so long as precision is good. If, for example, one is interested only in measuring sound *reduction* due to a suppressor, it may not be necessary to obtain the true dB values so long as the with- and without-suppressor measurements have good precision and the *difference* between the two can be relied on.

A return to Figure 17.1 is useful in visualizing how the concepts of accuracy and precision might apply in dB measurements of gunshots. A device that has a sufficiently fast response time and the ability to consistently detect and store the peak value at point A in the figure would provide accurate measures. Consider a second device with a relatively slow but very

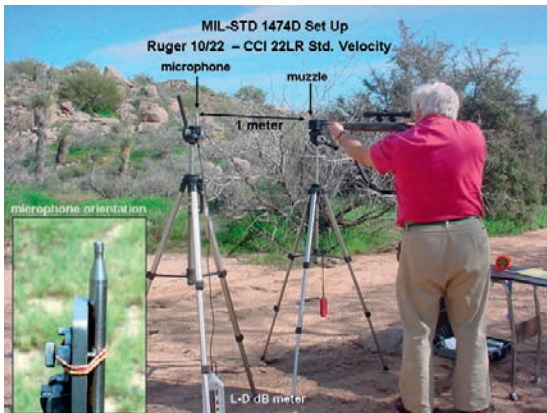


FIGURE 17.2 Freddy Mead of Devon, England, demonstrates the test configuration in February 2005 near Forensic Science Services, Carefree, AZ.

reproducible rise time that consistently detects and stores the dB level at point B. The values measured at B will not be accurate measures of the peak dB, but this is not to say that they are necessarily without value. This second “inaccurate” device may still be useful and acceptable if our purpose is to reliably measure sound *reduction* as the result of a suppressor.

This can be ascertained in a number of ways. Measuring suppressed and unsuppressed gunshots by some standardized method with a suppressor of known characteristics might be one approach. Using the very properties of sound level reduction over distance (to be discussed later) offers another approach to validating the acceptability of the “inaccurate” device. There are, however, inexpensive sound meters (about \$100 total cost) that are simply incapable of providing any useful measure of gunshot dB levels (although they may be useful for estimating the noise level coming from a sound system in a teenager’s bedroom).

Standardized Test Platform and Protocol

The previously cited MIL-STD-1474C and the current standard 1474D set down the equipment requirements and call for the microphone to be positioned 1.6 meters (63 inches) above a flat, nonreflective surface (e.g., grass) and 1 meter (39.37 inches) directly to the left and at 90 degrees to the muzzle of the firearm. Of the three scales available with most dB meters (A, C, and LIN), the A scale has been used historically. With it, the electronics in the instrument modify the measurement to approximate the response or sensitivity of the human ear. Whatever scale one elects to use, its identity should be included in the report—that is, dB(A), dB(C), or dB(LIN).

Wind and very high humidity can have an effect on the microphone used to measure dB levels of gunshots. Both the U.S. military and NATO specify that gunshot measurements are to be made when wind velocities are less than 5 m/s (16 mph). To be safe, we strongly suggest an allowable wind speed maximum of no more than 10 mph. Likewise, avoid carrying out tests when the relative humidity is at or above 90%. With humidity greater than 95%, moisture condensation on the microphone diaphragm may result in a decrease in microphone sensitivity.

The barrel of the firearm at the moment of discharge is to be parallel to the terrain. This arrangement can be accomplished with two carefully placed tripods as depicted in Figure 17.2. The minimum number of required measurements ranges from 3 to 5 whenever a pre-existing database is available (see MIL-STD-1474D, Section 5.2.1.2, p. 37). The requirements

TABLE 17.3 Peak dB Values for Selected Firearms Using MIL-STD 1474C

dB	Firearm
165	308 Winchester
163	M16
162.5	.45 Colt 1911
156	12-gauge shotgun
153	.22LR pistol-4 in. barrel
141	Ruger 10/22
139	Ruger 77/22

Source: From the work of Dr. Philip Dater.

for background levels during the measurement of peak dB levels must be at least 40 dB below the peak value (Section 5.2.2.3, p. 37).

This is easily accomplished in a reasonably quiet outdoor environment where the ambient dB level is typically on the order of 50 to 55 dB. Rise time requirements, given in MIL-STD-1474D, Section 5.3.1.1.5 (page 39), call for a rise time of no greater than 20 microseconds for the measuring device. A faster rise time would, of course, be highly desirable, but be prepared for a considerable increase in the cost of the unit. It has been found that grass is unnecessary. This, and the influence of other potential parameters that might conceivably affect dB levels, will be discussed later in this chapter.

Table 17.3 provides some of Dr. Dater's results for selected firearms and ammunition using the standard arrangement just described. Some may find it desirable or of greater interest to measure the peak sound pressure levels of a firearm at the position of the shooter's ear (with the firearm held in the normal shooting position) and possibly at alternate heights or orientations. A detailed description or photographs of such alternate arrangements are strongly recommended in actual casework. The effect on peak dB level as a result of microphone position and orientation will also be demonstrated later in this chapter.

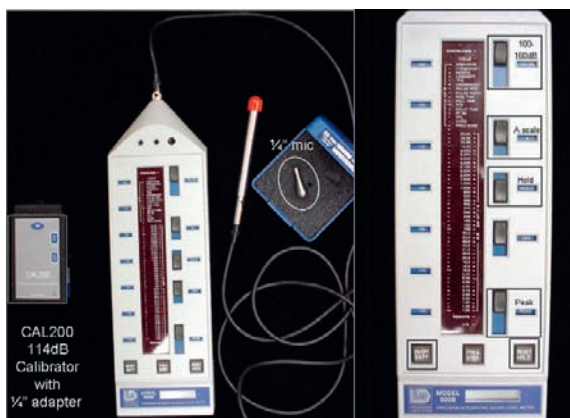
Exposure Limits and Required Hearing Protection

MIL-STD-1474D, Section 5.1.2, calls for hearing protection for any impulse sound that is greater than 140 dB. A 140-dB(A) level is very near that produced by most .22RF rifles firing .22LRHV ammunition. A complicated equation is given in Section 5.1.2 (page 36) for daily exposure limits to such sounds. These limits stand to be of interest to range masters and shooters spending prolonged time on a shooting range. Forensic firearms examiners are keenly aware of the need for adequate ear and eye protection when test-firing firearms (as evidenced by a number of older examiners wearing hearing aids or frequently asking people to repeat themselves during conversation).

Table 17.4 provides some extreme dB levels, including the level at which death of hearing tissue occurs. This stands to be of interest in civil cases where permanent hearing damage is claimed as the result of a single incident such as a burst firearm or a discharge with the muzzle very near the claimant's ear.

TABLE 17.4 A Selection of Extreme dB Values

Peak dB	Source–Effect
127.5	Tinnitus begins
150	Sensation of being compressed
158 (continuous)	Body vibrations—nausea
172	Fog created in air
174	Air begins to heat up
175.8	1 ton of TNT detonated at 250 ft.
180	Death of hearing tissue
187	1 ton of TNT detonated at 100 ft.
192.5	1 ton of TNT detonated at 60 ft.

**FIGURE 17.3** Larson-Davis 800B with Model 2530 V_c -in. random incident microphone, a sound level system and settings for dB measurements of gunshots.

Calibration and Control Tests

Figure 17.3 shows the Larson-Davis 800B system that we use, along with the appropriate settings for the measurement of gunshot dB levels. Modern dB meters capable of accurately measuring the peak dB levels of gunshots and other impulse sounds typically have some means of calibration testing and adjustment, but the devices used for this purpose involve some sort of steady tone at a particular frequency and dB level. There is a shortcoming in relying totally on such calibrators since they are neither a gunshot nor even an impulse sound of short duration.

The procedure that we describe and recommend employs a common firearm–ammunition combination discharged multiple times in a specific configuration to serve as a control and as a means of verifying proper performance of the measuring system. The average peak dB(A) values along with the standard deviation for them provide a quantitative measure of the system’s performance and can be compared to past records for the same instrument. This is of considerable importance for sharing and comparing results with others carrying out dB measurements of impulse sounds with comparable equipment.

TABLE 17.5 Control Gun/Ammunition Results for a Six-Year Period: 2003–2009

137.3 ± 0.2 (<i>n</i> = 10)	Temp. = 75° F RH = 20% P = 29.80-in. Hg Elev. = 3000-ft. MSL
137.3 ± 0.9 (<i>n</i> = 10)	Temp. = 72° F RH = 12% P = 30.10-in. Hg Elev. = 3000-ft. MSL
137.6 ± 0.6 (<i>n</i> = 10)	Temp. = 75° F RH = 80% P = 29.30-in. Hg Elev. = 5000-ft. MSL
137.6 ± 0.2 (<i>n</i> = 10)	Temp. = 66° F RH = 15% P = - Hg Elev. = 5500-ft. MSL
137.2 ± 0.6 (<i>n</i> = 5)	Temp. = 85° F RH = 16% P = 30.30-in. Hg Elev. = 7500-ft. MSL
138.1 ± 0.4 (<i>n</i> = 10)	Temp. = 62° F RH = 70% P = 30.35-in. Hg Elev. = 8500-ft. MSL
137.5 ± 0.5 dB(A)	Average

Note: Data for a Ruger 10/22 carbine with 18.5-in. barrel and CCI standard-velocity 22LR ammunition.

The concept of a reliable and reproducible control source of an actual gunshot stands to overcome the shortcomings of a constant tone calibrator. The use of the same make and model of firearm with the ammunition described herein will also allow intercomparison of data and results. This approach is little different from the use of a control specimen in other analytical methodologies such as gas chromatography (toxicology and arson analysis), and it overcomes the criticism that the customary calibration procedure is not an impulse sound or a gunshot.

Users of dB meters capable of measuring peak dB values of gunshots are free to select any firearm–ammunition combination that they deem appropriate and reliable. For a control gunshot, we selected a common Ruger 10/22 carbine with an 18.5-inch, 6-right barrel and CCI's standard-velocity, 22LR ammunition loaded with 40-gr lead round-nose bullets (product #0032). With the MIL-STD-1474D setup and our L-D 800B dB meter set on the A scale, the average peak dB(A) of this gun–ammunition combination is 137.5 ± 0.5dB(A) when tested over a 6-year period at locations ranging from 1500 to 8500 feet (1457–2590 meters) above mean sea level and over a temperature range of 60 degrees F to 85 degrees F (16 degrees C to 29 degrees C).

Three other Ruger 10/22 carbines firing the same ammunition gave results comparable with those produced by our control rifle (within ±0.2dB of each other) when tested at the same time and at the same location. A sampling of these tests is shown in Table 17.5.

In actual practice, at least five shots from the control rifle and ammunition are measured by the L-D 800B system prior to any testing, and the results compared to the target value. If there is good agreement with past results, testing of the evidence firearm and ammunition is carried out. At the conclusion of this testing a final series of a minimum of five shots with the control rifle and ammunition completes the analytical protocol.

Some Useful Examples

Over the last six years we have carried out numerous tests and comparisons, many of which will be presented in Part 2 and Part 3 of this series. We have selected a small number for inclusion in this book or two reasons:

- So that a potential purchaser of a dB meter will have a practical database to draw upon for evaluating any device under consideration.
- To provide some initial insight into the range of values that one can expect to encounter.

For the first example, we kept the rifle and standoff distance constant (our standard Ruger 10/22 with the microphone at 1 m left of the muzzle) and fired a number of brands

TABLE 17.6 Representative Results for Ruger 10/22 with Microphone, L-D 800B Using MIL-STD-1474D

Brand/Description	Lot No.	Ave. dB $\pm$ 1sd ($n = 5$)	Ave. Vel. @ 10ft.
CCI 22LR SV	E12K02	137.1 $\pm$ 0.4 dB(A)	1015 $\pm$ 6 fps
CCI 22LR SV	E10N05	136.7 $\pm$ 0.4 dB(A)	1008 $\pm$ 29 fps
Remington 22Short HV-HP	N14C2A	135.0 $\pm$ 0.5 dB(A)	1164 $\pm$ 14 fps
Remington 22LR SV	K13H1B	136.5 $\pm$ 0.3 dB(A)	1099 $\pm$ 19 fps
Remington 22LR HV-HP	Y06R2E	140.8 $\pm$ 0.5 dB(A)	1264 $\pm$ 29 fps
Federal 22LR HV-HP	4BT086	137.0 $\pm$ 0.3 dB(A)	1222 $\pm$ 10 fps
Winchester Wildcat 22LR	EE1Y	140.2 $\pm$ 0.3 dB(A)	1271 $\pm$ 11 fps
PMC Zapper 22LR	22CC2096	140.0 $\pm$ 0.2 dB(A)	1181 $\pm$ 26 fps

Note: Data for various types and brands of 22RF ammunition.

SV = standard velocity; HP = hollow point; HV = high velocity; LR = long range.

TABLE 17.7 Representative Handgun Results, with L-D 800B Using MIL-STD-1474D

Pistol Description	Barrel Length	Ammunition	Ave. dB $\pm$ 1sd ($n = 5$)	Ave. Vel. @ 10ft.
High Standard 22LR	6.0 in.	Rem. HV-HP	149.0 $\pm$ 0.3 dB(A)	1138 $\pm$ 16 fps
Raven 25 Auto	2.25 in.	Fed. 50-gr FMJ	153.3 $\pm$ 0.5 dB(A)	718 $\pm$ 6 fps
Mauser 32 Auto	3.25 in.	Blazer 71-gr TMJ	155.2 $\pm$ 0.3 dB(A)	900 $\pm$ 12 fps
Beretta 380 Auto	3.75 in.	Rem. 95-gr FMJ	156.2 $\pm$ 0.3 dB(A)	955 $\pm$ 8 fps
S&W 38 Special	4.0 in.	Win. 158-gr LRN	157.1 $\pm$ 0.5 dB(A)	719 $\pm$ 18 fps
Glock 17 9 mmL	4.25 in.	Win. 115-gr FMJ	157.4 $\pm$ 0.6 dB(A)	1199 $\pm$ 15 fps
Glock 17 9 mmL	4.25 in.	Win. 124-gr FMJ	157.4 $\pm$ 0.3 dB(A)	1126 $\pm$ 15 fps
Glock 17 9 mmL	4.25 in.	Win. 147-gr JHP	155.7 $\pm$ 1.1 dB(A)	1040 $\pm$ 5 fps
Beretta 40 S&W	4.75 in.	Win. 180-gr FMJ	158.4 $\pm$ 0.1 dB(A)	985 $\pm$ 14 fps
Colt 45 Auto	5.0 in.	Win. 230-gr FMJ	156.7 $\pm$ 0.6 dB(A)	802 $\pm$ 5 fps

Note: Fed. = Federal; Rem. = Remington; Win. = Winchester.

of .22RF ammunition, both subsonic and supersonic. The results of these tests are shown in Table 17.6.

Table 17.7 provides a sampling of results for a number of handguns. It is useful and illustrative in several ways. The firearms tested are considerably louder than the control rifle and ammunition but are more representative of firearms encountered in casework. They also cover a fairly wide range of calibers, velocity values (both subsonic and supersonic), and bullet weights.

The reader will find much of interest in these data. For example, it is somewhat surprising that supersonic shots compared to subsonic shots from the same 22 caliber rifle are not necessarily louder, although they are qualitatively different.² It should be understood that the dB(A) values are *peak* values and not an additive or integrated expression of all the

²See the Federal 22LR high-velocity hollow point results versus the CCI 22LR standard-velocity results in Table 17.6

sources of sound in a gunshot. Both tables provide velocity values (measured with a CED chronograph), a parameter that has not appeared in previous publications.

Interim Summary

The loudness of gunshots and the ability of earwitnesses to hear them at various distances and locations can be of interest in certain cases. The effectiveness of attempts to suppress the sound of gunshots, particularly with homemade devices, is another area of forensic interest and inquiry. An evaluation of the effectiveness of legally manufactured suppressors can only be accomplished with a sound level meter capable of accurately measuring dB levels. Very few sound level meters are up to this task. The previous sections provided the parameters that must be met in accurately measuring such brief and intense sounds. The results for a number of typical firearms were provided so that a potential purchaser of such equipment can test and evaluate the capabilities of a unit under consideration.

A procedure was described that will allow users of suitable dB meters to verify the proper performance of their units with a control source of gunshots. This has some advantages over a steady tone calibrator, which is often supplied with high-quality sound level meters.

The Effects of Variables on dB Measurements

A number of variables that stand to affect peak dB levels deserve mention and evaluation. These include microphone position, microphone standoff distance, scale selection, barrel length, subsonic versus supersonic discharges, muzzle pressure, and environmental variations such as humidity and altitude.

Concerns or questions regarding the last two, as well as several related parameters are effectively dealt with by revisiting Table 17.5. Relative humidity measurements ranged from a low of 12% to a high of 70% and site elevations from 3000 to 8500 feet MSL. Temperatures ranged from a low of 62 degrees F to 85 degrees F and barometric pressures from 29.30" Hg to 30.30" Hg. The average dB(A) results over this substantial distribution of environmental parameters showed no significant variation that could be attributed to any one factor or combination of factors.

Although we recommend recording the environmental conditions and site elevation at the time of testing, these results show that any effects are lost or buried within the normal statistical variation of the measurements. As a practical matter, the combined effects of temperature, humidity, and atmospheric pressure will fall within or below the typical measurement error of about ± 1 dB(A).

There are, however, some obvious environmental factors that affect instrumental measurements: reflective surfaces such as walls and concrete floors, substantial ambient noise, and wind. We strongly suggest that virtually all dB tests be carried out in an open environment in relatively calm conditions with no nearby reflective surfaces or objects that might obstruct the sound path between the muzzle and the microphone. The exception to this is a situation where one wishes to study the possible effects of intervening or reflective objects.

Perceived Sound Levels and Sound Level Meter Scales

Although we may not think in terms of logarithms, our perception of sound levels seems to respond on this basis. For example, a 3-dB difference in sound levels corresponds to a

barely perceptible change to a human listener. A 5-dB change is clearly noticeable, and a 10-dB increase is usually perceived as twice as loud. Doubling the standoff distance of a sound source over relatively short distances typically reduces the dB level by 6. But there are complicating factors. For one, a given dB level tells us nothing about the frequency content of the sound or noise. This relates to our subjective perception of the *quality* of a gunshot; a sharp *crack* for a modern centerfire rifle shooting supersonic bullets versus a *boom* for a traditional black powder rifle shooting subsonic bullets. These noticeable differences are undoubtedly related to differing frequency distributions of these types of gunshot.

MULTIPLE FIREARMS OF THE SAME MAKE AND MODEL

The control rifle used in checking the performance of our sound level meter was a common Ruger 10/22 carbine with a particular lot of standard-velocity 22LR ammunition. An important question arises out of this: *How much variation, if any, occurs if one uses another rifle of the same make, model, and barrel length?*

As a test of the possible influence of an individual rifle on peak dB values, four additional Ruger 10/22s were tested in the same manner using the same ammunition. One was stainless steel; the others were comparable to the control rifle (blued steel with a wooden stock). These rifles gave results that varied within 0.2 dB(A). The average dB(A) level of the stainless steel rifle was within 0.6 dB(A) of our control rifle.

Microphone Position and Standoff Distance

It may be of interest to some researchers and investigators to measure dB levels at the shooter's ear position or at a location other than the 1 meter directly left of the muzzle position used in many of the tests reported in this chapter. The ear position would place the microphone at a nominal 45-degree angle rearward and to the right or left of the muzzle (the choice depending on whether the shooter is right- or left-handed). In this configuration, there is some "shadowing" of the report by the subject's head, and somewhat reduced dB values can be expected compared to those when the microphone is positioned the same distance directly right or left of the muzzle. The simple fact that the sound from a firearm tends to be projected away from the gun is a contributing factor.

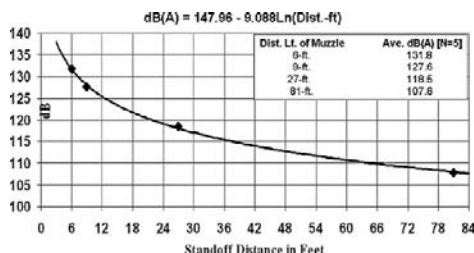
By way of example, the average dB(A) level of the Ruger Model 10/22 carbine and CCI standard-velocity ammunition was measured 1 meter left of the muzzle at 0.8 meters above ground level (AGL), at the standard 1.6-meter AGL, 1 meter right of the muzzle, and 1 meter to the rear along a 45-degree angle (all at 1.6m AGL); the results of the test is shown in Table 17.8. An inspection of this table quickly confirms that there is some reduction of the peak sound level either through shielding or shadowing of the sound by the shooter's body or due to the forward projection of the sound when dB readings are taken at the approximate position of the human ear. AGL height in this experiment made no significant difference in the average dB(A) level.

The effect of standoff distance is of considerable interest for several reasons. There may be situations where the evidence firearm is so loud as to be at the upper end or even beyond the range of the dB meter when the 1-meter standoff distance for the microphone is used. In

TABLE 17.8 Microphone Position Evaluation for a Ruger 10/22 Carbine with CCI Standard Velocity Ammunition

Position	Ave. dB(A) (<i>n</i> = 10) ± 1 sd
1 meter left – 1.6 meters AGL	138.1 ± 0.4
1 meter left – 0.8 meters AGL	138.8 ± 0.7
1 meter left-rear 45° – 1.6 meters AGL	133.5 ± 0.5
1 meter right – 1.6 meters AGL	137.7 ± 0.4

Note: Conditions: 8500-ft. MSL, 62°F, 70% RH, 30.32 in. Hg.

**FIGURE 17.4** Graph showing the relationship of decibels versus microphone standoff distance for a Ruger 10/22 rifle with CCI 22LR standard velocity ammunition.

such a situation, choosing a carefully measured distance, say 3 meters, 10 feet, or 5 meters, will result in lower, on-scale dB values.

The standoff distance and microphone position should always be included in the investigator's report. If, for some reason, it is of particular importance to obtain the standard 1-meter value (or a value even closer to the source), measurements at three or more known standoff distances can be reduced to a graphic and the equation that best fits the data points used to calculate the standard 1-meter dB(A) value.

Figure 17.4 is an example of this concept. In this case the average dB(A) level of the Ruger control rifle and ammunition was tested at 6 feet, 9 feet, 27 feet, and 81 feet. The results were reduced to a graphic in PowerPoint, and the equation that best fit the data was generated with this program. The resultant equation,

$$dB(A) = 147.96 - 9.088 \ln(\text{Dist.-ft})$$

was used to calculate the dB level at the usual 1-meter (3.2808-foot) standoff distance. This calculation produced the result of 137.2dB(A), a value in very good agreement with the 6-year average of 137.5dB(A) ± 0.5 dB for our L-D 800B system.

From this example it should be apparent how one might determine the 1-meter standoff distance value for a firearm that exceeded the capability of the dB meter at this distance. Moreover, one could calculate the dB(A) level for much closer standoff distances, which could be useful in assessing possible or likely permanent hearing damage if a particular firearm–ammunition combination were discharged very near or immediately adjacent to an individual's ear.

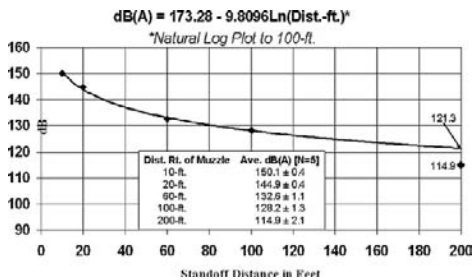


FIGURE 17.5 Graph showing the relationship of average decibels versus microphone standoff distance for a Colt 1911A1 with Winchester FMJ ball ammunition.

In the literature, the dB(A) level associated with the death of hearing tissue (refer to Table 17.4) is 180dB(A). A brief inspection of the equation for the Ruger 10/22 control rifle and ammunition gives a maximum dB(A) value of 147.96 at a distance of 0.0 feet, showing that 180dB(A) cannot be achieved with this firearm–ammunition combination.

The second and third reasons for taking measurements at various nonstandard distances is to gain some understanding of how peak dB levels depreciate over distance and to assess the sort of dB values a particular gun–ammunition combination would produce at some substantial distance from the gun. The reader is in for a bit of a surprise in this latter regard.

Fundamental physics would tell us that the amplitude (pressure level) of sound depreciates in direct relation to the square of distance. That is, a sound of intensity x at 1 meter would have an intensity of $1/4x$ at 2 meters and $1/9x$ at 3 meters, and so forth. A complicating factor to this notion is that we normally measure and report sound pressure levels in their logarithmic form of decibels.

A number of tests with both rifles and handguns were carried out with multiple measurements at various distances along a line directly to the left or right of the muzzle over open, flat terrain. These tests all revealed the same general finding; a regular relationship results (for which an equation can be derived), but it only holds out to a distance of about 100 feet. This is also true if the dB(A) values are converted to sound pressure levels. At this distance and beyond, the data fall further and further outside (below) the projected graphic.

Moreover, whether plotted as dB(A) versus distance or the analog values of SPL versus distance, the theoretical square of the distance prediction does *not* match the actual data. A major factor causing this anomalous fall-off of dB(A) values is believed to be the preferential absorption of the higher frequencies of a sound over distance by the atmosphere.

This is within our common experience if we give the matter a little thought. The sound of thunder from a nearby lightning strike has a sharp *crack*, whereas a distant lightning strike has a deep *boom*. The higher frequencies in a gunshot and in thunder are preferentially absorbed as they pass through the atmosphere, leaving the lower frequencies to travel over the greater distances. This skews and defeats the predicted dissipation of the sound of gunshots over distance.

This is not to say that useful information is unavailable from measurements of dB levels over a series of standoff distances, but it does mean that one is in perilous territory if one hopes to predict the dB levels of gunshots at considerable distances based on a set of measurements taken over much shorter distances. This revelation has resulted in “Haag’s Rule”: *You just gotta measure it!* By way of example, Figure 17.5 shows the average dB(A) results for

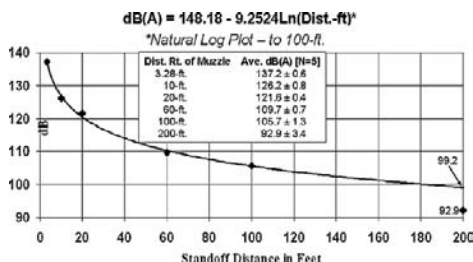


FIGURE 17.6 Graph showing the relationship of average decibels versus microphone standoff distance for a Ruger 10/22 rifle with CCI .22LR standard-velocity ammunition.

a Government 1911A1 .45 Automatic firing U.S. military ball ammunition measured over flat, unobstructed ground at distances of 10, 20, 60, 100, and 200 feet to the right of the muzzle.

These data can be plotted a variety of ways but all show a significant departure at the 200-foot distance based on any graphic representation on the earlier data points—121.3 dB(A) versus 114.9 dB(A). This same test procedure was carried out at the same site with the Ruger 10/22 control rifle and ammunition, with the same result; the 200-foot dB(A) level was markedly lower than an extrapolation of the 10- to 100-foot results—namely, 92.9 dB(A) measured against 99.2 dB(A). (See Figure 17.6.) These results (with the exception of the 200 feet) are best represented by the logarithmic equations shown in these two figures.

Sound Level Meter Scale Selection

Virtually all sound level meters offer several scales for the taking of measurements. The A scale has been used here for nearly all measurements since it mimics the variations in frequency sensitivity of the human ear. The L-D 800B sound level meter (and many others) offers a choice of three scales: A, C, and LIN (also known as the Z scale on some contemporary dB meters). Although the A scale would seem the logical choice for measuring gunshot dB levels, it was considered of interest to measure the average peak dB level of the control rifle–ammunition combination with each scale. These 10-round tests produced the following results with the microphone positioned 3 feet to the left of the muzzle:

- A scale: 138.6 ± 0.4 dB(A)
- C scale: 137.4 ± 0.8 dB(C)
- LIN scale: 142.4 ± 0.5 dB(LIN)

The site data for these tests were 3000 feet MSL, $T = 63$ degrees F, $RH = 42\%$, $P = 30.03''$ Hg. The A and C scale results for this particular gun–ammunition combination were within 1.2 dB units of each other, with the A scale results being higher. This is at odds with a prediction based on the frequency suppression aspects of the A and C scales and would suggest that the bulk of the energy source is above 1000 Hz, where the C scale has slightly more suppression than the A scale. The LIN results were substantially higher for the obvious reason that no filtering occurs with this setting.

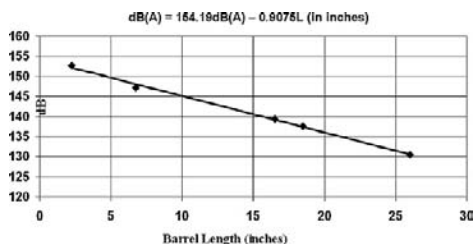
Barrel Length

Barrel length has an obvious influence on dB level. This was demonstrated with a Sterling semiautomatic pistol (2.25-inch barrel), a High Standard semiautomatic pistol (6.75-inch

TABLE 17.9 Results for .22LR Firearms with Various Barrel Lengths

Firearm – Barrel Length	Ave. dB(A) and Ave. Vel. at 10 ft.
Sterling semiautomatic pistol – 2.25-in.	152.7 ± 0.8dB(A) @ 732 ± 13 fps
High Standard semiautomatic pistol – 6.75-in.	147.2 ± 0.2dB(A) @ 944 ± 2 fps
Rossi M62 carbine – 16.5-in.	139.4 ± 0.2dB(A) @ 1036 ± 9 fps
Ruger 10/22 control rifle – 18.5-in.	137.5 ± 0.8dB(A) @ 1038 ± 17 fps
Remington 40X rifle – 28-in.	130.5 ± 0.7dB(A) @ 1064 ± 10 fps

Note: Data for CCI standard-velocity ammunition – 40 gr. LRN; average dB(A) and velocity.

**FIGURE 17.7** Graph showing the relationship between barrel length and average peak decibels for CCI standard velocity .22LR with 1M microphone standoff distance.

barrel), a Rossi M62 carbine (16.5-inch barrel), the Ruger 10/22 control rifle (18.5-inch barrel), and a Remington 40X competition rifle (28-inch barrel). These 22LR caliber firearms were tested according to MIL-STD-1474D. A CED chronograph was positioned 10 feet beyond the muzzle of each firearm. All tests were conducted at the same site and within minutes of each other. The results are given in Table 17.9.

The average dB levels for each gun were plotted against barrel length, producing the interesting graphic depicted in Figure 17.7. As can be seen, a regular relationship exists and is best expressed by the equation

$$\text{dB(A)} = 154.19 \text{ dB(A)} - 0.9075 L$$

where L equals barrel length in inches. It is interesting to consider the barrel length required to produce a dB(A) level of 0 (the assumed threshold for human hearing). This computation yields a barrel length of 169.9 inches (14.2 feet). Conversely, inserting 0 for a barrel length in this same equation produces a theoretical dB(A) level of 154.19.

Supersonic versus Subsonic Shots

The same three rifles were used, this time with Winchester Xpert 22LR-HVHP ammunition to evaluate the effect of supersonic-versus-subsonic bullets of the same basic size and caliber. The Sterling and High Standard pistols were not used for this demonstration since the ammunition produced subsonic bullets when fired from these pistols. Table 17.10 republishes the results for these three rifles with the subsonic CCI ammunition along with the

TABLE 17.10 CCI Standard-Velocity .22LR versus Winchester Xpert High-Velocity Results for Three Barrel Lengths

Firearm – Barrel Length	Ave. dB(A) and Ave. Vel.* at 10 ft.
Rossi M62 carbine – 16.5-in.	139.4 ± 0.2 dB(A) @ 1036 ± 9 fps
<i>Rossi M62 carbine – 16.5-in.</i>	<i>141.1 ± 1.0 dB(A) @ 1173 ± 26 fps</i>
Ruger 10/22 control rifle – 18.5-in.	137.5 ± 0.8 dB(A) @ 1038 ± 17 fps
<i>Ruger 10/22 control rifle – 18.5-in.</i>	<i>138.8 ± 0.6 dB(A) @ 1174 ± 8 fps</i>
Remington 40X rifle – 28-in.	130.5 ± 0.7 dB(A) @ 1064 ± 10 fps
Remington 40X rifle – 28-in.	130.4 ± 1.1 dB(A) @ 1198 ± 9 fps

*The velocity of sound at this site was approximately 1127 fps.

Note: Winchester high-velocity values in italics.

average dB(A) and average velocity values obtained with the supersonic Winchester ammunition (shown in italics).

The results of the tests are somewhat surprising in that a nominal 1-dB increase took place with the two relatively short-barreled rifles but no increase occurred with the long-barreled Remington 40X. Since the L-D 800B dB meter records the *peak* value (and *not* the first pressure wave to reach the microphone), one might conclude that the elevated dB(A) values were a measure of the sonic *crack* (shock wave) produced by the supersonic Winchester bullets, and that this *crack* was essentially 1 dB louder than the gunshot itself. This hypothesis immediately fails when one examines the Remington 40X results, which found no significant difference between supersonic and subsonic discharges.

An alternate hypothesis might be the gas pressures (blast) at the muzzle as the bullet emerges. Under this hypothesis those pressures were sufficiently similar to the gas pressures of the long-barreled Remington 40X rifle that any small difference had no measureable effect on the dB(A) levels. The matter of subsonic versus supersonic projectiles will be revisited at the end of this chapter.

VELOCITY AND MUZZLE PRESSURE VERSUS PEAK dB

It would seem logical that peak dB values associated with the discharge of a firearm would bear a close relationship to muzzle velocity or muzzle pressure or both. To test these hypotheses a series of 223 Remington handloads were assembled using incremental amounts of Alliant's Reloder 15 powder and Speer 55-gr FMJ-BT (M193) bullets. The powder charges ranged from 12.0- to 26.0-gr and were loaded in 2.0-gr increments with 3 rounds for each load. A 20-inch AR-15 was used along with a CED chronograph positioned 10 feet in front of the muzzle.

For this particular test, the L-D 1/4-inch microphone was placed 10 feet to the left of the muzzle. The site conditions were as follows: 3000 feet MSL, 72 degrees F, 19% RH, 29.90" Hg. The muzzle pressure values for each shot were subsequently calculated with the *QuickLOAD* program and the shot's measured muzzle velocity. The results of these shots and muzzle pressure calculations are given in Table 17.11. It should be noted that all of these bullets were supersonic.

TABLE 17.11 Average dB(A), Velocity, and Pressure Results for Tests Done with 20-in., 1-in., and 7-in. Twist AR-15

Velocity	dB(A)	Calculated Muzzle Pressure
1388 fps	135.6	2300 psi
1408 fps	135.4	2367 psi
1570 fps	136.3	3026 psi
1598 fps	136.8	3138 psi
1623 fps	138.4	3218 psi
1650 fps	137.9	3334 psi
1843 fps	138.3	4130 psi
1845 fps	138.5	4135 psi
1891 fps	139.3	4347 psi
1987 fps	140.0	4755 psi
2003 fps	139.6	4804 psi
2056 fps	141.3	5035 psi
2270 fps	141.4	5900 psi
2281 fps	141.9	5950psi
2303 fps	141.5	6044 psi
2451 fps	142.1	6673 psi
2464 fps	142.0	6695 psi
2506 fps	142.0	6867 psi
2798 fps	143.4	7943 psi
2811 fps	143.0	7990 psi
2820 fps	142.6	8024 psi
3006 fps	143.0	8638 psi
3020 fps	143.4	8679 psi
3077 fps	143.0	8856 psi

* Velocity values measured at 10 ft beyond the muzzle with a CED chronographs; results arranged according to increasing velocities.

Note: Muzzle pressure values calculated from the QuickLOAD® program; reloader 15 propellant; Speer 55-gr FMJ-BT bullet; Met./site data 3000-ft. MSL 72°F 19% RH 29.90-in. Hg.

The same data were also plotted in the xy coordinate system. “Best fit” equations were then made as linear, logarithmic, exponential, and polynomial functions of the data. The polynomial equation gave the best fit for both the dB(A) versus velocity and dB(A) versus muzzle pressure (see Figures 17.8 and 17.9).

Similar experiments were carried out with a 7.62×39 mm SKS and a long-barreled 44-40 lever action rifle using incremental loadings of propellants suitable for these firearms. The experiments produced plots of muzzle pressure and muzzle velocity versus dB(A) that were more linear than those generated by the AR-15. This was apparently due to the lower muzzle pressures and muzzle velocities generated by these firearms and propellant charges. The tests with these rifles did support the earlier observation that there is no sudden or

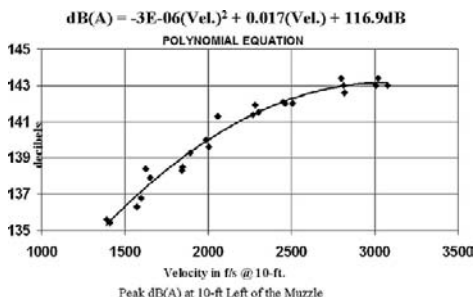


FIGURE 17.8 Graph showing the relationship between velocity and peak dB(A) for an AR-15 H-Bar rifle with 20-in. barrel; handloads with reloder 15 powder and 55-gr FMJ bullets.

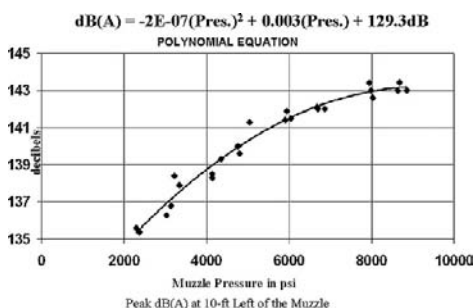


FIGURE 17.9 Graph showing the relationship between calculated muzzle pressure and peak dB(A) for an AR-15 H-Bar rifle with 20-in. barrel; handloads with reloder 15 powder and 55-gr FMJ bullets.

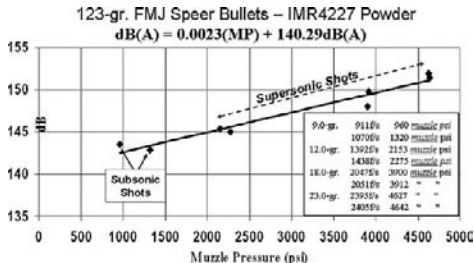


FIGURE 17.10 Graph showing the relationship between calculated muzzle pressure and peak dB(A) for a Russian SKS rifle with 20-in. barrel; tests were 7.62×39 mm at 10-ft stand-off distance.

noticeable jump in dB(A) values when the initial velocities of the bullets go from subsonic to supersonic. A careful inspection of Figures 17.10 and 17.11 illustrate this.

Interim Summary

Some of the most common questions and issues arising from the measurement of gunshot decibel levels were addressed in the preceding sections. The various experimental results listed in the tables and illustrated in the figures should give the reader a relatively clear understanding of what one can anticipate regarding the effects of environmental factors, microphone position, and microphone standoff distance, as well as gun-ammunition variables.

Suggested techniques and limitations for calculating dB levels at locations other than the actual microphone location were described.

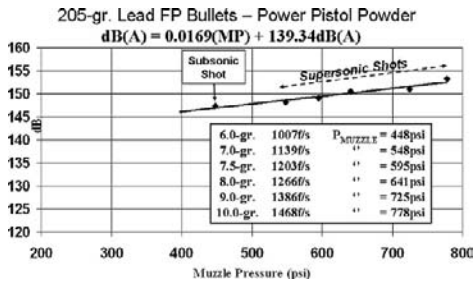


FIGURE 17.11 A graph showing the relationship between calculated muzzle pressure and peak dB(A) for a Winchester '73 rifle with 30-in. barrel; tests were .44-40 at 1M standoff distance.

Some situations may involve the dB level of gunshot sounds at some distance from the source compared to non-firearm-generated noise at the listener's location. For example:

How loud is a gunshot from a particular gun–ammunition combination fired 100 yards distant from a person located in a living room of an apartment as compared to the slamming of a door at the adjacent apartment? Would a gunshot at some given distance be significantly louder than the ambient background noise? How much louder must a distance impulse sound be to be readily noticeable? How do gunshots compare to other impulse sounds such as the popping of a toy balloon or a paper bag?

Suppressed and Unsuppressed Firearms

There is a substantial amount of advertising information available and a few trade publication articles regarding the amount of sound suppression accomplished by various brands of professionally manufactured suppressors. It is not the purpose of this chapter to generate a lengthy list of test results for a variety of firearms. A few representative examples, listed in Table 17.12, will suffice. The table also provides an opportunity to observe the effect of suppressors on bullet velocity and compares equivalent peak sound pressure levels for suppressed and unsuppressed shots from a number of firearms. This information has seldom, if ever, been provided in other sources.

The matter of supersonic-versus-subsonic ammunition in the same suppressed firearm is an additional parameter to be addressed here. The A-weighted sound pressure levels (dB(A) values) for a number of commercial suppressors fitted to a representative sampling of firearms were tested using the Larson-Davis 800B sound level meter described earlier in this chapter. In several instances the standoff distance was modified from the previously described MIL standard of 1 meter directly left of the muzzle to 3 meters (9.8 feet), as noted in Table 17.12. This was necessary because the unsuppressed report of the test firearm was at or near the upper limit of the L-D 800B. The last three entries in this table are noteworthy in that the firearm (an M14 rifle) and suppressor were held constant and the ammunition was varied.

This approach was pursued further with a popular 22 caliber pistol (the Walther P22) and a state-of-the-art suppressor (a Gemtech OUTBACK-II), shown in Figures 17.12(a) and (b). This combination was singled out for a second series of tests in an evaluation of different brands and types of 22 caliber rimfire ammunition discharged with and without the suppressor. These tests compared supersonic against subsonic ammunition followed by cartridges with ever-decreasing power and velocity. The results of these tests are given in Table 17.13.

TABLE 17.12 Selected Suppressor Tests

Firearm	Ammunition	Ave. dB(A) Unsuppressed	Suppressor	Ave. dB(A) Suppressed
Beretta	Remington 22LR	144.4 ± 0.3 (n = 5)	Gemtech Slimline	116.2 ± 4.5 (n = 5)
<i>Bobcat</i>	Subsonic	microphone 1M left		= 28.2 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 721 ± 16 fps to 757 ± 16 fps with the suppressor. The dB(A) level of the first suppressed shot was 124.0. All subsequent shots were ca. 10 dB(A) lower. The average dB(A) values convert to peak pressure levels of 3319 and 129 dynes/cm ² for a 25.7-fold peak pressure reduction.				
F-N	5.7 × 28 mm	155.9 ± 0.3 (n = 5)	Gemtech SFN-57	125.8 ± 2.2 (n = 5)
<i>FiveSeven</i>	SS192 ball	microphone 1M left		= 30.1 dB(A) reduction
Notes: The dB(A) level of the first suppressed shot was 129.0. All subsequent shots were lower by 4–5 dB(A). The average dB(A) values convert to peak pressure levels of 12,475 and 390 dynes/cm ² for a 32-fold peak pressure reduction.				
Colt 1911A1	S&B 45ACP	149.3 ± 0.2 (n = 5)	Gemtech SOS45	134.3 ± 2.4 (n = 5)
	230-gr. FMJ	microphone 3M left		= 15.0 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 869 ± 17 fps to 854 ± 14 fps with the suppressor. The average dB(A) values convert to peak pressure levels of 5835 and 1038 dynes/cm ² for a 5.62-fold peak pressure reduction.				
H/K SOCOM	S&B 45ACP	149.2 ± 0.2 (n = 5)	Knight OHG	128.9 ± 3.0 (n = 5)
<i>Mark 23</i>	230-gr. FMJ	microphone 3M left		= 20.5 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 879 ± 10 fps to 834 ± 17 fps with the suppressor. The average dB(A) values convert to peak pressure levels of 5768 and 557 dynes/cm ² for a 10.4-fold peak pressure reduction. Suppressed shot 1 gave 134.1 dB(A); all subsequent shots were ca. 7 dB(A) lower.				
H/K USP	S&B 45ACP	150.0 ± 0.1 (n = 5)	TAC-003	139.5 ± 1.9 (n = 5)
	230-gr. FMJ	microphone 3M left		= 10.5 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 874 ± 10 fps to 890 ± 6 fps with the suppressor. The average dB(A) values convert to peak pressure levels of 6325 and 1888 dynes/cm ² for a 3.35 fold peak pressure reduction. Suppressed shot 1 gave 142.4 dB(A); all subsequent shots were ca. 2–3 dB(A) lower.				
M14 rifle	MAL 7.62NATO	152.0 ± 0.3 (n = 5)	M14-DC	135.0 ± 1.1 (n = 10)
	147-gr. FMJ	microphone 3M left		= 17.0 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 2688 ± 19 fps to 2739 ± 20 fps with the suppressor. The average dB(A) values convert to peak pressure levels of 7962 and 1125 dynes/cm ² for a 7.08-fold peak pressure reduction. Suppressed shot 1 gave 136.9 dB(A); all subsequent shots were ca. 2 dB(A) lower.				
M14 rifle	Hornady TAP	152.2 ± 0.2 (n = 10)	M14-DC	134.0 ± 1.3 (n = 10)
	168-gr. JSP	microphone 3M left		= 18.2 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 2620 ± 15 fps to 2628 ± 7 fps with the suppressor. The average dB(A) values convert to peak pressure levels of 8148 and 1002 dynes/cm ² for an 8.13-fold peak pressure reduction. Suppressed shot 1 gave 136.8 dB(A); all subsequent shots were ca. 2 dB(A) lower.				
M14 rifle	Fed. Gold Medal	152.0 ± 0.4 (n = 10)	M14-DC	133.3 ± 1.5 (n = 10)
	168-gr. JHP	microphone 3M left		= 18.7 dB(A) reduction
Notes: The average velocity values at 7 ft. went from 2601 ± 18 fps to 2593 ± 14 fps with the suppressor. Suppressed shot 1 gave 136.4 dB(A); all subsequent shots were ca. 2–3 dB(A) lower. The average dB(A) values of 152.0 and 133.3 convert to peak pressure levels of 7962 and 925 dynes/cm ² for an 8.61-fold peak pressure reduction. Bolt closure without a cartridge gave an average dB(A) of 107.6 ± 1.0 and with a cartridge, 103.8 ± 1.1 (n = 5).				



FIGURE 17.12 (a) Walther P22 and OUTBACK-II suppressor. (b) Walther P22 with OUTBACK-II suppressor attached.



An inspection of the data in this table reveals several matters of interest. The A-weighted sound pressure levels of the subsonic CCI Mini-Mag and the Federal Lightning cartridges, with velocities on the order of 950 and 1000fps at 10 feet beyond the muzzle, were suppressed by 28.7 and 28.8 decibels, respectively, whereas the supersonic CCI Stinger rounds, at an average velocity of 1223fps were only suppressed by 21.1 decibels.

This substantial difference can be appreciated better when the average dB(A) level of 130.0 for the suppressed supersonic CCI Stinger shots and the average dB(A) for the two suppressed subsonic cartridges of 122.3 are converted to analog peak pressure levels. The dB(A) values of 130.9 for the suppressed supersonic CCI Stinger ammunition and 122.3 for the subsonic ammunition translate to peak pressure values of 702 dynes/cm² and 261 dynes/cm², respectively, a nearly threefold reduction in peak pressure level. By way of comparison, the mere closing of the slide of the P22 pistol registered 107 dB(A). The fall of the hammer on an empty chamber produced a value of 108 dB(A).

The individual velocity values for each shot in these tests were compared with the associated dB values to see if there was either a direct relationship (high velocity = high dB) or an inverse relationship (high velocity = low dB). A plot of dB(A) versus velocity for the suppressed and unsuppressed CCI Mini-Mag showed *no* relationship between velocity and dB(A) level. (See Figures 17.13(a) and (b).)

This was of interest since it was postulated that the bullets launched with the higher velocities might also have higher muzzle pressures and therefore higher dB(A) values. The reciprocal notion was also considered, that bullets with lower velocities might be the

TABLE 17.13 Suppressor Results for a Walther P22 Pistol and Gemtec OUTBACK-II Suppressor with MIL-STD-1474D Setup – Averages of Five Measurements

	Ave. Vel. @10Ft	Average dB(A)	dB(A) Reduction
<i>CCI STINGER 22LR 32-GR CU-PLATED HP</i>			
No Suppression	1181 ± 36 fps	152.0 ± 0.8 dB(A)	–
With Suppressor	1223 ± 35 fps	130.9 ± 1.4 dB(A)	21.1 dB(A)
<i>CCI MINI-MAG 22LR 40-GR CU-PLATED HP</i>			
No Suppression	933 ± 16 fps	151.1 ± 0.7 dB(A)	–
With Suppressor	950 ± 28 fps	122.3 ± 1.3 dB(A)	28.8 dB(A)
<i>FEDERAL LIGHTNING 22LR HIGH-VELOCITY 40-GR LRN</i>			
No Suppression	991 ± 15 fps	151.0 ± 0.7 dB(A)	–
With Suppressor	1000 ± 14 fps	122.3 ± 1.3 dB(A)	28.7 dB(A)
<i>CCI CB 31-GR 22SHORT LRN</i>			
No Suppression	645 ± 26 fps	145.0 ± 0.8 dB(A)	–
With Suppressor	645 ± 24 fps	118.0 ± 1.9 dB(A)	27.0 dB(A)
<i>AGUILA COLIBRI 22LR 20-GR CONICAL LEAD BULLET</i>			
No Suppression	349 ± 12 fps	133.1 ± 1.3 dB(A)	–
With Suppressor	9 fps	115.1 ± 1.9 dB(A)	18.0 dB(A)

consequence of less than complete burning of the propellant in the barrel followed by ignition in the atmosphere upon emergence, thus producing an elevated dB(A) level. Neither of these hypotheses is supported by a study of the figures.

Homemade Suppressors

A host of homemade suppressors have appeared over the years, ranging from the very crude (raw potatoes stuck on the end of the barrel, plastic drink bottles filled with some sort of packing taped to the barrel) to the relatively sophisticated (e.g., devices with baffles and heat-absorbing fillers). Six devices, ranging from an automotive oil filter to various assemblages of plastic pipe with some type of silicon rubber as a filler or end plug, were attached to a Ruger 10/22 carbine and tested according to the usual MIL-STD-1474D protocol. The results are given in Table 17.14.

Pillows as Silencers

One of us has been involved in several murder cases over the last 45 years in which common pillows were used to reduce the report of a firearm. We selected five handguns for some dB(A) suppression measurements with common bed pillows containing either polyester fiber or duck down. Data on the effectiveness of pillows, along with the ammunition used, are presented in Table 17.15.

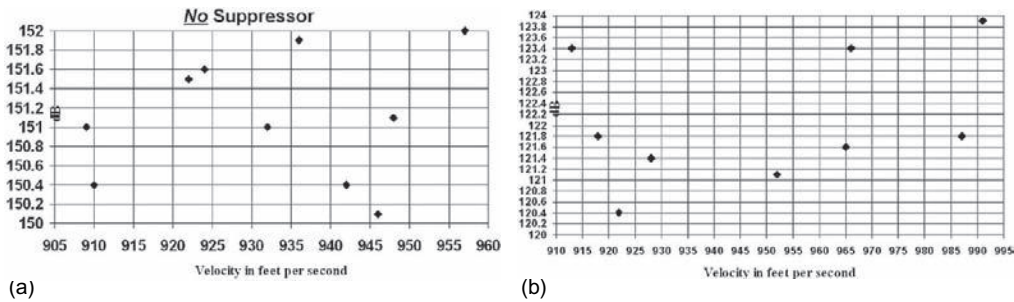


FIGURE 17.13 (a) Graph showing the relationship between calculated peak dB(A) and velocity for a Walther P22 pistol with CCI 22LR Mini-Mag *without* a suppressor. (b) Graph showing the relationship between calculated peak dB(A) and velocity for a Walther P22 pistol with CCI 22LR Mini-Mag *with* a Gemtech OUTBACK-II suppressor.

TABLE 17.14 Results for Six Homemade Suppressors for a Ruger 10/22 Carbine and L-D 800B with MIL-STD-1474D Setup

Suppressor	Ave. dB(A) Suppressed	Ave. dB(A) Reduction	Equivalent Peak Pressure Level
WINCHESTER WILDCAT 22LRHV AVERAGE dB(A) = 141.4 ± 0.3 dB(A) (n = 10)			
Equivalent Peak Pressure = 2350 dynes/cm ²			
1	131.0 ± 1.6 (n = 10)	10.4	10 dynes/cm ² = 3.3x reduction
2	129.4 ± 1.3 (n = 10)	12.0	590 dynes/cm ² = 4.0x reduction
3	132.6 ± 3.6 (n = 10)	8.8	853 dynes/cm ² = 2.8x reduction
4	129.9 ± 2.2 (n = 10)	11.5	625 dynes/cm ² = 3.4x reduction
5	128.7 ± 1.5 (n = 10)	12.7	545 dynes/cm ² = 4.3x reduction
6	129.0 ± 0.6 (n = 10)	12.4	564 dynes/cm ² = 4.2x reduction
CCI STANDARD VELOCITY 22LR AVERAGE dB(A) = 137.8 ± 0.9 dB(A) (n = 10)			
Equivalent Peak Pressure = 1552 dynes/cm ²			
1	125.3 ± 0.5 (n = 10)	12.5	368 dynes/cm ² = 4.2x reduction
2	124.2 ± 1.6 (n = 10)	13.6	324 dynes/cm ² = 4.8x reduction
3	129.9 ± 2.2 (n = 10)	7.9	625 dynes/cm ² = 2.5x reduction
4	123.0 ± 0.6 (n = 10)	14.8	282 dynes/cm ² = 5.5x reduction
5	123.2 ± 0.6 (n = 10)	14.6	289 dynes/cm ² = 5.4x reduction
6	122.2 ± 1.3 (n = 10)	15.6	258 dynes/cm ² = 6.0x reduction

The dB(A) levels for the selected firearms and ammunition were measured with the Larson-Davis 800B system, with the microphone positioned 10 feet directly to the left of the muzzle. First, the 22 caliber revolvers were fired with their muzzles pressed tightly against a pillow containing polyester fill but *without* covering the cylinder gaps. Next a single shot from each of the centerfire revolvers was fired with a polyester-fill pillow folded over each

TABLE 17.15 Pillows as Silencers

.22LR RIMFIRE REVOLVERS—MUZZLE ONLY IN THE PILLOW		
H&R Model 626 22LR with 5.5-in. Barrel – Winchester Wildcat 40-gr LRN		
Average dB(A) ($n = 10$) = 138.7 $\pm$ 1.2 dB		
Pillow shots = 137.3/138.8 dB		
dB reduction negligible		
High Standard Model R101 22LR with 3-in. Barrel – Winchester Wildcat 40-gr LRN		
Average dB(A) ($n = 10$) = 140.6 $\pm$ 0.4 dB		
Pillow shots = 139.6/139.9 dB		
dB reduction negligible		
CENTERFIRE REVOLVERS – CYLINDER COVERED		
S&W Model 15 38 Special Revolver, 4-in. barrel with Remington-UMC 158-gr LRN		
Ave. vel. @ 10 ft.	Avg. dB(A) @ 10 ft. Lt.	dB(A) polyester pillow shot @ 10 ft.
742 $\pm$ 20 fps ($n = 7$)	146.4 $\pm$ 0.7 ($n = 7$)	123.3 (23.2 dB(A) reduction)
<i>Peak Pressure Reduction</i>		
Average dB(A) @ 10 ft. = 146.4 dB(A) = 4178.6 dynes/cm ²		
Pillow shot = 123.3 dB(A) @ 10 ft. = 292.4 dynes/cm ² = 93% reduction		
RUGER BLACKHAWK 357 MAGNUM REVOLVER, 6.5-IN. BARREL WITH FEDERAL 125-GR JHP		
Ave. vel. @ 10 ft.	Ave. dB(A) @ 10 ft. Lt.	dB(A) polyester pillow shot @ 10 ft.
1422 $\pm$ 22 fps ($n = 7$)	151.7 $\pm$ 0.4 ($n = 7$)	144.5 (7.2 dB(A) reduction)
<i>Peak Pressure Reduction</i>		
Average dB(A) @ 10 ft. = 151.7 dB(A) = 7691.8 dynes/cm ²		
Pillow shot = 144.5 dB(A) @ 10 ft. = 3357.6 dynes/cm ² = 56% reduction		
SEMIAUTOMATIC PISTOL—FOLDED PILLOW		
S&W M39 9MM WITH 4-IN. BARREL, WINCHESTER 115-GR FMJ		
Ave. vel. @ 10 ft.	Ave. dB(A) @ 10 ft. Lt.	dB(A) polyester pillow shots @ 10 ft.
1146 $\pm$ 17 fps ($n = 5$)	145.7 $\pm$ 0.5 ($n = 5$)	123.5 (22.2 dB(A) reduction)
		121.5 (24.1 dB(A) reduction)
<i>Peak Pressure Reduction</i>		
Average dB(A) @ 10 ft. = 145.7 dB(A) = 3855 dynes/cm ²		
Pillow shot-1 = 123.5 dB(A) @ 10 ft. = 299 dynes/cm ² = 92% reduction		
Pillow shot-2 = 121.5 dB(A) @ 10 ft. = 240 dynes/cm ² = 94% reduction		
S&W M39 9MM WITH 4-IN. BARREL, WINCHESTER 115-GR FMJ		
Ave. vel. @ 10 ft.	Ave. dB(A) @ 10 ft. Lt.	dB(A) duck down pillow shots @ 10 ft.
146 $\pm$ 17 fps ($n = 5$)	145.7 $\pm$ 0.5 ($n = 5$)	132.1 (13.6 dB(A) reduction)
		139.1 (6.6 dB(A) reduction)

TABLE 17.15 (Continued)*Peak Pressure Reduction*Average dB(A) @ 10 ft. = 145.7 dB(A) = 3855 dynes/cm²Pillow shot-1 = 132.1 dB(A) @ 10 ft. = 805 dynes/cm² = 79% reductionPillow shot-2 = 139.1 dB(A) @ 10 ft. = 1803 dynes/cm² = 53% reduction**S&W M39 9MM WITH 4-IN. BARREL, FEDERAL 124-GR JHP +P+**

Ave. vel. @ 10 ft.	Ave. dB(A) @ 10-ft. Lt.	dB(A) polyester pillow shots @ 10 ft.
1171 ± 8 fps (<i>n</i> = 5)	146.5 ± 0.8 (<i>n</i> = 5)	133.1 (13.4 dB(A) reduction)
		125.6 (20.9 dB(A) reduction)

*Peak Pressure Reduction*Average dB(A) @ 10 ft. = 146.5 dB(A) = 4227 dynes/cm²Pillow shot-1 = 133.1 dB(A) @ 10 ft. = 904 dynes/cm² = 79% reductionPillow shot-2 = 125.6 dB(A) @ 10 ft. = 381 dynes/cm² = 91% reduction**S&W M39 9 MM WITH 4-IN. BARREL, FEDERAL 124-GR JHP +P+**

Ave. vel. @ 10 ft.	Ave. dB(A) @ 10-ft. Lt.	dB(A) duck down pillow shots @ 10 ft.
1171 ± 8 fps (<i>n</i> = 5)	146.5 ± 0.8 (<i>n</i> = 5)	130.9 (15.6 dB(A) reduction)
		131.6 (14.9 dB(A) reduction)

*Peak Pressure Reduction*Average dB(A) @ 10 ft. = 146.5 dB(A) = 4227 dynes/cm²Pillow shot-1 = 130.9 dB(A) @ 10 ft. = 702 dynes/cm² = 83% reductionPillow shot-2 = 131.6 dB(A) @ 10 ft. = 760 dynes/cm² = 82% reduction

in an effort to cover their cylinder gaps. Velocity values at 10 feet beyond the muzzle for the two centerfire revolvers were also measured with a CED chronograph and are included in the data.

An S&W Model 39 9 mm semiautomatic pistol was discharged in a similar manner (pillow folded) so that the ejection port was covered and the slide restricted. Pillows with polyester fill and duck down were used for these final tests. The most conspicuous finding from a study of this table is that *no* significant reduction in the peak dB level of a revolver is likely to occur unless the cylinder and cylinder gap are tightly wrapped in the pillow.

There are several additional aspects of importance to firearms examiners in cases where a pillow has been used to muffle the report of a firearm. Substantial and conspicuous gunshot residues will typically be deposited on the entry side of the pillow and along the bullet's path through the pillow. Unburned and partially burned powder particles can be expected along the bullet's path. Thermal effects in the form of melted and partially melted polyester fibers will typically be present at the entry hole in pillows containing this filler. Useful pattern information may also be present that relates to the design of the responsible firearm. Cylinder gap deposits coupled with muzzle deposits not only identify the firearm as a revolver but also provide a useful indicator of barrel length. (See Figure 17.14.)



FIGURE 17.14 A pillow and gun after the discharge of a Ruger Blackhawk. Note the obvious barrel length relationship between the cylinder gap deposits and damage and the muzzle deposits and entry hole.

Semiautomatic pistols may leave a faint deposit of gunshot residue from the chamber-ejection port area in addition to substantial deposits from the muzzle. Processing such a pillow with an appropriate gunshot residue reagent such as sodium rhodizonate will further reveal useful pattern information. Some of the pillow's filler will be driven into the entry wound. Common fillers are polyester fiber or goose/duck down. Some filler should also be found embedded in the nose/ogive area of lead bullets and in the hollow-point cavities of JHP bullets.

SUPERSONIC BULLETS

As the distance from a firearm such as a high-powered rifle increases, the dB level of the gunshot rapidly decreases. However, a supersonic bullet passing near a person located downrange will be quite loud and may, under certain circumstances, be mistaken for a gunshot. This misperception can lead to all sorts of perceptual errors on the part of earwitnesses that deserve to be recognized and understood by investigators and forensic firearms examiners.

Anyone who has pulled targets on a 500- or 1000-yard high-powered rifle range has experienced the sound of a supersonic bullet passing overhead. The shock wave emanating from such a bullet is comparable to the *crack* of a bullwhip. Unlike subsonic bullets, the approach of supersonic bullets cannot be heard by earwitnesses since the velocity of such bullets is above the speed of sound. Any sense of direction of the shot based on the *crack* heard by a downrange earwitness is likely to be misleading at best and simply in error at worst. Moreover, the actual report of the responsible firearm may be obscured by the *crack* or simply so quiet that it is not recognized as an associated event.

This misperception is illustrated in Figures 17.15(a) and (b). The gun's report will, of course, reach the downrange earwitness *after* the arrival and passage of the bullet. This phenomenon, known as "lagtime," if recorded, has useful reconstructive properties, as was discussed in Chapter 13.

Distances of 100 to 200 yards will allow high-velocity rifle bullets to be reproducibly and safely passed within a fixed standoff distance to a dB meter's microphone and will also allow for a separation between the report of the gun and the bullet's supersonic *crack*. Some initial testing was carried out with one 224 caliber rifle and three 30 caliber rifles and selected bullets, with the L-D 800B's microphone located 100 yards downrange and 5 feet off to the side of the bullets' flight paths. A second series of shots was fired with several of these same rifles

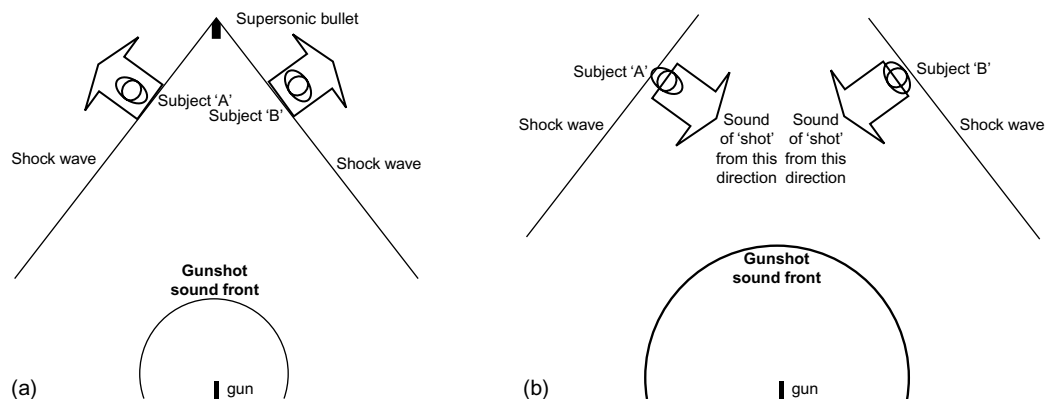


FIGURE 17.15 (a) Arrival of a supersonic bullet's shock wave at downrange locations of two earwitnesses. (b) Perception of direction after the passage of a supersonic bullet's shock wave by two earwitnesses at downrange locations.

and ammunition, with the microphone repositioned 200 yards downrange. Values of 147 to 151 dB(A) for the 224 caliber and 30 caliber rifles, respectively, were obtained at these two distances when the supersonic bullets passed within 5 feet of the microphone.

Additional tests were carried out with two centerfire rifles (a 5.56 mm Bushmaster AR-15 and a 7.62 × 54R Dragunov) at a downrange distance of 200 yards but with a nominal microphone standoff distance of 10 feet. In this second series of tests, the dB(A) levels of the rifles were measured 10 feet to the left of each rifle as well as at the 200-yard (600-foot) location. These tests again revealed that the *crack* of a supersonic bullet was quite loud and comparable to that of many firearms measured at the same standoff distance.

It is also noteworthy that both series of tests showed that the same bullet registered the same dB(A) values at 100 and 200 yards despite some loss of velocity over the additional 100 yards of flight. These tests revealed that the dB(A) levels of the supersonic 30 caliber bullets registered approximately 3 dB(A) higher than the 224 caliber bullets at distances of 100 and 200 yards, indicating that the *size* of the bullet plays some role in the dB level of the supersonic shock wave. The dB(A) values of the firearms themselves, when measured at a distance of 200 yards, were on the order of 100 to 112.

After giving some thought to these initial tests and results, it was deemed desirable to further evaluate Mach number, bullet size (caliber), and nose shape. The shock wave (Mach cone) emanating from a supersonic bullet possesses substantially different shapes depending on the Mach number. At very high Mach numbers (e.g., Mach 3) the half-angle of the Mach cone is small, but by the time the bullet drops to Mach 1.1, the Mach cone is detached from the bullet and forms a wide-angled parabolic shape just ahead of the bullet.

Since it is certain that a bullet at Mach 3 is giving up more energy per second than it is at Mach 1.1, and that some portion of this energy loss goes into sound production, it seemed reasonable that the dB level of a supersonic bullet might vary considerably depending on the Mach speed. To test this notion, handloads for a 22-250 varmint rifle using 50-gr Sierra BlitzKing bullets were assembled to provide nominal 200-yard Mach speeds of 2.8, 2.2, 1.8, and 1.4. The five-shot results for each Mach level are shown in Table 17.16. From an

TABLE 17.16 Bullet dB(A) versus Bullet Mach Number for 22-250 Handloads with Varmint Rifle, 26-in. Barrel, and 50-gr Sierra Blitzking

GROUP A			
Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel./Mach No. and 10 ft. from Bullet Path @ 200 yds	
3788 fps	142.5	3131 fps	M2.78
4062 fps	142.9	3367 fps	M2.99
3757 fps	143.0	3104 fps	M2.75
3805 fps	143.3	3146 fps	M2.79
3809 fps	142.6	3149 fps	M2.79
	142.3 ± 0.3	Average M = 2.82 ± 0.10	
GROUP B			
CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel./Mach No. and 10 ft. from Bullet Path @ 200 yds	
2991 fps	142.3	2421 fps	M2.15
3048 fps	142.8	2474 fps	M2.19
2996 fps	142.4	2426 fps	M2.15
2982 fps	142.5	2413 fps	M2.14
3042 fps	142.4	2468 fps	M2.19
	142.5 ± 0.2	Average M = 2.16 ± 0.02	
GROUP C			
CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel./Mach No. and 10 ft. from Bullet Path @ 200 yds	
2542 fps	141.8	2010 fps	M1.78
2553 fps	141.4	2020 fps	M1.79
2464 fps	141.5	1939 fps	M1.72
2482 fps	142.1	1955 fps	M1.73
2560 fps	141.8	2026 fps	M1.80
	141.7 ± 0.3	Average M = 1.76 ± 0.04	
GROUP D: 14.1-GR RELODER 7			
CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel./Mach No. and 10 ft. from Bullet Path @ 200 yds	
2179 fps	142.0	1672 fps	M1.48
2251 fps	141.4	1742 fps	M1.54
2097 fps	140.8	1594 fps	M1.41
1906 fps	141.8	1426 fps	M1.26
1952 fps	141.9	1465 fps	M1.30
	141.6 ± 0.5	Average M = 1.40 ± 0.12	

Note: MET data: 66°F 63% RH 30.30-in. Hg 9050-ft. MSL Mach 1 @ 66°F = 1127.8 fps.

inspection of the average dB(A) results it can be seen that there was no significant difference in the dB(A) values over a twofold range of Mach levels for this particular 224 caliber bullet.

The prospect of bullet size (caliber) having some notable effect on dB(A) values for supersonic bullets was addressed by preparing handloads with 45 caliber jacketed bullets launched from a long-barreled, single-shot rifle with open sights and then comparing the results with that from .224-caliber bullets fired under the same conditions, at the same testing site, and with similar downrange velocities. Nose shape was also addressed in this series of shots by employing a flat-nosed, hollow-point bullet with a truncated cone profile and an FMJ bullet with a smooth, round-nose profile. The two bullets, the velocity results, and the downrange dB(A) data for these shots are given in Table 17.17.

Interim Summary

The dB(A) level of the 300-gr Hornady JHP-TC bullet at downrange velocities of approximately 1500fps produced a dB(A) level of 147.1 ± 0.3 . The 224 caliber JSP-BT Sierra BlitzKing rifle bullet at a similar downrange velocity produced a dB(A) level of 141.6, for a difference of 5.5dB(A), further indicating that size (caliber) does play a role in the dB(A) level of supersonic bullets.

The dB(A) levels of the 300-gr 45 caliber JHP-TC bullets versus the 230-gr 45 caliber FMJ-RN bullets at downrange velocities of 1500fps and 1700fps produced dB(A) levels of 147.1 ± 0.3 and 147.0 ± 0.4 , respectively, indicating that nose shape plays little or no role in dB(A) production.

The dB(A) levels of the 300-gr JHP-TC bullets at downrange velocities of approximately 1500fps and 1240fps produced dB(A) levels of 147.1 ± 0.3 and 144.9 ± 0.4 , respectively, for a nominal difference of 2dB(A). If these are true and accurate values, these results are contrary to the results for the 224 caliber JSP-BT rifle bullet, whose dB(A) level remained virtually unchanged over a wide velocity range.

Two matters raise some questions regarding this apparent 2-dB(A) difference. Unlike the 224 caliber bullets fired from a varmint rifle with a telescopic sight, the 45 caliber bullets could not be delivered to the 200-yard “target” location with a high degree of accuracy. This was particularly true for the slightly undersized 230-gr round-nosed bullets, which means that they may or may not have passed within 10 feet of the L-D microphone. Also, when one considers the two average dB(A) values and includes plus and minus three standard deviations, there is overlap at the 146-dB(A) level, raising the possibility that the 2-dB(A) difference may not be significant.

The central point to be realized and remembered from these tests is that the supersonic *crack* of a bullet is quite loud and comparable to that of many gunshots. This, along with the direction of the supersonic bullet’s sound propagation, can result in erroneous perceptions by earwitnesses located at considerable distances from the actual gunshot when one of these bullets passes near the witnesses’ location.

A FRAME OF REFERENCE FOR JUDGES AND JURORS

Some means of providing courts and juries with a meaningful and useful frame of reference for testimony regarding dB levels of gunshots under various circumstances and distances is clearly desirable. The logarithmic world of decibels; A, C, and Z scales; and even

TABLE 17.17 Bullet Size, Design, and Shape versus Bullet dB(A) with 45-70 Handloads, Single-Shot Rifle, and 32-in. Barrel

300-GR HORNADY JHP-TC

Group A

CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel. @ 200 yds and 10 ft. from Bullet Path
2022 fps	147.1	1503 fps
2003 fps	147.3	1487 fps
2066 fps	147.3	1537 fps
2068 fps	147.4	1540 fps
2022 fps	146.6	1503 fps
	147.1 ± 0.3	

Notes: The average dB(A) for the .224-caliber Sierra bullet at this approximate downrange velocity and location was 141.6 ± 0.5 for a dB(A) difference of 5.5.
The report of this .45-caliber rifle-ammunition combination alone (fired at a right angle to the 200-yd. microphone) was 98.8 dB(A).
The average dB(A) 10 ft. to the left of the muzzle was 150.2 ± 0.4 .

300-GR HORNADY JHP-TC

Group B

CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. Vel. @ 200 yds and 10 ft. from Bullet Path
1640 fps	144.3	1227 fps
1665 fps	145.1	1244 fps
1667 fps	145.3	1245 fps
1660 fps	145.1	1240 fps
1668 fps	144.9	1246 fps
	144.9 ± 0.4	

Note: The average dB(A) for this bullet at the higher velocity was 147.1 ± 0.3 for a nominal dB(A) difference of 2 dB(A).
The average dB(A) 10 ft. to the left of the muzzle for this load was 148.2 ± 0.1 compared to 150.2 ± 0.4 for the heavier handload in Group A.

230-GR SIERRA FMJ-RN

Group C

CED Velocity @ 10 ft.	dB(A) @ 200 yds Downrange	Calc. vel. @ 200 yds and 10 ft. from Bullet Path
2566 fps	146.9	1732 fps
2484 fps	147.5	1668 fps
2528 fps	147.1	1702 fps
2564 fps	146.9	1730 fps
2528 fps	146.5	1702 fps
	147.0 ± 0.4	

Note: The average dB(A) for the 300-gr jacketed hollow-point bullet at a comparable downrange velocity was 147.1 ± 0.3 .
The average dB(A) 10 ft. to the left of the muzzle for this load was 153.2 ± 0.3 compared to 150.2 ± 0.4 for the 300-gr JHP-TC bullet and heavier handload of Group A.
Site elevation = 9000 ft.; temperature = 64°F RH = 29%; barometer = 30.30-in. Hg; wind calm

peak pressure values of dynes per square centimeter is probably not an easy one for courts and juries to grasp. How can they relate to, or appreciate, the testimony of a witness regarding an average measurement of 107 dB(A) for a 9mm pistol discharged with evidence ammunition at a distance of 200 yards?

Does it help to add that the background level of “noise” at the scene registered 50 to 60 dB(A) under conditions comparable to the shooting incident? Is a value of 107 dB(A) twice as loud as a 50-dB(A) level of steady background noise? Something is needed to which these special audiences can relate, something that might even be produced in a courtroom or just outside the courthouse, where a jury might assemble for a demonstration. Toward this end three sources of brief impulse sounds were evaluated: handclaps, balloons popping, and paper sandwich bags bursting.

Handclaps measured under the MIL-STD-1474D testing configuration were quickly found to be quite variable and near impossible to standardize. We produced an average dB(A) value of 121 ± 2 for 10 events (highest value = 124.9). One of our wives generated a dB(A) average of 118 ± 3 with a maximum value of 123.1.

So-called “penny balloons,” “water balloons,” or small party balloons were tried next, with much better success. These are inexpensive and available in many stores in quantities of 200 per package. They are about 2 inches long uninflated and achieve dimensions of about 3×5 inches when inflated to the point of near bursting. The testing method simply involved popping fully inflated balloons with a pointed object while positioned 1 meter away from the L-D 800B microphone. The results for 10 bursts produced an average dB(A) value of 133.1 ± 1.7 at a distance of 1 meter from the microphone (highest value = 136.5). These results are in the area of many gunshots.

The third approach used common paper sandwich bags. As with the balloons, these were inflated and then immediately burst, resulting in an average dB(A) value of 137.8 ± 3.6 at a distance of 1 meter from the microphone (highest value = 142.4).

But the matter of relating a measured gunshot value such as a 107-dB(A) reading for a distance of 200 yards remains, as do questions such as *How loud is that? Is a person likely to hear it against or above a background level of 50 to 60 dB(A)?* These questions can be addressed by comparing average dB(A) values versus distance from the source for one of the “reference” sounds. For this purpose the toy balloons were used. Multiple bursts at selected standoff distances were plotted to produce the familiar relationship depicted in Figure 17.16, including the equation that best fit the data:

$$\text{dB(A)} = 133\text{dB(A)} - 8.6562\text{Ln}(X)$$

where X equals the standoff distance in meters.

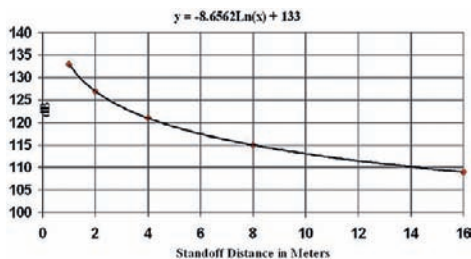


FIGURE 17.16 Graph showing the relationship between average dB(A) and microphone standoff distance for popped penny balloons.

This equation allows one to calculate the standoff distance necessary to produce any dB(A) value at, or less than, 133. Inserting the earlier example of 107 dB(A) into this equation, a distance of 20 meters (approximately 66 feet) is obtained. This result could, of course, be checked by one or more actual tests at this distance, but testifying that the 200-yard, 9 mm gunshot would be about as loud as popping a toy balloon at a distance of about 70 feet seems justified and defensible.

SUMMARY AND CONCLUDING COMMENTS

Professionally made suppressors do a very effective job of suppressing the report of the firearms for which they are designed. This is especially apparent when one converts the before and after dB(A) values to analog peak sound pressure levels and calculates the sound reduction as a ratio or percentage.

Homemade suppressors are usually crudely made and appear so. Their effectiveness can vary greatly. Moreover, they usually do not maintain a constant level of suppression with continued use primarily because of their amateur construction and their internal degradable sound-deadening material.

A common bedroom pillow filled with either polyester fiber or down can make a very effective silencer for handguns if the muzzle is pressed firmly against it and the pillow is carefully folded around the gun at the moment of discharge.

The use of a pillow as a suppressor generates much physical evidence on and in the pillow as well as in the wound track of the gunshot victim. The challenging part is recognizing that a pillow was used. Such recognition must start at the time of autopsy. The use of a pillow as a sound suppressor will greatly reduce or obviate gunshot residues around the entry wound, leading to error in the autopsy report insofar as the pathologist's assessment of muzzle-to-victim distance. However, the responsible pillow will show copious gunshot residue and possibly pattern information that relates to the firearm used.

Supersonic bullets passing near a downrange earwitness can produce an impulse noise that is very much like a gunshot both in quality and dB level. The earwitness may fail to hear or recognize the actual gunshot because of its remote distance and/or reduced dB level compared to the supersonic bullet's *crack*. The earwitness's sense of shot direction will likely be wrong if it is based on the supersonic shock wave emanating from the bullet.

The measured dB(A) values for several representative bullets showed little to no significant change over a range of velocity values. Bullet size (caliber) does appear to play a role, but bullet shape made no difference in the supersonic dB values in the study reported here.

Some ideas for assisting courts and juries in understanding dB values as they relate to gunshots and similar impulse sounds were presented at the conclusion of this chapter. These involve common items such as balloons and paper sandwich bags that are well-known to those who might be confronted and confounded by such otherwise technical testimony.

This chapter should have provided the interested reader with one or more ideas as to how he or she might design a testing protocol, select a suitable dB meter, and carry out specific experiments dealing with high-intensity impulse sounds such as gunshots.

CHAPTER KNOWLEDGE

- What materials can you think of that might act as a "silencer" when attached to or used to cover a firearm?
- What areas in your jurisdiction or area of coverage would be problematic for a long-distance reconstruction involving sound; what areas would simplify the analysis of sound evidence?
- If you were investigating a long-distance shooting, where would you search for potential recordings of the event?

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Ultimate Objectives, Reports, and Court Presentations

INTRODUCTION

A number of techniques for the documentation and processing of shooting scenes were presented in preceding chapters. The reader was exposed to a variety of exterior and terminal ballistic phenomena related to the behavior of projectiles in stable and unstable flight and their ultimate effects on various target materials. The importance of trace evidence transfers associated with ballistic events and available laboratory examinations to interpret this evidence was demonstrated through case examples taken from actual shooting incidents. In one way or another they are all directed toward an effort to reconstruct what did and what did not occur.

Virtually every discussion and example was directed toward one or more of the 12 objectives listed at the end of Chapter 1.

EXPLAINING WHAT RECONSTRUCTIONISTS DO

The examination of shooting scenes and the subsequent reconstruction of a shooting incident is very much like any other investigation involving collisions, impact damage, trace evidence exchanges, pattern recognition, and certain analytical tests. In some respects, the techniques employed in processing a shooting scene can be viewed as an applied physical science and, as such, the various methods and techniques are well known, routine, readily verified, and repeatable. The results of a properly conducted shooting incident investigation are documented and preserved, allowing the accuracy of any findings to be evaluated at a later time.

The reconstructive process must also involve unbiased analytical thinking and the application of *the scientific method* to evaluate various explanations of one or more events in a shooting incident. Just as with the broader fields of forensic science and criminalistics, the methods and techniques employed in the reconstruction of shooting incidents are drawn from scientific disciplines such as chemistry, physics, mathematics, ballistics, trigonometry,

and microscopy. For example, the sodium rhodizonate test for lead comes from broad field of chemistry and the subspecialty of chemical spot tests for trace amounts of metals. The measurement of the angular components of a bullet's flight path utilizes very basic trigonometric calculations taught in every high school trig course.

The calculation of a bullet's flight time, angle of departure, and angle of fall involves the use of computers and exterior ballistics programs, the results of which can be checked for accuracy multiple ways, including actual test firings. The observation of embedded bone particles and fibers in a bullet involves the use of a basic laboratory microscope. The identity of these and other trace materials can be established, rechecked, and verified in several ways.

The analytical methods employed in a modern forensic laboratory are nondestructive. This is of great value because it means that other specialists and forensic scientists can reexamine the evidence if requested to do so by a litigant or ordered to do so by a court.

LEGAL CHALLENGES AND RECONSTRUCTISTS' ROLE IN LITIGATION

The foregoing measures will not necessarily thwart critics. One litigant or another will not be pleased with even the most thorough and well-documented reconstruction. *Any* physical evidence that implicates a particular person or interest in some form of wrongdoing is prejudicial. Legal challenges may be raised in several forms beyond that of any alleged prejudicial effect. The foreseeable claims might be that shooting incident or shooting scene reconstruction is a "*new science or technique*" or that it is based on "*untried and unproven scientific principles*."

This claim, put to one of us many years ago in a courtroom in Iowa, was the very genesis of this book. It should be apparent from a most basic reading of the book and inspection of its many references that the claim is untrue. But the person on the stand in an evidentiary hearing or during a voir dire examination at trial needs to be prepared for such challenges. Bad testimony leads to bad case law. Both the attorney soliciting expert testimony regarding a shooting reconstruction and the witness called by this attorney need to be conversant in the scientific method and how objective, testable measures and techniques were used in the reconstruction of the incident. These matters are of great importance because there are rules of evidence and case law at both the state and federal level that govern the admissibility of evidence and expert testimony. A review of the important elements and language from these sources should be helpful.

The 1923 *Frye* decision by the District of Columbia Court of Appeals addressed the matter of expert testimony. This case is still the standard for admissibility in a number of U.S. jurisdictions. *Frye* requires that the proffered technique and expert testimony have "...gained general acceptance in the particular field in which it belongs." Some states have added to this either by statute or case law. If the challenge is based on a claim that shooting reconstruction is a "*new, untried and unproven science or technique*," it should clearly fail under *Frye*. *The Gun in the Case*, written by G.G. Kelly more than 40 years ago and referred to in Chapter 1 describes the reconstruction of numerous cases over the period from 1929 to 1958 and should be noted.

The many articles dealing with shooting scene reconstruction that have appeared over the last 30 plus years in the *Journal of the Association of Firearm and Tool Mark Examiners* are probably the most important assets to the proponent of such testimony. This is a respected journal, peer-reviewed by the relevant scientific community. AFTE contains the largest membership of forensic firearm examiners and criminalists dealing with shooting investigations in the world. Its members include examiners and scientists in the private sector and those employed in government crime laboratories.

Articles appearing in this journal have often been presented at one of AFTE's annual international seminars. Upon submission to the journal, they are sent to one or more reviewers who have special knowledge or experience regarding the particular subject matter. Upon publication, the article is disseminated to the relevant scientific community. This allows others working in the same field to evaluate and test any new technique. If a technique cannot be replicated or flaws are found in it, a letter to the editor or a counter article should follow.

There are, of course, other scholarly journals in which peer-reviewed articles dealing with shooting scene reconstruction have appeared. Many of these have been cited at the end of each chapter.

It is a good idea for shooting incident reconstructionists to become involved in reputable forensic organizations. There are *many* organizations and study groups that provide support and interaction for members of this profession. The following are some of the larger ones:

- Association of Firearm and Tool Mark Examiners (AFTE), www.afte.org
- American Academy of Forensic Sciences (AAFS), www.aafs.org
- California Association of Criminalists (CAC), www.cacnews.org
- Midwest Association of Forensic Scientists (MAFS), www.mafs.net
- Northwest Association of Forensic Scientists (NWAFS), www.nwafs.org/
- Northeastern Association of Forensic Scientists (NEAFS), www.neafs.org
- Southern Association of Forensic Scientists (SAFS), www.southernforensic.org
- Southwestern Association of Forensic Scientists (SWAFS), www.swafs.us
- Association for Crime Scene Reconstruction (ACSR), www.acsr.org
- The International Association for Identification (IAI), www.theiai.org

Preparing Witnesses

A witness at a hearing or a trial should be prepared to give common examples of shooting reconstructions that are carried out daily in forensic laboratories throughout the world. One would be distance determinations based on powder patterns and shotgun pellet patterns, or the common cone fracture produced by a BB strike to a plate glass window that allows the direction of impact to be determined.

In 1975 new Federal Rules of Evidence were passed by Congress. Federal Rule 702 addresses and controls expert witness testimony in all federal courts, and many state courts have essentially adopted it. The rule states:

If scientific, technical or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training or education may testify thereto in the form of an opinion or otherwise.

The last part of this excerpt is particularly important.

The use of the little word “or” means that the witness need not necessarily be a scientist with a degree in one of the physical sciences. He or she may presumably qualify as an expert based on experience alone. In actuality, most witnesses will have training (shooting reconstruction courses), knowledge (a study of the relevant literature), skill (practice in carrying out the various techniques associated with shooting reconstruction), and experience (prior casework). This should be brought out by the proponent attorney. Education (a degree in chemistry, physics, or mathematics) is an asset but not a requirement. The use of the scientific method or scientific methodology does not require a degree in science.

Rule 702 goes on to set conditions regarding the opinion testimony as follows: (1) the testimony must be based on sufficient facts or data; (2) the testimony must be the product of reliable principles and methods; and (3) the witness has applied the principles and methods reliably to the facts of the case. On the basis of these conditions, it should be fairly easy to envision how the questioning might go in a motion hearing:

Q. Was there sufficient data for you to form an opinion in this case?

Q. What data did you rely upon in forming your opinion?

Q. What principles are involved in carrying out the tests you performed?

Q. What method(s) did you use?

Q. Are these recognized principles and methods among your peers? Please explain.

Q. Did you apply them in a manner that is designed to produce reliable results? Please explain.

It should be noted that infallibility is neither required nor possible in any human endeavor and the witness should be prepared to concede this. But he or she should also be prepared to explain those measures taken to minimize the chance for error and that the method used allows an independent review of the evidence and tests.

Rules Related to Testimony

There are three other Federal Rules of Evidence that should be of interest to the proponent of expert testimony:

- Rule 104 provides that the preliminary questions concerning the qualifications of a person to be an expert witness and the admissibility of the evidence are in the province of the court. A jury will never hear the results of any reconstructive efforts if the court is not satisfied regarding the witness’s qualification or the admissibility of the evidence examined by the witness.
- Rule 401 defines relevant evidence as *evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence.*
- Rule 402 provides that nearly all relevant evidence is admissible.
- Rule 403 excludes relevant evidence *if its probative value is substantially outweighed by the danger of unfair prejudice, confusion of the issues, or it is misleading the jury, or by considerations of undue delay, waste of time or needless presentation of cumulative evidence.*

In 1993 the U.S. Supreme Court changed the *Frye* standard when it handed down its decision in the *Daubert* case. The Court dismissed the “general acceptability” standard and replaced it with the Federal Rules of Evidence and added five criteria by which scientific testimony must be evaluated before it can be admitted:

- Testability of the Scientific Principle
- Known or Potential Error Rate
- Peer Review and Publication
- Maintenance of Standards and Controls
- General Acceptance in a Particular Scientific Community

The Court provided no guidance on how these criteria were to be weighed, so one might conclude that they have equal weight. They should be relatively easy to meet if the witness has carried out the various practices described in this text. As for the first criterion, we are dealing with the physical world and tangible evidence that can be photographed, measured, and tested in various ways, with those tests being documented and preserved. The tests can be shown to be repeatable and reliable, with their origins based on other established and accepted bodies of scientific knowledge.

Regarding criterion 2 (Known or Potential Error Rate), we regularly discussed confidence limits (uncertainty of measurements) in this book and offered suggestions on how to evaluate “error rate” in actual casework. An article regarding uncertainty limits as they relate to shooting reconstruction should be helpful when addressing such concerns: “The Accuracy and Precision of Trajectory Measurements” (L. Haag, 2008. *AFTE Journal*, Vol. 40, No. 2, pp. 145–182). Among other topics the article discusses is the creation of empirical trajectories under fixed, known conditions.

Perforations of objects created by bullets were evaluated and reconstructed with the methods used in actual shooting events and the amount of true scientific error was calculated. These results were reported in the article. Many of the thousands of data points in the study were collected from live-fire shooting incident reconstruction classes taught at our school. A major aspect of the article is the evaluation of the accuracy and precision of what shooting incident reconstructionists do at scenes.

The third criterion listed (Peer Review and Publication) and the fifth (General Acceptance) naturally flow from the many articles on shooting scene reconstruction appearing in professional journals. The existence of various training courses and workshops in shooting incident reconstruction add more support to criterion 5. However, the witness must be cognizant of these criteria and rules of evidence if they are applicable in the jurisdiction where reconstruction testimony is to take place.

There is an alternate view that holds that the requirements of *Daubert* do not apply if the witness is functioning in a technical, rather than a scientific, role. This view arises out of the opening language of Federal Rule 702: *If scientific, technical or other specialized knowledge will assist the trier of fact...*

This rule takes the position that the reconstruction of shooting scenes and shooting incidents is an applied science in which the witness utilizes well-known and well-established scientific techniques and objective measuring methods to arrive at his or her opinions. In this role the witness acts purely as a technician, following a checklist or “cookbook” procedure at a shooting scene. This role does not involve any analytical thinking or use of the scientific method. In certain respects this argument has some validity.

A mark on a brick wall is observed at a shooting scene, and the investigator tests it for copper and lead. The examiner in the laboratory sees some embedded material on a bullet from a gunshot victim, places it in the SEM, and observes mineral grains. In these examples the crime scene investigator and the laboratory analyst simply carry out tests because it is a part of their job. Most, if not all, of the techniques, tools, reagents, and analytical instruments used in shooting incident reconstruction at this “technician level” are well known in the field of criminalistics and its subspecialty, forensic ballistics. But it would be dangerous to assume that every court will take the view that *Daubert* or *Daubert*-like requirements do not apply to the “technician.”

A reader living in the United States should be mindful that *Daubert* and its progeny have taken from scientists the responsibility of determining the validity of a scientific procedure or test and transferred it to jurists. Anyone carrying out reconstructive efforts at shooting scenes, or even in a laboratory, should be familiar with the pertinent Federal Rules of Evidence and the four requirements of *Daubert*. He or she should also be prepared to address these rules and requirements as they might relate to the tests and procedures utilized in reconstructive efforts.

REPORTS AND REPORT WRITING

Individuals employed by government agencies no doubt have specific formats for the writing of reports on routine matters. There is considerable variation in style and level of detail in reports coming out of crime laboratories around the world. The matching of a fired bullet to a submitted firearm is a common example. After the usual inventory and description of the various submitted items, the examiner’s report might read,

The 9 mm Luger pistol, serial number 12345 submitted by Detective Smith on May 2, 2005, was determined to have fired the full metal jacketed bullet in the packet marked Item 6 from the medical examiner’s office...

or simply

Item 6 was fired by item 2.

With the latter version, which is seen all too frequently, the reader must go back through the documents to figure out what item 6 and item 2 are and where they came from. Reports from the private sector and nongovernmental organizations show an even wider range of styles and formats depending on the complexity of the case.

There are some rules at the federal level that address reports by experts. In criminal cases, Rule 16 (G) of the Federal Rules of Criminal Procedure states,

At the defendant’s request, the government must give to the defendant a written summary of any testimony that the government intends to use under Rules 702, 703, or 705 of the Federal Rules of Evidence during its case-in-chief at trial.

This seems very general but at the same time also seems to call for a more narrative report. This is particularly true if the report relates to a reconstruction of a shooting incident.

The rule regarding reports in civil cases is much more involved and explicit. Rule 26, section 2, subpart (B) of the Federal Rules of Civil Procedure reads, in part,

Except as otherwise stipulated or directed by the court, this disclosure shall, with respect to a witness who is retained or specially employed to provide expert testimony in the case or whose duties as an employee of the party regularly involve giving expert testimony, be accompanied by a written report prepared and signed by the witness.

The report shall contain a complete statement of all opinions to be expressed and the basis and reasons therefore; the data or other information considered by the witness in forming the opinions; any exhibits to be used as a summary of or support for the opinions; the qualifications of the witness, including a list of all publications authored by the witness within the preceding ten years; the compensation to be paid for the study and testimony; and a listing of any other cases in which the witness has testified as an expert at trial or by deposition within the preceding four years.

A TEST FOR THE READER

Now it is the reader's turn to use the information presented in the chapters of this book. In Figures 18.1 through 18.16, are examples of bullets that struck various materials or impact sites. Consider the photographs in these figures as evidence you are viewing at a shooting incident scene or in the laboratory.

- What would you suggest as suspected impact materials in the scene based on observations of the projectiles? Where might the projectiles have been, or what might they have struck?
- What expectations would you have for departure angle, or angles of incidence?
- How would you characterize the expected behavior of projectiles from the impact sites given?
- Which type of firearm or caliber might you expect?
- Which caveats and limitations might you include in your analysis?

The answers in the following paragraphs are specific to the individual photos.

Figure 18.1: This bullet shows classic bow effect properties. Note how the top side appears to be pristine while the underside is sandblasted. The pattern of the bow effect suggests that the bullet was stable when it impacted the ground. While impact angles from this bullet would be difficult to assess, we know it was fired below the critical angle since it was not recovered underneath the surface. We would also expect that departure angles from the impact with the dirt could be quite high based on the yielding surface model.

Figure 18.2: This photograph is the only lineup of projectiles in this assemblage of examples. The reader should focus on the facets visible at the close edge of the left and middle bullets. All three possess numerous white, glittering powdered areas of embedded glass, as well as "checking" on the ogives. The bullet at the far left is different from the others and has the tell-tale flat nose, indicating that it was the first to defeat the tempered-glass



FIGURE 18.1 Bullet recovered from a shooting incident scene.



FIGURE 18.2 Bullets recovered from the body of a decedent found in the driver's seat of a vehicle.



FIGURE 18.3 Interior of a car seat cushion.

window. This example is more realistic than some presented in Chapter 8, on glass, because it shows how an interpretation of this type can still be done with hollow-point bullets. While no scale is given in this image, the lack of cannelures suggest an autoloading-style cartridge, and indeed, these are 45 Automatic caliber bullets.

Figure 18.3: The inside of this car seat contains a large amount of “vaporized” lead from an impact. The amount shown is completely inconsistent with impacts created by pistol caliber projectiles. Observation of this kind of deposit should indicate to the investigator that the situation involves a rifle.

Figure 18.4: The left side of this 45 Automatic caliber bullet (as viewed) shows a slightly burnished area. While a specific conclusion about *exactly* what caused this may not be possible without knowing more about the possibilities of the scene, it is clear that the bullet does not possess a flat spot from an unyielding surface interaction. Therefore, incident angle may



FIGURE 18.4 Bullet recovered from a gunshot wound without bone impact.



FIGURE 18.5 A photograph of a 12-gauge shotshell found in the street at a "shots fired" call.

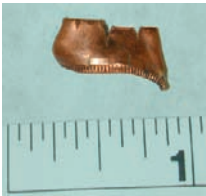


FIGURE 18.6 Bullet fragment recovered from the floor of an apartment.

not be accurately attained, but we may expect large departure angles. In fact, this bullet was ricocheted from wood.

Figure 18.5: Without scale, it may be difficult to see that this is a 12-gauge shotshell, but just as important is the information gleaned from the text on the side of the hull. The most important number is the "8", which tells us that we should be looking for relatively small shot. Two aspects of the information suggest we should be anticipating lead shot: (1) there is no mention of steel, and (2) the fact that this is a "Sporting Clays" load as opposed to one marked for waterfowl (most if not all hunting shotshells for use near water are required to be nonlead). Additionally, the star crimp at the mouth is an added characteristic that we should not expect of a slug projectile if the text on the side were worn away. Given that this is a "shots fired" scenario, and not a situation with a known impact area, the investigator should be aware that spotting impacts from these small pellets may be quite difficult at medium to long range from the location of the shooting. Use of the sodium rhodizonate test for lead at suspected impact sites may be needed.

Figure 18.6: This fragment represents approximately half of the ogive area of the bullet jacket. The manufacturing characteristics observed suggest that a revolver-style cartridge is involved, and in fact this is a .38 Special caliber fragment. Without greater detail, we may not be able to ascertain what this bullet struck; however, because the ogive area is



FIGURE 18.7 Nonperforating impact in the windshield of a car.



FIGURE 18.8 Bullet recovered from the street near a shooting scene.

not striated or damaged, and the other half of the ogive area is missing, we would expect this bullet to have struck at a shallow angle. If it had struck something orthogonally, we would expect indications of damage on the ogive of the bullet jacket. Because the skives, or stress cuts, in the nose are not splayed out or bent rearward, soft damage, or wound ballistic effects, are not suspected.

Figure 18.7: Sufficient detail is not given in this image for a determination of direction of travel or caliber; however, it is clear that the terminal ballistic interaction follows the yielding surface model. Because the material struck has been deformed and altered, a ramp in front of the bullet may very well have been created as it departed the medium, resulting in a high departure angle. The bullet from this impact would be expected to be heavily saturated with embedded white, powdered glass. Note all the powdery glass below the impact itself.

Figure 18.8: This full-metal-jacketed 45 Automatic bullet did not strike anything particularly hard based on the view given. There is little to no deformation of the bullet itself and merely a deposit of black over the majority of the ogive and bearing surface. While there may be other materials that could allow for a deposit like this, this specific bullet was fired through two sidewalls of a very thick rubber tire. This was sufficient to slow the bullet down enough that it was not subsequently damaged by tumbling across the ground.

Figure 18.9: This full-metal-jacketed 9mm Luger bullet was actually shot through 2 inches of ballistic soap prior to impacting hard stone at a shallow angle. As with true tissue, we do not expect to see any traces of soap/biological material adhering to a full-metal-jacketed bullet. The most important observation to be made in this case involves the *off-axis striae* on the flat spot at the ogive. This bullet was unstable when it made contact with the stone. The astute investigator should be asking what is in the scene or what may have been removed



FIGURE 18.9 Bullet recovered from a second-story apartment carpet.

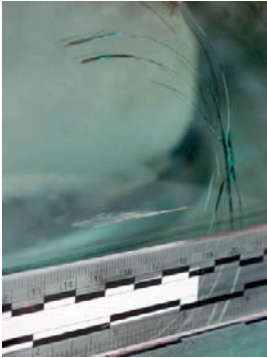


FIGURE 18.10 Vehicle windshield.



FIGURE 18.11 Three pellets recovered from the remains of a decomposed body in a forest.

from it (such as a victim or a decedent) that would have destabilized the bullet without significantly deforming it.

Figure 18.10: A counterpoint to Figure 18.7, this impact with a windshield was created with a 40 Smith & Wesson caliber full-metal-jacketed bullet. Here we expect a shallow departure angle because the surface was not deformed. Clearly, the terminal ballistic interaction in this photo follows the unyielding surface model. The bullet would have taken up the damage from this interaction. Direction of travel was from left to right as viewed based on (1) the parabolic shape of the impact on the left side and (2) the manner in which the cracks in the glass sweep back and around the path the projectile took. The bullet was fired from a firearm possessing a right-hand twist based on the asymmetrical Chisum trail on the right side.

Figure 18.11: A search of the area under the decomposed body could potentially help locate additional pellets given this scenario. From Chapter 16, on shotguns and shotshells, the reader should have observed that these copper-plated pellets were from a buffered shotshell based on the orange peel effect on their surface. Additionally, no curved, striated areas are seen on any of the pellets, so a shotcup more than likely protected them from direct contact with the barrel on their way toward the muzzle. If only three pellets were recovered, it is possible

that these are the only three to have struck the decedent, therefore indicating some amount of range to the shot. Our other option is that these were the only three to have penetrated as opposed to perforated. If any clothing is recovered from the decomposed body, the unenviable task of searching for perforations in it becomes the next step.

Figure 18.12: This nose view of a 9mm Luger caliber hollow-point bullet provides us with several investigative leads. One aspect is that the hollow-point cavity appears to be partially mushroomed. This could be due to a lack of performance by the bullet, a very short wound path (an arm or a graze), or low velocity. The sand grains are not at all unexpected considering the fact that the recovery location was listed as “from dirt”; however, closer examination and cleaning would reveal that the dirt is not driven into the nose. Another item of importance is the blue/purple fiber running from the central area of the cavity toward the lower right corner of the photograph. A large number of thinner white fibers are also present. This bullet would be a good candidate for DNA testing and comparison to determine who, if anyone, this bullet perforated.

Figure 18.13: Another 45 Automatic bullet, devoid of cannelure, and showing no patent indication of having struck anything hard; however, examination of the area between the two land impressions on the upward surface should show the reader a *very* subtle flat spot on the ogive. This bullet could very well be associated with the impact shown in Figure 18.8, following the unyielding surface model. The damage observed on this bullet would not at all be what we would expect from an impact like that shown earlier in Figure 18.5.

Figure 18.14: A classic example of a pistol bullet that struck asphalt at a shallow angle. The jagged, damaged, upper side of this 9mm Luger caliber bullet reflects the irregular

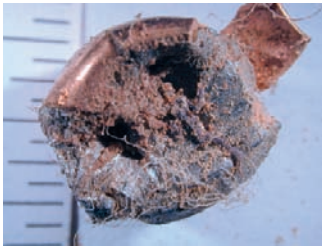


FIGURE 18.12 Bullet recovered from the dirt at a homicide scene.



FIGURE 18.13 Bullet recovered from a shooting scene.



FIGURE 18.14 Bullet recovered in the street at a shooting scene.

craggy nature of the asphalt it struck. Departure angles would be fairly unpredictable, and there would be no better determination of angle of impact than “shallow angle.” In many cases for this type of terminal ballistic interaction, the jacket and core would have separated. The reader should look carefully for traces of black asphaltic material trapped in the nooks and crannies of the damaged area. He or she should also look in the impact site (if it can be found) for powdered aggregate, a “fresh” black appearance, and pieces of bullet material (copper and lead).

Figure 18.15: This is not an average fired cartridge casing. Three predominant features exist that should give the investigator a clue to a potential sequence of events in this suspected suicide. First, there is a swollen area extending from about one-third of the way from the head all the way out to the mouth of this .40 Smith & Wesson caliber cartridge casing. Next, a crack or failure of the cartridge casing is visible right at the beginning of the over-obtured section. Finally, the primer shows two off-center impressions. All of these combined should be telling the investigator that this cartridge was fired in the wrong caliber chamber. In this case, it was fired in a .45 ACP caliber pistol. Even though bullets from mismatches such as this do not typically travel at their normal discharge speed, they still may easily have enough velocity to lethally penetrate a head or a torso. Because this is an under-sized bullet, we would not expect a normal gunshot residue pattern if this were a close-range shot. Much of the powder is not burned and would have passed by the bullet as it balloted down the barrel. If a hollow-point bullet were used, it most likely would not have expanded because of its instability and lack of “nose-first” attitude.

Figure 18.16: An unparalleled, classic example of “soft damage.” The true expansion or mushrooming demonstrated here gives the reader a visual reference for understanding that a hollow point in open form is very much like a plane with the airbrakes thrown out. The knurled cannellure around the circumference of the bullet suggests that we may be dealing with a revolver-style cartridge. In this case, the bullet was loaded in a .38 Special caliber cartridge. The adherence of the lead core to the jacket should alert the investigator that he may be dealing with an electroplated, or bonded, type of projectile. That a bullet can be collected from clothing is an idea that sometimes does not make sense to laypersons, jurors, or those



FIGURE 18.15 Cartridge casing recovered at the scene of a suspected suicide.



FIGURE 18.16 Bullet recovered from a victim’s clothing.

who have not dealt with shooting scenes, but in fact the phenomenon of bullets escaping and perforating a body without sufficient speed to then defeat the overlying clothing is not at all uncommon.

SUGGESTED GENERAL OUTLINE FOR REPORTS

A suggested general outline for a reconstruction report is given in the accompanying box. It should be recognized that each case may be unique unto itself, and reports and the results presented may need to be altered, reformatted, and otherwise changed to reflect this.

RECONSTRUCTION REPORT OUTLINE

Caption and Title Page
Documents Received and Reviewed
Case Overview
Matters Not in Dispute
Specific Reconstruction Issues
Scene Description—Scene Processing
Physical Evidence Received
Observations, Tests, Results
Summary and Conclusions
Reservations/Additional Testing Suggested or Contemplated
Disposition of Evidence
Attachments: List of Publications, List of Trial and Deposition Testimony, Fee Schedule

Sample Case and Report

We have prepared a sample report for a hypothetical shooting incident in which certain reconstructive efforts were carried out. This report includes all of the required Rule 26 elements for a *civil* case at the *federal level* plus our preferred format and style. The hypothetical case used as the basis for this sample report involves an undercover federal narcotics officer who later states that he approached a parked vehicle for the purpose of a drug purchase.

Upon reaching the driver's door, the driver suddenly produced a pistol and fired one shot through the tempered-glass side window striking the officer in the left shoulder. The officer states that as he staggered back and toward the rear of the car, he drew his pistol and fired three rapid shots. One of these shots struck the driver in the left forehead and killed him. A passenger in the vehicle survived with minor injuries from flying glass. The undercover officer also survived his shoulder wound.

By the time the vehicle is examined, no visible glass remains in the driver's side window. Three cartridge cases from the roadway and one from inside the vehicle are recovered and impounded as evidence. These items and the bullets from the deceased driver and the wounded officer, along with the two guns and remaining ammunition, are submitted to the examiner.

The passenger's account is quite different from the officer's. He states that he and his friend were simply sitting in the car listening to a music CD when this individual with a

gun in his hand came up to the driver's window and beat on it with his gun. His terrified friend tried to start the car to escape the situation but could not. At this point the side window shattered and the witness saw the gun starting to come into the car. His friend happened to be armed and produced a pistol from somewhere in the vehicle and fired one shot toward his assailant at the same time a fusillade of shots entered the car.

CASE #05/12345

REPORT
of
July 15, 2005
In the matter of
the Death of John Johnson
and
the Wounding of Officer Sam Smith
prepared for
The Office of the United States Attorney
123 North Main Street
Any City, USA
by
Lucien C. Haag, Criminalist
Carefree, AZ 85377

Introduction

This investigation was initiated on July 8, 2005, upon the receipt of a request from AUSA Sterling Allgood of the Officer Involved Shooting (OIS) Review Detail of the U.S. Attorney's Office. A number of documents and photographs were also submitted to this examiner as follows:

- The Arizona State Police Case Report related to this July 6, 2005, incident
- The Arizona State Police Property Inventory of items impounded
- The ASP Scene Diagrams and a CD of digital scene photographs (TIFF images)
- The Autopsy Report of John Johnson (to include photographs and diagrams of the wound)
- A Witness Statement from passenger Jordan Jones dated July 6, 2005
- A transcript of the Interview of Officer Sam Smith dated July 7, 2005

Case Overview

This incident involved a confrontation between Officer Sam Smith and John Johnson that occurred on July 6, 2005, at approximately 8 p.m. in front of the residence at 2909 South Third Street.

According to Jordan Jones, an exchange of gunshots occurred between the deceased driver, John Johnson, and an armed male subject later identified as Sam Smith. The subject Smith approached the driver's side of the Johnson vehicle with a gun in his hand, yelled and beat on the driver's side window with this gun until it shattered. The driver (Johnson) attempted to start the car but was unsuccessful. At this point Jones describes the subject's gun as entering the vehicle,

whereupon the driver produced a gun. Both guns fired at the same time. Jones believes that the driver got off only one shot when he slumped across the center console of the vehicle.

According to Officer Sam Smith, he approached the Johnson vehicle (a blue, 2002 Camaro) believing that it was occupied by a drug dealer from whom he planned to make an undercover buy. Upon reaching the driver's window he was surprised to see that it was not the individual he expected. What's more, this subject produced a gun and fired a shot at him through the driver's side window. He staggered back away from the window, drew his pistol and fired three to four shots as he tried to position the "B" pillar of the vehicle between himself and the driver. It was only then that he realized that there was another occupant in the vehicle. About this time a marked patrol car that had been stationed around the corner arrived on the scene.

Matters Not in Dispute

It is *not* in dispute that Officer Sam Smith fired multiple shots (3) at the decedent from his Glock pistol and that one of his shots resulted in the driver John Johnson's death from a single gunshot wound to the head. The entry wound was somewhat irregular and was located just above the left eye. The path was front to back and left to right.

It is also *not* in dispute that the driver fired one shot from a Colt .45 Automatic pistol recovered from the floorboard of the decedent's vehicle.

Reconstructive Issues

From a review of the two witness's statements, the sequence of shots and the position of Officer Smith when he was shot and when he fired his pistol are at issue in this shooting incident.

Scene and Vehicle Examination

The scene at 2909 South Third Street was inspected on July 11, 2005. Three circles of fluorescent orange paint were still quite visible on the pavement where three fired cartridge cases could be observed in the scene photographs. Four lines or stripes of the same type of spray paint corresponding to the positions of the four tires of the Johnson vehicle could also be seen.

The distances between these locations were measured and related to the reference point shown in the ASP scene diagram. The character and appearance of the pavement were noted and photographed and the slope of the pavement in this area measured in both the N/S and E/W orientations with a digital inclinometer. All notes, measurements, and photographs taken during this scene inspection were placed in the laboratory file on this case.

The *Johnson vehicle* was examined at the ASP impound yard on this same date.

The general dimensions of the blue 2002 Chevrolet Camaro were measured, to include the size of the opening of the missing driver's side window, the height of the window sill above ground level, and numerous other measurements, all of which were recorded and placed in the laboratory file on this matter.

Inspection of the molding around the driver's door revealed multiple particles of diced tempered glass trapped in the upper molding. These were photographed in place, then marked as to their exterior surface and secured in a small evidence collection box marked "05/12345 tempered glass from top edge of driver's side window." Following this the driver's door panel was carefully removed and its interior components examined and photographed. Remaining tempered glass was observed, photographed, and marked as to interior/exterior surface, then samples collected from the window carrier. Considerable shattered tempered glass was also observed

and photographed in the bottom of the driver's door. This glass included sections with obvious radial fractures. These pie-shaped sections were reinforced with clear plastic tape, marked, and impounded with the previous items.

A probable bullet graze mark was observed on the front edge of the driver's side "B" pillar. This was photographed and measurements taken of its location relative to fixed reference points on the vehicle and relative to its height above ground level. A piece of copper bullet jacket was observed trapped in a chrome molding just forward of this apparent graze mark. This was photographed in place, then removed and impounded for later laboratory examination. Chemical tests for copper and lead were carried out on this mark with positive results for both metals. The direction of this graze mark (based on the presence of a pinch point) was from back to front (relative to the long axis of the vehicle) and in the area normally occupied by the driver.

No subsequent downrange impact point was found that could be aligned or associated with this graze mark.

Two bullet holes and penetrating bullet paths were found in the interior of this vehicle. One entered near the center of the dash by grazing the on-off control for the radio/CD player and then proceeding on into the various components of the dash. The track of this bullet was plotted and the angular components diagrammed and photographed. Back-extrapolation of this bullet's path indicated that it passed through an area just to the rear of the central area of the driver's side window. [See photographs in this file.] The bullet was ultimately recovered and impounded.

The second bullet hole in the interior of the vehicle was in the door of the glove box. This bullet perforated the glove box door after striking it at a shallow, near-horizontal incident angle. Upon opening the glove box door the bullet was observed embedded in the right interior side of the glove box. Back-extrapolation of this bullet's flight path (using the probe method as before) led to an area just left of the central area of the driver's side window.

Evidence Received and Examined

On July 11, 2005, at 4 p.m. the following items of evidence were received by the undersigned examiner at the central laboratory.

From Investigator Baker (U.S. Attorney's Office)

- The three (3) 40 S&W caliber cartridge cases listed as having been recovered from the scene at 2909 S. 3rd Street.
- One 45 Automatic cartridge case listed as having come from the driver's side floorboard.
- A 40 S&W caliber Glock pistol, serial number ABC123 with left-hand holster and seven (7) rounds of Speer Gold Dot ammunition.
- A Model 1911A1 45 Automatic pistol, serial number 654321 with 6 rounds of full-metal-jacketed round-nose ammunition.
- A medium-caliber jacketed hollow-point bullet in a medical examiner's vial and labeled as coming from John Johnson.
- A large-caliber, full-metal-jacketed bullet in a hospital vial and labeled as coming from Officer Sam Smith.

Retrieved from the decedent's vehicle by this examiner on 7/11/2005:

- Tempered glass samples removed from the upper molding of the driver's door.
- Tempered glass samples removed from the window carrier inside the driver's door.

- Pie-shaped sections of tempered glass removed from the lower interior of the driver's door.
- A small copper bullet jacket fragment recovered approximately 1 inch from a bullet graze mark in the driver's side "B" pillar.
- A fired bullet recovered from behind the radio/CD player.
- A fired bullet recovered from inside the glove box.

Observations, Tests, and Results

Glock Pistol and Ammunition from Officer Sam Smith This pistol was found to be fully operative and functioned as intended by the manufacturer. It was in a like-new condition and showed no evidence of impact damage, nor was any embedded glass found on this pistol.

Fired cartridge cases of the same brand and type ejected directly to the right with this pistol held in the usual shooting position (grip pointed down toward the ground, muzzle horizontal).

The ammunition with this pistol is Speer Gold Dot loaded with 180-gr JHP bullets.

Cartridge Cases—Pavement at the Scene These three 40 S&W caliber cartridge cases bear the Speer headstamp. They were identified as having been fired in the submitted Glock pistol.

Cartridge Case—Driver's Floorboard This cartridge is a WWII vintage .45 Automatic military cartridge comparable to the ammunition recovered in the decedent's .45 Automatic pistol.

Bullets from the Decedent's Vehicle Both of these bullets are 40-caliber, 180-gr Speer Gold Dot bullets possessing polygonal rifling engravings comparable to those found in Glock pistols.

Both of these bullets possess numerous particles of embedded glass and multiple "facets" on their ogives (nose portions).

Bullet Fragment from the Chrome Molding, Graze Mark Area of the Decedent's Vehicle This item consists of a 5-gr fragment of a copper bullet jacket. It is unsuitable for identification purposes but does possess a "land" impression from polygonal rifling.

Bullet from the Decedent, John Johnson This bullet is a deformed but otherwise unexpanded .40-caliber, Speer Gold Dot bullet weighing 175 grains and possessing polygonal rifling engravings comparable to those found in Glock pistols. It possesses obvious blue paint transfers on one side of its nose. There is also an area of missing bullet jacket material just aft of the blue paint transfers. No glass damage or embedded glass was present on this bullet.

Bullet from Officer Sam Smith This bullet a 45 caliber, 230-gr FMJ bullet fired from a fire-arm possessing conventional, 6-left rifling engravings. The nose of this bullet has a smooth, flattened area containing pulverized particles of glass. The flattened area is at right angles to the long axis of the bullet, indicating a near-orthogonal impact with glass prior to striking Officer Smith.

Pieces of Tempered Glass from the Upper Molding of the Driver's Side Window These pieces of diced tempered glass were examined under shortwave ultraviolet light and found to fluoresce on the surfaces marked "E" for exterior.

Pieces of Tempered Glass Removed from the Window Carrier in the Driver's Door These pieces of diced tempered glass were examined under shortwave ultraviolet light and found to fluoresce on the surfaces marked "E" for exterior.

Two Pie-Shaped Sections of Tempered Glass from Inside the Driver's Door Cone fracturing was found and photographed at the convergence points on these two sections of tempered glass.

These items were examined under shortwave ultraviolet light and found to fluoresce on the surfaces possessing the cone fracturing.

Summary and Conclusions

Pie-Shaped Sections of Shattered Tempered Glass

These sections of tempered glass possess radial fractures and cone fracturing at the convergence point. These phenomena are the result of the first bullet striking and shattering this tempered glass window. Shortwave ultraviolet light examination of these sections of glass and known specimens collected from the decedent's vehicle revealed that this glass was made by the tin float method. This process causes one side of such glass to fluoresce when illuminated with shortwave ultraviolet light and the opposite side to simply transmit or absorb the SW-UV light. From the observations on the evidence sections and the information derived from the known specimens taken from the 2002 blue Camaro, the bullet that shattered this window came from *inside* the vehicle.

Bullets Recovered from the Blue Camaro

Both of these 40 caliber Gold Dot bullets struck and perforated previously failed tempered glass, as evidenced by the "faceting" on their ogives. Although they show extensive impact damage, they have retained their original weights.

John Johnson's Fatal Gunshot Wound

This 40-caliber Gold Dot bullet is associated with the grazing strike to the "B" pillar of the decedent's blue Camaro. The reasons for this are the presence of blue paint transfers on this bullet and the missing 5 grains of bullet jacket material. This missing area on the bullet corresponds to the 5-gr bullet jacket fragment found trapped in the chrome molding immediately adjacent to the graze mark in the "B" pillar. The other two bullets fired by Officer Smith did not experience any weight loss.

The alignment of the graze mark with the area occupied by the driver places the shooter to the rear of the "B" pillar and firing along a forward and left-to-right path.

The total absence of any glass damage or embedded glass in this bullet indicates that the glass was no longer present in the window when this bullet entered the occupant area of the decedent's vehicle.

Bullet Recovered from Officer Smith's Gunshot Wound

This bullet is the first shot fired, as evidenced by the smooth, even flattening of its nose, in which pulverized glass was found. This finding is also supported by the results of the shortwave ultraviolet light examinations of the sections of shattered side window glass. The nose-on flattening experienced by this bullet also establishes this shot as having been fired directly through and out the driver's side window, with Officer Smith located somewhere beyond (downrange) of the side window.

Trajectories of Officer Smith's Three Shots

The paths of the three shots fired by Officer Smith show substantial changes or differences in their azimuth components. The bullet that struck the glove box came through the previously shattered glass of the driver's side window with a slight back-to-front angle. The shot that struck the radio/CD player entered the previously shattered driver's side window with an azimuth angle of approximately 45 degrees along a back-to-front path. The fatal shot that first grazed the "B" pillar struck and entered the decedent's vehicle along an azimuth angle estimated to be 15 to 25 degrees.

These angles required the shooter to change his position between at least two of these shots.

This is contrary to the account given by the passenger, Jordan Jones, wherein he describes Smith as immediately outside the driver's window and firing into the vehicle.

This account does support Officer Smith's account insofar as his movements while returning fire.

Other Reconstructive Issues

The passenger, Jordan Jones, also described Smith as breaking out the driver's side window with his pistol, then thrusting his gun into the occupant area and firing all of his shots in very rapid succession.

This account is refuted for multiple reasons. The 45 caliber bullet from the decedent's pistol passed through and shattered the tempered glass in the driver's side window. Two of Officer Smith's bullets passed through failed tempered glass. His expended cartridge cases were found *outside* the vehicle, not inside the vehicle as one would expect if his pistol had been discharged in the manner described by Jones. The graze mark on the exterior of the "B" pillar also refutes the account provided by Jordan Jones. No impact damage or embedded glass was found on Officer Smith's pistol. No close-range gunshot residues or powder stippling were found around the decedent's entry wound when examined by the medical examiner.

Additional Testing

This report may be amended in the event additional testing is requested or carried out.

No such tests have been requested nor are any contemplated at this time.

Disposition of the Evidence

All of the submitted items were returned to their respective containers, resealed, marked, and transferred to the Evidence Impound Facility on July 15, 2005, at 4:55 p.m.

Signed,

Attachments

1. CD containing a PowerPoint file of scene photographs, vehicle photographs, chemical test results on the vehicle, and reconstruction photographs taken by this examiner.
 2. List of publications relied on and/or authored by the examiner.
 3. List of trial and deposition testimony for the last 4 years.
 4. Current fee schedule and CV.
-

The preceding example may be more involved than necessary, particularly regarding the attachments. It was modeled along the lines of a civil case filed in federal court. Criminal cases in federal and state courts do not presently require such detail. Nonetheless, this report was for the purpose of exposing the reader to different ideas and perhaps a different style for writing reports dealing with reconstructive issues.

CONCLUDING COMMENTS ABOUT THE BOOK

Among the many things included in the Appendix to this book are some suggested direct examination questions for use at trial. It is expected that the interested reader will

make copies of these and any other lists or illustrations in the Appendix for subsequent modification and use in the reader's jurisdiction or laboratory.

The classical definition of a science is an orderly body of knowledge with principles that are clearly enunciated. Additional requirements specify that the subject be susceptible to testing and that it be reality-oriented. This book has been an effort to organize the many aspects of shooting incident reconstruction into an orderly body of knowledge. The guiding principles have been unbiased analytical thinking and the application of the scientific method.

The basis and purpose of, and the various interpretations for, each technique or procedure in this book have been described and references have been provided. Methods for documenting and preserving the evidence so that it can be reviewed by others and ultimately presented to a court or jury have been presented. All of the matters dealt with are reality-oriented. A ricocheted bullet removed from a body and found to contain particles of embedded asphalt is quite real.

We have been very careful to use the phrases *shooting scene*, *shooting incident*, and *shooting incident reconstruction*. The phrases *crime scene* or *crime scene reconstruction* have been avoided for several reasons. Not all instances of firearms use or even misuse are crimes. A police officer or armed homeowner defends himself against an armed assailant, and the criminalist is requested to examine and reconstruct this scene. Neither shooter is charged with a crime.

A hunting accident or the discharge of a dropped firearm may result in some form of civil litigation, but no crime is ever charged. Whether a criminal or a civil matter, the ultimate goal of criminalistics is the same, and that is the reconstruction of events. This is accomplished through an examination and evaluation of the physical evidence with the purpose of determining what did and did not occur.

This book focused on the various characteristics of firearms and firearms-generated evidence and on certain phenomena associated with them that have reconstructive properties. Eyewitness accounts are notoriously untrustworthy. Participants in a shooting incident may have strong motives to misrepresent the facts. A careful, thoughtful, thorough and well-documented reconstruction provides an objective and clear voice to this otherwise silent evidence.

References and Further Reading

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- Frye v. United States* 293 Fed. 1013 (D.C.Cir. 1923).
- Kumho Tire Co. v. Carmichael*, 526 U.S. 137 (1999).
- U.S. v. St. Jean* 45 M. J. 435 1996 CAAF Lexis 117 (1996).

Appendix

SHOOTING INCIDENT EVALUATION AND RECONSTRUCTION: DOCUMENTS SOUGHT OR REQUESTED

- ☐ POLICE/SHERIFF'S REPORT, to include any supplements, witness statements, diagrams, sketches, scene photographs, and video walkthroughs
- ☐ AUTOPSY REPORT, to include any anatomical diagram(s)
- ☐ AUTOPSY PHOTOGRAPHS (particularly of the gunshot wounds before and after clean-up, with and without probes if used)
- ☐ EMERGENCY MEDICAL RECORDS (E.R./trauma records)
- ☐ EMT records
- ☐ COPY OF THE EVIDENCE IMPOUND LIST
- ☐ CRIME LAB REPORT(S), to include bench notes, worksheets, any diagrams, photos, and/or videotapes prepared by the examiner(s)
- ☐ SUPPLEMENTAL OR ADDITIONAL EXPERT WITNESS REPORTS, to include photographs, bench notes, case files, reports
- ☐ STATEMENT/DEPOSITION of the shooter(s)
- ☐ STATEMENT/DEPOSITION of the victim(s)
- ☐ STATEMENT/DEPOSITION of any witnesses
- ☐ COPY OF THE COMPLAINT/ALLEGATION/PLEADINGS (civil)
- ☐ ANY PERTINENT INTERROGATORIES or DEPOSITIONS (civil)
- ☐ ANY MEDIA PHOTOGRAPHS or VIDEOTAPES taken at the time of the incident
- ☐ Other:

MATERIALS CHECKLIST FOR SHOOTING SCENE EXAMINATION

- ☐ RUBBER GLOVES/PROTECTIVE SUPPLIES
- ☐ BULLET METAL REAGENTS + BENCHKOTE (Filter Paper) + SPRAYERS
- ☐ LASERS + REFLECTIVE CARD (for laser photography)
- ☐ TRIPODS with ADAPTERS for CAMERAS and LASERS
- ☐ HIGH-INTENSITY FLASHLIGHT(S) and MAGNIFIER (STEREOSCOPE)
- ☐ DIGITAL INCLINOMETER
- ☐ PLUMB BOB
- ☐ ANGLE-MEASURING DEVICES: Half- and full-zero-edge protractors
- ☐ POCKET CALCULATOR with SCIENTIFIC FUNCTIONS
- ☐ COMPASS
- ☐ PROBE KIT or DOWEL RODS
- ☐ COLORED STRING LINES, TACKS, and REUSEABLE ADHESIVE
- ☐ TAPE MEASURES/SCALES (for photography)
- ☐ DISTANCE-MEASURING DEVICE
- ☐ MASKING TAPE and DOUBLE STICK TAPE
- ☐ MARKING SPRAY PAINT
- ☐ FINGERPRINT BRUSH & POWDER + FINGERPRINT CARDS
- ☐ MARKING PENS
- ☐ EVIDENCE LOCATION MARKERS, NUMBERS/LETTERS and CONES
- ☐ VIDEOCAMERA + STILL CAMERA with capture/storage devices, GRAY CARD
- ☐ REMOVABLE STROBE (FLASH) UNIT if laser photography is to be used
- ☐ DIGITAL CALIPERS
- ☐ DIGITAL MICROMETER
- ☐ LARGE CALIPERS
- ☐ TOOLS (for disassembling car door panels, etc.)
- ☐ DREMEL TOOL/SMALL SAW/SCALPEL/KNIFE/CUTTING TOOLS
- ☐ ASSORTED EVIDENCE COLLECTION CONTAINERS
- ☐ WORKSHEETS/NOTEPAD/PHOTOLOG
- ☐ MAGNET

Other materials _____

Case file/phone # of contact person _____

Date/time of arrival _____

Persons present _____

Date/time of departure _____

VEHICLE DATA, MEASUREMENTS, AND BEHAVIOR WITH OCCUPANTS AND/OR MOVEMENT

Identification information: Make _____ Model _____

Color _____ VIN _____

Plate _____ Engine _____

- ☐ Transmission type
- ☐ Front/rear wheel drive _____
- ☐ External dimensions
- ☐ Suspension characteristics (height changes with occupant loading)
- ☐ Tire sizes and description
- ☐ Height of vehicle body above ground level
- ☐ Height and dimensions of window and door openings
- ☐ Positions of windows/method of operation (manual/electric)
- ☐ Thickness of side/rear window glass (if struck)
- ☐ Documented samples of side/rear window glass collected (if struck)
- ☐ Angle of windshield (if struck) relative to horizontal plane
- ☐ Interior dimensions of occupant area
- ☐ Position of front seat(s), head rest, seat back(s), door locks
- ☐ Marking of vehicle position at the scene*
- ☐ Position of front tires*
- ☐ Position of shifting lever*
- ☐ Position of steering wheel*
- ☐ Position of parking brake*
- ☐ Position of center arm rest/console hatch
- ☐ Glove box locked/unlocked
- ☐ Ballistic "accessibility" of struck tires (if any)
- ☐ Manufacturer's diagrams of vehicle
- ☐ Modifications to vehicle (if any)
- ☐ Behavior of vehicle in motion (if appropriate)
- ☐ Nature and/or effects of scene terrain
- ☐ Other _____

*For vehicles struck at rest and not subsequently moved.

LOGSHEET FOR PROJECTILE STRIKES
TO VEHICLES

Case # _____ Vehicle Description _____

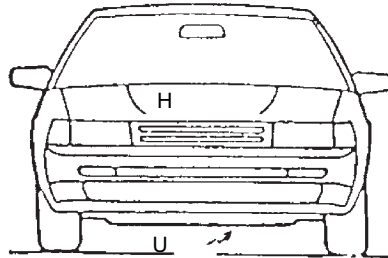
Reference Point on Vehicle _____

Strike	Distance	Height	Vertical ∠	Azimuth ∠	Comments

Key: F = front; H = hood; R = rear; T = trunk lid; D = driver’s side; Rf = roof; P = passenger’s side; U = underside.

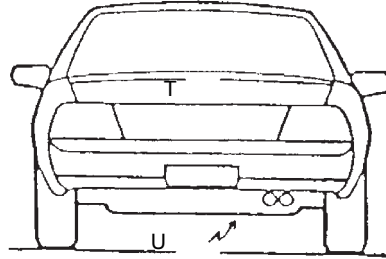
SOME USEFUL FORMS FOR THE EXAMINATION OF VEHICLES

FRONT VIEW

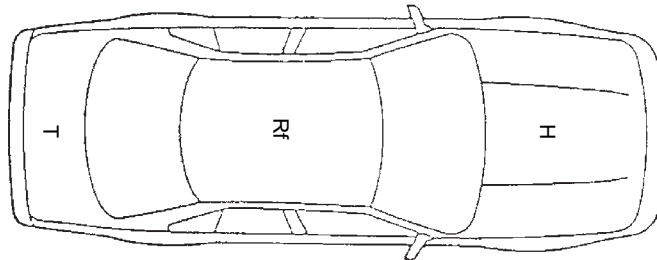


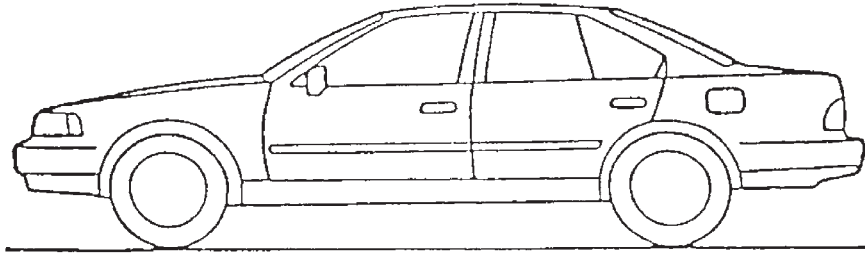
F

REAR VIEW



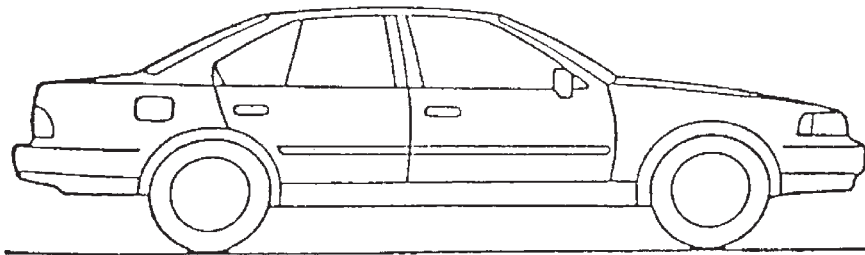
R





LEFT SIDE PROFILE VIEW

D



RIGHT SIDE PROFILE VIEW

P

OFFICER-INVOLVED SHOOTINGS (OISS)

Questions for Officers

When did you load your gun?

How, exactly, did you load it (admin top off, not topped off)?

How many cartridges are in your extra mags?

Do you always load these mags and the firearm in the same way?

What ammunition is in the firearm, additional mags?

Please describe each shot as best you can, with respect to direction and target?

Please describe the time intervals between each shot (taped audio or video)?

Describe what you saw of the other party's firearm (loading it, reloading it, pointing it, operating it, etc.).

Did you fire from a standing position, crouched, kneeling, and so forth?

Do you recall how tightly you were holding the firearm?

Do you know of any problems with your firearm?

For each shot fired, can you describe if you were hunching down, standing up straight, crouched, or in another positions?

Do you recall, for each shot fired, if you had to aim downward or upward? *Have officer demonstrate if needed.*

For each shot fired, did you have the gun upright, in a two-handed grip?

Did you have the gun in a rotated orientation (left/right) at the time any of the shots were fired?

Would you describe your grip on the gun as weak, medium, or strong?

Did you use the type of grip and shooting stance that was taught in the Academy?

Have the officer make diagrams and drawings of the shots and direction of fire, with their location and all other participants' locations.

SHOOTING RECONSTRUCTION CHECKLIST

I Firearm

A. Shooter's/Witness's Explanation of Pre-Discharge Condition of Firearm

1. Previous firings of this firearm (when, brand and type of ammunition, sample available?).
2. Storage and condition of the gun prior to the incident (previously cleaned, oiled, dirty, rusty, loaded, magazine separate from the gun, etc.).
3. Loading/preparation of the gun.
4. Source and type(s) of ammunition in the gun (brand, source, bullet weight, type).

Proposed laboratory evaluation: _____

B. Shooter's/Witness's Explanation of Manner of Discharge

1. Manner in which the gun was held (e.g., one hand, two hands, arms extended, canted, etc.). [Measure approximate height above ground level and any upward or downward angles if possible.]
2. Means of discharge (e.g., double action, single action, dropped, "slam-fire," etc.).
3. Manner in which the gun was sighted. [Note the settings of any optical sight on the firearm; mark and secure these settings.]
4. Conduct of the shooter/participants relative to the firearm after the discharge of the firearm (e.g., gun recoiled, reloaded, action cycled, gun dropped, tossed, magazine removed, etc.).

Proposed laboratory evaluation: _____

C. Location, Position and Orientation of Recovered Firearm

1. Record in the scene diagram and orientation photographs.
2. Take close-up photographs showing the configuration of the gun *before* the action is moved or opened. [Note: Ascertain if prints and/or DNA-containing cellular material are import and proceed accordingly.]
3. Documentation of:
 - a. Position of the cylinder (revolvers)/position of the slide (pistols)/position of the bolt/breech block (rifles or shotguns).
 - b. Position and sequence of cartridges in the cylinder (revolvers) including a description of each cartridge.
 - c. Position of the hammer (if present).
 - d. Position of any mechanical safety mechanism.
 - e. Magazine (if present) out or in. If in, was it fully seated?
 - f. Number of live rounds remaining in the magazine/type and description.
 - g. Live or expended cartridge in the chamber—yes/no. If yes, give description.
 - h. Position of cock and/or load indicators (if present).

- i. Visible damage to the gun. Note location(s) and preserve any trace evidence associated with such damage.
- j. Location and description of any visible trace evidence on the gun (blood, hair, tissue, fibers, paint smears, impact damage, etc.).

Proposed laboratory evaluation: _____

D. Trace Evidence Considerations

1. On and/or in the firearm (e.g., powder particles in the bore and chamber(s), “flares” on the face of a revolver cylinder, bullet metal deposits in the bore, primer lacquer particles on the breechface; hairs, fibers, blood, tissue; impactive transfers of trace evidence such as wood, asphalt, concrete particles).
2. On the victim or other objects (e.g., gunshot residues, powder deposits, bulletwipe; ricochet/graze marks containing bullet metal; firearm contact/imprint marks; cylinder gap deposits).
3. Clothing of the gunshot victim.
4. Clothing of the shooter.
5. Acquisition of comparison specimens (e.g., ammunition; materials from possible impact surfaces; comparison samples of blood, hair, fibers).

Proposed laboratory evaluation: _____

II Exterior/Terminal Ballistic Questions

A. Range Determinations

1. Information derived from the wound (stellate wound, atypical entry wounds, gunshot residue/powder pattern, penetration depth, etc.).
2. Directionality (bullet wipe, cone fractures, lead splash, deformation of struck surface or object, fracture lines in painted metal surfaces, pinch point, lead-in mark, etc.).
3. Gunshot residue/powder deposition and pattern.
4. Shot patterns (shotgun/shot cartridge shootings).
5. Wads, shotshell fillers, shot collars, shotcups, sabots (exterior ballistic characteristics).
6. Trajectory considerations (angle of departure, angle of fall, line of sight, midrange and maximum ordinate height, sight picture, bullet flight time, lagtime’).
7. Performance characteristics of the responsible gun/ammunition combination (general operation of the gun, GSR production, muzzle velocity of the projectile, cartridge ejection pattern, etc.).
8. Appearance, visibility of the gun, its discharge (sound, muzzle flash, etc.).
9. Weather conditions at the time of the shooting (if applicable and known).
10. Site description and MSL elevation (if applicable). *Note:* The elevation of the site, terrain features, and meteorological conditions are of interest or importance in long-range shootings.

Proposed laboratory evaluation: _____

B. Terminal Ballistic Phenomena

1. Penetration depth (as an expression of terminal velocity). *Note:* determined by measurement, radiographs (X-rays), interview of pathologist.
2. Penetration path/angle (as an expression of the bullet's pre-impact path). *Note:* Determine and/or document vertical and azimuth components of penetration path.
3. Projectile deformation/trace evidence transfers (degree of projectile deformation related to impact velocity; the character of bullet deformation may be relatable to the incident angle in ricochets and the nature of the impacted surface; examples of transfers are fabric imprints, embedded bone, soil, adhering tissue, blood, fibers, etc.).
4. Bullet wipe (usually contains traces of the bullet's composition, primer-generated residue and possibly bullet lubricant).
5. Sequence of shots through intersecting radial fractures in plate glass, plastics, ceramics, skulls, etc. Sequencing of shots through mixed bullet types (revolvers, barrel residues, trace evidence methods).

Proposed laboratory evaluation: _____

III Ejected Cartridge Cases/Misfired Cartridges/Unfired Cartridges

- A. Location(s) with measurements (shooting scene diagram).
- B. Orientation photographs.
- C. Close-up photograph(s).
- D. Cartridge description (headstamp, damage, adhering trace evidence).
- E. Nature and description of surface upon which cartridge was found.
- F. Nature of any nearby surfaces that cartridge may have struck (walls, fences).

Proposed laboratory evaluation: _____

IV Supplemental Background Information

- A. Prior use of the gun (when and where fired, number of shots fired, type of ammunition, persons present, fired cartridges picked up? cleaned afterwards?).
- B. Cartridges previously loaded or fired in the gun.
- C. Source and age of ammunition actually used in shooting incident (ammunition properties and characteristics—for example, bullet weight, composition and design, powder type and charge, cartridge headstamp, etc.). *Note:* Obtain cartridge box(s) if possible (for lot number).

Proposed laboratory evaluation: _____

V Miscellaneous Techniques and Comparisons

- A. Comparison of ammunition components (class characteristics, corresponding manufacturing marks, bunter marks, propellant type, propellant and/or primer chemistry, bullet weight, construction and composition, etc.).
 - B. Comparison of bullet cores and/or bullet fragments:
 - 1. Physical matches of cores to separated jackets; fragments to fragments; weight considerations.
 - 2. Instrumental analysis of projectile fragments; comparison of results with fired and/or unfired projectiles of the same type.
 - C. Acoustical evaluation and comparison of recorded gunshots:
 - 1. Description of equipment involved that recorded the gunshots and/or bullet passage/impact.
 - 2. Site conditions at the time the gunshots and/or bullet passage/impact sounds were recorded (meteorological conditions, wind speed and direction, sources of background noises, if any).
 - 3. Location and orientation of equipment involved.
 - 4. Distance(s) involved between the possible source of the shot(s) and the recording site.
- Proposed laboratory evaluation: _____
- _____
- _____

SUGGESTED GUIDELINES FOR RECONSTRUCTION AND REENACTMENT OF SHOOTING INCIDENTS

1.0 Scope

These guidelines are intended to provide direction for the forensic scientist undertaking a reconstruction or reenactment of a shooting incident. They describe the following:

- 1.1 Collection of data necessary to undertake the reconstruction.
- 1.2 Documentation required in the report.
- 1.3 Appropriate procedures and precautions for the presentation of a reconstruction or reenactment in court.

2.0 Definitions

- 2.1 *Reconstruction*: The determination of the sequence of two or more events in a particular incident utilizing information derived from the physical evidence; data from the analysis of the physical evidence; recognized physical laws and/or inferences drawn from experimentation related to the incident under investigation.
- 2.2 *Reenactment*: The demonstration of a reconstruction through the use of live actors or computer animation.
- 2.3 *Visual aid*: Any device used to demonstrate any aspect of a reconstruction or reenactment.
- 2.4 *Event*: A single occurrence, action, or happening.
- 2.5 *Incident*: A series of related events.
- 2.6 *Transfer evidence*: Evidence that is transferred from one object to another by virtue of the contact of the two objects.
- 2.7 *Trace evidence*: Physical evidence of a microscopic or submicroscopic size which, due to its small size, is deposited on or transferred to one or more objects without being manifestly apparent at the time of transfer or deposition. *Note*: Trace evidence is differentiated from transfer evidence in that contact is *not* required. Gunshot residues deposited on a victim or left in the bore of a firearm, for example, do not require contact.
- 2.8 *Impression evidence*: Evidence produced by the static deformation or dynamic alteration of one object by another.

3.0 Significance and Use

The reconstruction or reenactment of an event or incident may attempt to establish one or more of the following:

- 3.1 The manner in which a firearm was discharged.
- 3.2 The range from which a firearm was discharged.
- 3.3 The position or orientation of a firearm at the moment of discharge.
- 3.4 The location of the shooter at the time of discharge.
- 3.5 The position of the victim at the moment of projectile impact and/or the discharge of a firearm.

- 3.6 The number and/or sequence of shots in multiple discharge shooting incidents.
- 3.7 The presence of a person or object at a shooting scene.
- 3.8 Other exterior and/or terminal ballistic events that may have reconstructive value.
- 3.9 Establishment of a timeline for actions in an incident based on
 - 3.9.1 The physical requirements for movement or actions of persons.
 - 3.9.2 The considerations of operational requirements of mechanical systems or other objects or minimum rates of fire of the gun.
 - 3.9.3 Acoustical information derived from audio recordings (911 tapes, videotapes, audiotapes, etc.).

4.0 Data Collection

The reliability of any reconstruction or reenactment ultimately relies on the validity and accuracy of the underlying data. The forensic scientist must determine that the data that is relied upon is sufficiently accurate for the purposes for which it is used.

4.1 *Scene data*

- 4.1.1 The dimensions of the relevant area should be determined with reasonable accuracy.
 - 4.1.1.1 Data from interior rooms should include ceiling height, dimensions, layout (floor plan), and furnishings.
- 4.1.2 Photographic documentation of the scene should be thorough, but should not be considered a substitute for adequate sketches.
 - 4.1.2.1 Overall photographic documentation should include views from several angles.
 - 4.1.2.2 Photographic documentation should include intermediate and close-up views of all items of physical evidence.
 - 4.1.2.3 Particular attention should be paid to ensure adequate photographic documentation of evidence which, by its nature, cannot be removed from the scene. Examples are bullet holes in some types of walls, plate glass windows, certain bullet impact sites, etc.
 - 4.1.2.4 Videotaping of the scene may provide a useful adjunct to, but is not a substitute for, adequate still photography. Such videotaping should include a factual narrative of the scene or subject matter being videotaped. The narrator should qualify observations with terms such as “...appears to be a bullet hole, impact site, ricochet mark,” and so forth.

4.2 *Physical evidence data*

- 4.2.1 The locations of all items of physical evidence should be documented.
- 4.2.2 Critical scene information must be documented photographically and by such other methods as would allow another investigator who does not have access to the scene to use the photographs and data to evaluate the reconstruction. Some examples of common scene evidence which require careful documentation are:
 - 4.2.2.1 Projectile trajectories, bullet holes, and impact sites.
 - 4.2.2.2 Blood spatter patterns and blood trails.
 - 4.2.2.3 Expended cartridge cases, shotshell wads, gunshot residue deposits, etc.

5.0 Laboratory Testing

All data from laboratory examinations, analyses, or experiments should be recorded in a manner consistent with good scientific practice and in a manner that can be understood by another forensic scientist familiar with shooting incident reconstruction.

- 5.1 *Experimental verification in reconstruction:* Experimental verification of all stages of the reconstruction should be theoretically possible and, when possible, actually carried out.
 - 5.1.1 Elements of the reconstruction that are not, at least in principle, experimentally verifiable should not be included in the report, testimony, or visual aids used at trial.
 - 5.1.2 Any experiments should be designed to test specific hypotheses or accounts of an incident and should include appropriate controls.
 - 5.1.2.1 The variables associated with an experiment should be explicitly identified, and any assumptions made should be explicitly stated.
 - 5.1.3 Experiments should be designed to reproduce those elements of the original circumstance that, in the opinion of the forensic scientist, are relevant to the purposes of the experiment.
 - 5.1.4 Reliance on statements of witnesses or actors in the incident should be kept to a minimum and, when utilized, so stated in any reconstructive effort.
 - 5.1.4.1 If the forensic scientist relies on any witness or actor statement as a part of a reconstruction, it is highly desirable to design tests or experiments to evaluate such statements when possible. In the reconstruction the investigator should:
 - 5.1.4.1.1 Evaluate whether the statement is reasonably correct and reliable.
 - 5.1.4.1.2 Specifically refer to the statement in any report or testimony.
 - 5.1.5 If the reconstruction refutes the account given by a witness or actor, the specific basis of such refutation should be clearly stated in any subsequent report.

6.0 Presentation of a Reconstruction or a Reenactment

The purpose of the reconstruction or reenactment is to give the client, attorney, court, or jury a clearer understanding of what happened in the incident under consideration. It is also appropriate to state those matters and events that can be excluded as having occurred. Whether in a written report, by means of photographic or other documentation, or in testimony, it is incumbent on the forensic scientist to be certain that the recipient has a clear understanding of the nature of the investigator's opinion, including the limitations and uncertainties of that opinion.

- 6.1 *Written report:* A written report should convey to an untrained reader who is familiar with the basic facts under consideration the expert's view of what happened. This report should also contain enough data that the technically sophisticated reader can evaluate the methods used by the expert to arrive at the conclusions expressed in the report, and to make a preliminary evaluation of the reliability of the opinions expressed in the report.

- 6.1.1 All documents reviewed should be explicitly identified in the report.
- 6.1.2 If any additional information has been used in the reconstruction, the source and nature of that information should be explicitly stated in the report.
- 6.1.3 All items of physical evidence received or examined should be listed in the report.
- 6.1.4 The source of any reference material used in experiments or tests should be explicitly described in the report. For example:
 - 6.1.4.1 Tables of ballistic data.
 - 6.1.4.2 Tables or data relating to body dimensions and/or gunshot wounds in bodies.
- 6.1.5 Data from experiments or observations should be included in reports in such a way so as to provide the technically astute reader a basis for evaluating the opinions expressed in the report.
- 6.1.6 Computer programs used for the analysis of data or the production of information used for the reconstruction should be identified.
- 6.1.7 If photographic or videotape documentation is supplied with the original report, the photographs or videotape should be referred to in the report, and copies should be made available to interested parties.

6.2 *Testimony*

- 6.2.1 The purpose of testimony is to convey to the court or jury those pertinent elements of the reconstruction that can be stated with a reasonable degree of scientific certainty by the forensic scientist or witness.
- 6.2.2 The expert should not include in testimony or visual aids information that is not based on his technical evaluation of the evidence or circumstances of the incident.
- 6.2.3 The witness should provide the court and jury with an understandable assessment of the reliability of conclusions. Such an assessment should include:
 - 6.2.3.1 Statements of reasonable alternative possibilities.
 - 6.2.3.2 Estimates of the uncertainty (margin of error) in experimental results.

6.3 *Presentation of reenactments*

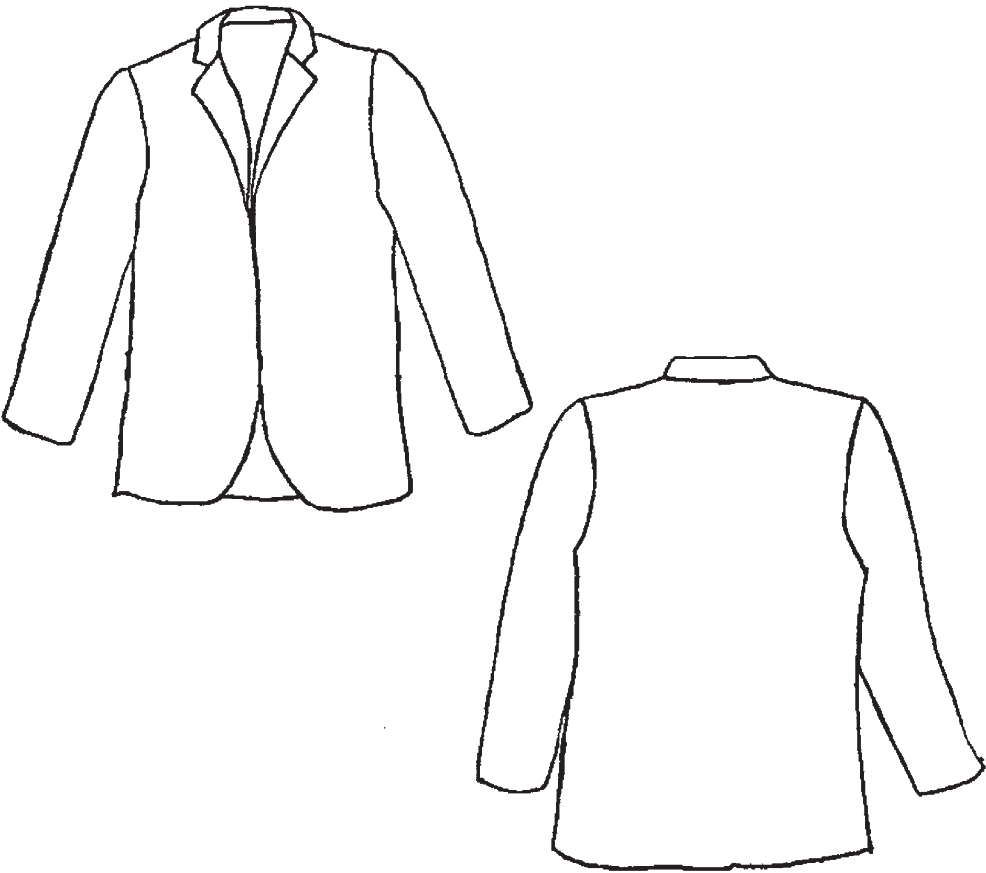
- 6.3.1 It must be recognized that it is not possible to determine all of the elements necessary for a reenactment of an incident with the same degree of reliability.
- 6.3.2 The courtroom presentation of a reenactment of a shooting incident will be at the discretion of the trial judge. It is incumbent on the forensic scientist who developed the reenactment to advise the court as to what elements of the reenactment can be verified by the witness and what elements are assumptions.
 - 6.3.2.1 The expert must remember that many of the unverifiable aspects of a reenactment (e.g., facial expressions of participants, positions of hands and arms, positions of persons or objects prior to the earliest moment of the reconstruction) may be critical to arguments made by counsel and can have an undue impact on a jury.
 - 6.3.2.2 While the determination that a visual aid or reenactment is “more probative than prejudicial” is up to the trial judge, the expert must be sure that the judge is aware of which aspects of the reenactment or visual aid can be defended scientifically and which cannot.

WORKSHEET FOR COAT

Examiner _____ Case # _____

Item # _____ Date _____

Remarks: _____

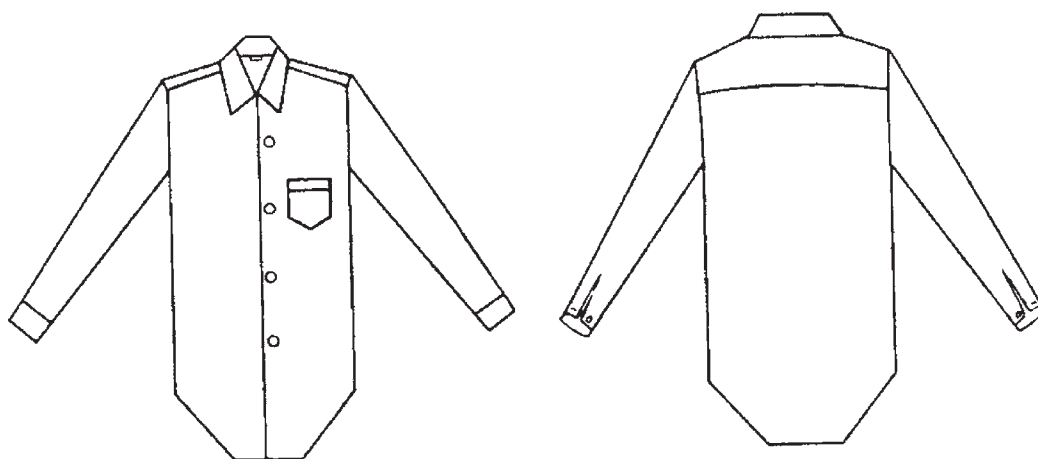


WORKSHEET FOR LONG-SLEEVED SHIRT

Examiner _____ Case # _____

Item # _____ Date _____

Remarks: _____



WORKSHEET FOR UNDERSHIRT/T-SHIRT

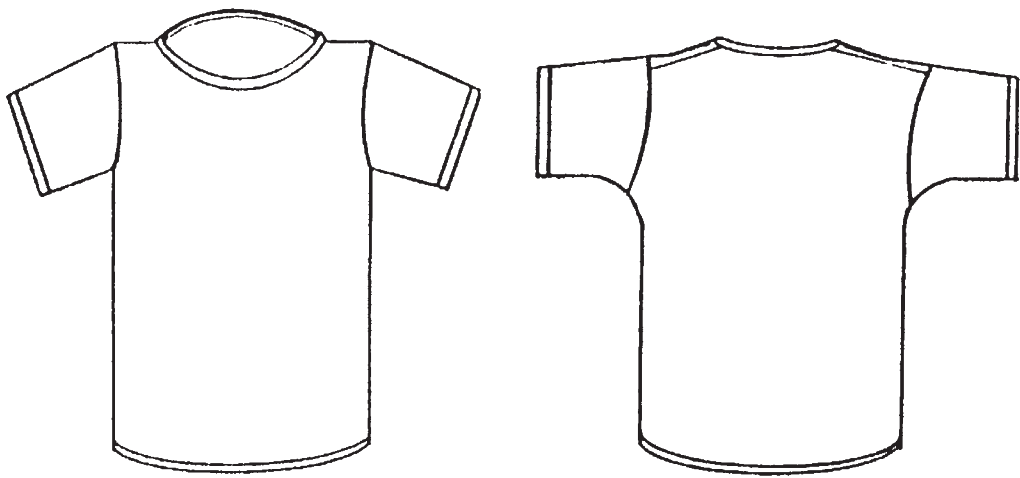
Examiner _____

Case # _____

Item # _____

Date _____

Remarks: _____

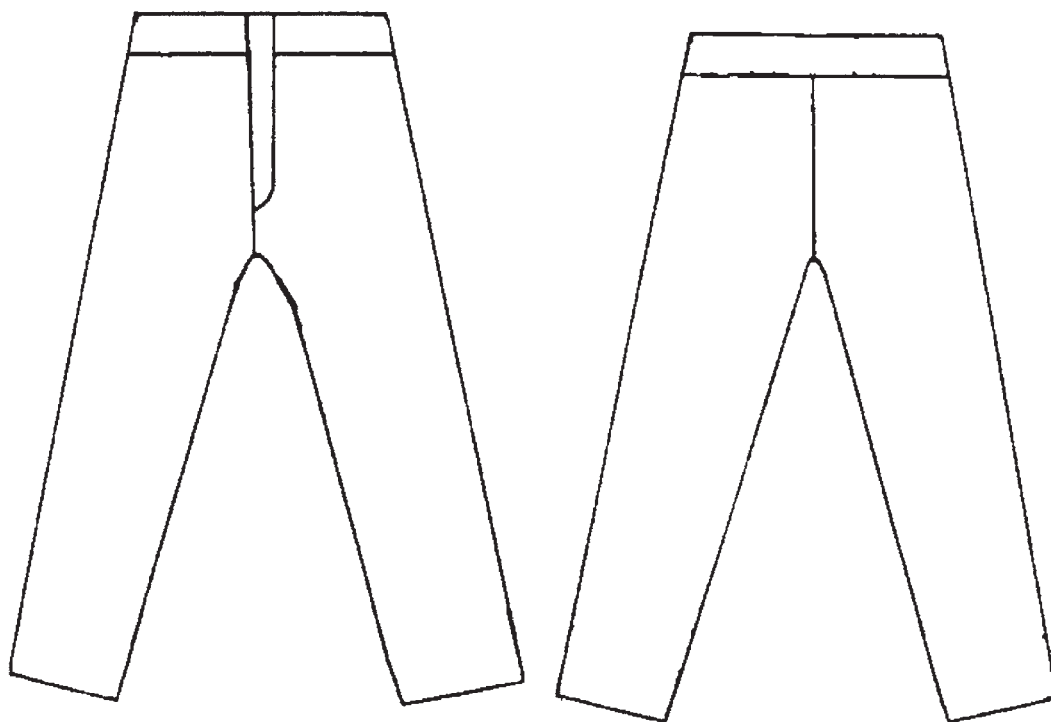


WORKSHEET FOR PANTS

Examiner _____ Case # _____

Item # _____ Date _____

Remarks: _____

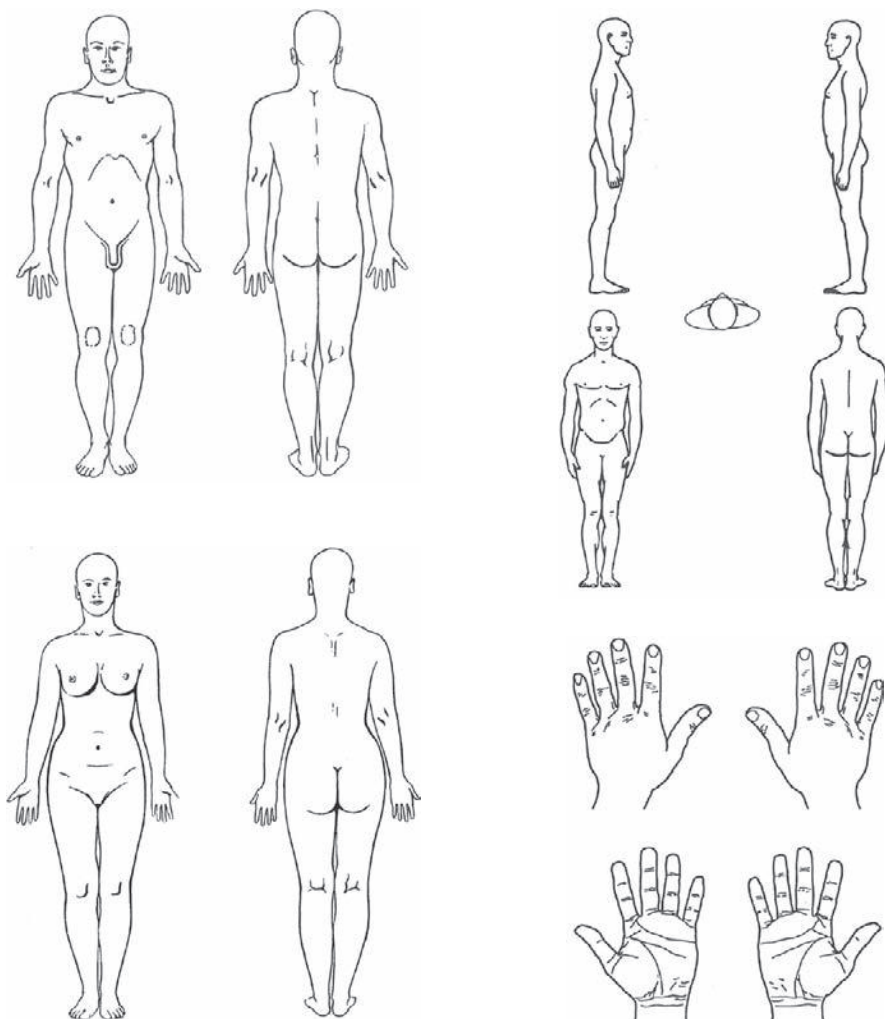


DRAWINGS TO USE TO SHOW THE ESTIMATED PATH OF THE PROJECTILE

Examiner _____ Case # _____

Item # _____ Date _____

Remarks: _____



SOME CYCLIC RATES OF FIRE FOR RECOIL-OPERATED SEMI-AUTOMATIC PISTOLS MEASURED WITH A PACT IV TIMER

Formulas Associated with Rates of Fire

Cyclic Rate, CR (in rds. per minute) = $(60 \div \text{average shot-to-shot time in seconds})$

or

$$CR = [(X - 1) \div T_x] \times 60$$

where

X = number of shots

T_x = time to fire X shots

Average shot-to-shot interval =

$$I = 60 \div [CR + 1]$$

Time to fire X shots =

$$T_x = I \times [X - 1]$$

or

$$T_x = 60[X - 1] \div [CR]$$

A test of this set of formulas is given below by comparison to a professional shooting timer's readout using a Glock 17 and Winchester 11-gr FMJs:

Information from timer: 10 rds. in 2.110s = **255 RPM**

Shot-to-shot times = .259/.225/.230/.239/.216/.257/.231/.230/.223s

(Calculated average shot to shot time = 0.2344)

Calculations

Cyclic Rate (CR) =

$$[60 \div \text{shot-to-shot time in seconds}] = [60 \div 0.2344] = 255.9 = \mathbf{256 \text{ RPM}}$$

$$CR = [(X - 1) \div T_x] \times 60 = [(10 - 1)/2.110] \times 60 = 255.9 = \mathbf{256 \text{ RPM}}$$

where

X = number of shots

T_x = time to fire X shots

Average shot-to-shot interval =

$$I = 60 \div [\text{CR} + 1] = 60/(256 + 1) = \mathbf{0.2335\text{ s}}$$

Time to fire X shots =

$$(T_x) = I \times [X - 1] = 0.2335 \times (10 - 1) = \mathbf{2.1\text{ s}}$$

Firearm	Average Cyclic Rate	Ave. Shot-to-Shot Interval (s)	5 rds. (s)
Glock 17 9 mm	245 ± 20 RPM (no target) = ~4rds./s	0.24	0.98
	175 ± 50 RPM (directed fire) = ~3rds./s	0.34	1.36
Glock 22 .40 S&W	208 ± 12 RPM (directed fire) = ~3.5rds./s	0.29	1.15
S&W M39 9 mm	260 ± 32 RPM (no target) = ~4.3rds./s	0.23.	0.92
Starfire 9 mm	236 ± 16 RPM (no target) = ~4rds./s	0.25	1.01
Ruger P85 9 mm	229 RPM (no target) based on 10 rds. in 2.349 s	0.26	1.04
SIG P226 9 mm	248 ± 15 RPM (no target) = ~4rds./s	0.24	0.96
	78 ± 14 RPM (directed fire) = ~1.3rds./s	0.76	3.00
Beretta 85F .380 Auto	218 RPM (no target) based on 7 rds. in 1.645 s	0.27	1.10
Beretta 92F 9 mm	237 RPM (no target) based on 6 rds. in 1.262 s	0.25	1.01
	173 RPM (directed fire) based on 6 rds. in 1.733 s	0.34	1.38
Beretta 96 .40 S&W	248 RP (no target) based on 5 rds. in 0.926 s	0.24	0.93
	160 ± 58 RPM (directed fire) = ~3rds./s	0.37	1.49
Colt 1911A1 .45 Auto	253 RPM (no target) based on 7 rds. in 1.420 s	0.24	0.94

Note: "No target" means to fire as fast as possible with no effort to aim the pistol. "Directed fire" means to aim the pistol at a man-sized target for each shot.

Source: Adapted from Haag, L.C., 2000. Rates of fire for some common semi-automatic and full automatic firearms. *AFTE J.* 32(3) 252–258.

CONVERSION AND COMPUTATIONAL FACTORS

U.S. to Metric	Metric to U.S.
Length/Distance	
1 in. = 25.4 mm (2.54 cm)	1 mm = 0.03937 in.
1 yd = 0.9144 m	1 cm = 0.3937 in.
1 ft = 0.3048 m	1 m = 1.0936 yd (3.2808 ft)
Velocity/Speed	
fps $\times$ 0.3048 = m/s	m/s $\times$ 3.2808 = fps
fps $\times$ 0.6818 = mph	m/s $\times$ 3.60 = kph
mph $\times$ 1.609 = kph	kph $\times$ 0.6214 = mph
Gravitational Acceleration (g)	
32.17 fps/s	980.7 cm/s/s
Weight/Mass	
1 gr = 0.0648 g	1 g = 15.432 gr
1 oz = 28.35 g	1 kg = 2.203 lbs
1 lb = 16 oz = 454 g	
7000 gr = 1 lb	
lb/g = slugs	
Energy	
ft-lb $\times$ 0.1382 = kg-m	kg-m $\times$ 7.233 = ft-lb
ft-lb $\times$ 1.355 = j (joules)	j $\times$ 0.7375 = ft-lb
	kg-m $\times$ 9.805 = joules
K.E. (ft-lb) = grains $\times$ velocity ² / 450,380 where projectile velocity is in fps	
Momentum	
lb-sec $\times$ 0.454 = kg-sec	kg-sec $\times$ 2.203 = lb-sec
Momentum: (lb-sec) = grains $\times$ velocity / 225,190 where projectile velocity is in fps	
Pressure	
1 bar = 14.5036 psi	780 mm = 29.92-in. Hg
1 atm = 29.92 in. Hg = 780 mm Hg	1000 mb = 29.53 in. Hg
Force	
1 lb = 4.45 N (Newtons)	1 N = 10 ⁵ dyn = 0.2247 lb
	1 dyne/cm ² = 1.45 $\times$ 10 ⁻⁵ lb/in. ²
Area	
1 in. ² = 6.45 cm ²	1 cm ² = 0.155 in. ²
Area of a circle = πr^2	
Volume	
1 in. ³ $\times$ 16.38 = cm ³	1 cm ³ $\times$ 0.0610 = in. ³
gal. $\times$ 3.785 = l	l $\times$ 0.264 = gal
vol of a sphere = $4/3 \pi r^3$	
Temperature	
$^{\circ}\text{F} = 9/5^{\circ}\text{C} + 32$	$^{\circ}\text{C} = 5/9^{\circ}\text{F} - 32$
Speed of Sound (Sea Level and 15°C)	
1117 fps	340.4 m/s
Density of Water	
8.4 lb/gal (20°C)	0.99823 g/cc

TABLE OF COMMON BULLET WEIGHTS

The table that follows is not all-inclusive. Many uncommon and obsolete cartridges have been omitted. Moreover, bullets of alternate and uncommon weights can be hand-loaded in most of these cartridges. New loadings for certain cartridges frequently appear on the market and without prior notice.

Cartridge	Weights (in grains) and Basic Construction
.22 Short	27L 29L
.22 Long	27L 29L
.22 Long Rifle	27L 31L 32L 33L 36L 37L 38L 40L
.22 Magnum Rimfire	30J 33J 34J 40J 50J
.223 Rem. (5.56mm)	40J 45J 50J 52J 53J 55J 62J 64J 69J
.25 Automatic	35J 45J 50J
.30 (7.65mm) Luger	93J
.30 Carbine	110J
.32 Automatic	60J 65J 71J 73J 77J
.32 S&W	85L 88L
.32 S&W Long	83L 98L 100L
.32 Short Colt	80L
.32 Long Colt	82L
.32-20 WCF	100L 100J
.32 H&R Magnum	85J 95L 95J
7.62 × 39mm	122J 123J 124J 125J
7.62mm (.30) Tokarev	87J
7.62mm Nagant	108L
7.63mm (.30) Mauser	88J 93J
9mm Luger	90J 95J 100J 105J 115J 120J 123J 124J 147J
9mm Makarov	90J 95J
.38 S&W	145L 146L 200L
.380 Automatic	60J 82J 85J 88J 90J 95J 102J
.38 (Super) Automatic	115J 125J 129J 130J
.38 Short Colt	125L
.38 Long Colt	150L
.38 Special	95J 110J 125J 129J 130J 132J 140J 148L 147J 150L 158L 200L
.38-40 WCF	180J
.357 SIG	124J 125J 147J 150J
.357 Magnum	105J 110J 125J 140L 140J 142J 145J 150J 158L 158J 165J 170J 180J
.357 Maximum	158J 180J
.40 S&W	135J 140J 145J 155J 165J 170J 180J

Cartridge	Weights (in grains) and Basic Construction
10mm Auto	155J 170J 175J 180J 200J
.41 Short Colt	160L
.41 Long Colt	200L
.41 Remington Magnum	170J 175J 200J 210J 250J
.44 Russian	247L
.44-40 WCF	200J 225L
.44 Special	200L 180J 200L 200J 210L 240L 246L
.44 Magnum	180J 185J 200J 210J 240J 240L 250J 270J 300J
.45 Automatic	165J 185J 200J 225J 230J
.45 Auto Rim	230L
.45 Colt	200J 225J 225L 250J 250L 255L 300J
.454 Casull	240J 250J 260J 300J 350J
.455 Webley	262L 265L
.475 Linebaugh	400J
.480 Ruger	325J
.50 AE	300J 325J

Note: L = lead; J = jacketed.

LASER LIGHT BULB/OPEN SHUTTER PHOTOGRAPHY

Basic Equipment

Digital or 35 mm film camera with

- “B” (bulb) shutter capability
- Adjustable aperture (f-stop), and manual focus
- Cable release with lock
- Lens cap

Sturdy tripod

Removable flash unit

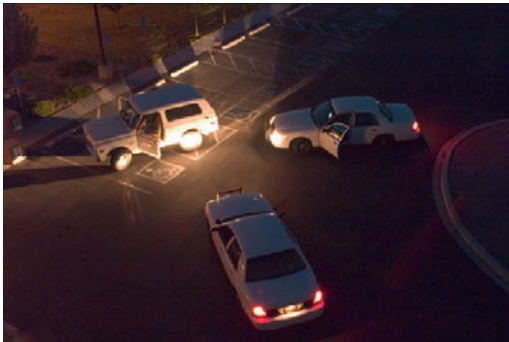
Laser(s) and mounting apparatus

White cardstock (glossy and flat)

Black cardstock (glossy and flat)

DIGITAL PHOTOGRAPHY OF LASER PATHS

- Position the white card handler at one end of the laser line. Stand on the side of the line *opposite* the camera and face the camera. (Several practice walks are recommended.)
- Insert the white card in the laser beam; orient the card at a 45-degree angle to the camera.
- Set the focus to manual and focus to the distance involved.
- For brighter conditions, set the ASA (ISO) to low settings (100 or lower); for darker conditions, set as high as 1000 or higher. (See Figure A.7.)
- Adjust the *f*-stop to get depth of field: a higher number (32) for greater depth of focus; a lower number (5.6) to let more light in.
- Adjust as you go by viewing each shot.
- Have the camera operator open the shutter with the cable release and lock it open.
- Walk the laser line at a walk (approximately 1 foot per second). Walk *faster* for green lasers.
- Clear all people out of the field of view, and pop off any strobes for fill light. Never point the flash toward the camera when using fill lighting.
- If multiple laser lines are to be photographed, cover the open lens with the lens cap or dark cardboard held tightly against the lens in between runs.
- Dotted laser lines may be created by cycling the card in and out of the beam as you move along the laser line. (See Figure A.8.)
- Signal the camera operator to release (close) the shutter by unlocking the cable release as the card handler reaches the end of the laser line.



Nikon D100 –28mm
f/10 –7 sec.
ISO 800
Darkness

FIGURE A.7 Nighttime scene as it originally appeared.



Nikon D100 –28mm
f/9 –14.2 sec.
ISO 800
Twilight

FIGURE A.8 Laser depiction of three shots by two shooters.



Nikon D100 –28mm
 f/9 –14.2 sec.
 ISO 800
 Twilight

FIGURE A.9 Dotted or dashed laser lines created by moving the reflective card in and out of the laser beam intermittently as the line is walked.

The key, and biggest advantage of working with a flexible digital platform such as the Nikon D100, is the ability to evaluate your image immediately. Bracketing settings (f stop, exposure time, number of fill flashes, ASA, etc.) is still the most effective, safest way to obtain the best finished product.

Source: Digital procedures and photographs by Michael Haag and Joe Foster, Albuquerque, NM, Police Crime Laboratory and Major Crime Scene Team, September 2005.

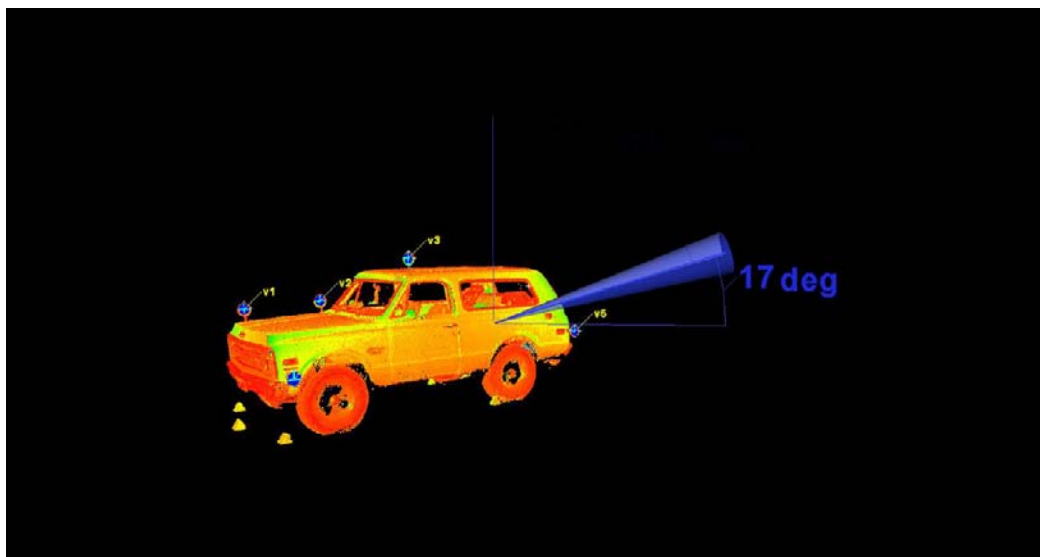


FIGURE A.10 Image showing approximately 500,000 individual data measurements.

Each measurement is accurate to approximately ± 5 mm. This is the same truck shown in the laser light images; however, with 3D laser scanning, the viewer can observe this data from any desired angle (i.e., above, around, below). A sample trajectory is also shown with vertical angle measurements based on the scanner's internal gravity-sensing equipment. A ± 5 -degree cone is then laid over the central measured trajectory. This data was captured with a Leica Geosystems C10.

SOME BULLET CORE AND JACKET WEIGHTS

In reading the table that follows, note that lead cores are removed by heating the pre-weighed bullet with a torch and melting and rapping the liquid lead out of the jacket.

Cartridge	Manufacture/Type	Bullet Weight	Jacket Weight	Core Weight
.224 in.	Sierra FMJ-BT	55 gr	16.5 gr	38.5 gr
.224 in.	Sierra JSP Blitz	55 gr	11 gr	44 gr
.32 Auto	Remington MJ-RN	71 gr	16 gr	55 gr
7.62 × 39 mm	Russian JHP	123 gr	33 gr (Fe)	88 gr + 1.5 gr plastic plug
.308 in.	Sierra JSP	125 gr	32 gr	93 gr
.310 in.	Hornady JSP	125 gr	26 gr	99 gr
.380 Auto	Remington FMJ-RN	95 gr	17 gr	78 gr
.380 Auto	Winchester FMJ-RN	95 gr	17 gr	78 gr
.380 Auto	Fiocchi FMJ-RN	95 gr	15 gr (brass)	80 gr
9 mm Luger	Winchester U.S.A. FMJ-RN	115 gr	21 gr	94 gr
9 mm Luger	Federal Hi-Shok JHP	115 gr	19 gr	96 gr
9 mm Luger	Federal-Am.-Eag. FMJ-RN	124 gr	21 gr	103 gr
9 mm Luger	Federal JHP	124 gr	21 gr	103 gr
9 mm Luger	Federal Am.-Ea. FMJ-TC	147 gr	23 gr	124 gr
9 mm Luger	Winchester Law Enf. JHP	147 gr	24.5 gr	122.5 gr
.38 ACP	PMC FMJ-RN	130 gr	26 gr	104 gr
.38/357 M	Winchester JHP	110 gr	15 gr	95 gr
.38 Special	Winchester SilverTip JHP	125 gr	5.5 gr (Al)	119.5 gr
.38/357 M	Winchester FMJ	130 gr	23 gr	107 gr
.357 M	Winchester SilverTip JHP	145 gr	22 gr	123 gr
.38/357 M	Winchester JSP	158 gr	23 gr	135 gr
.38/357 M	Federal JSP	125 gr	14 gr	111 gr
.357 M	Federal JHP	180 gr	21 gr	159 gr
.357 M	PMC Starfire JHP	150 gr	15 gr	135 gr
.40 S&W	Federal Hydra-Shok	155 gr	29 gr	126 gr
.40 S&W	Federal Hydra-Shok	165 gr	31 gr	134 gr
.40 S&W	Federal Hydra-Shok	180 gr	32 gr	150 gr
.40 S&W	Federal Tactical	165 gr	47 gr	118 gr
.40 S&W	Winchester U.S.A. FMJ	180 gr	29.5 gr	150.5 gr
.40 S&W	Winchester SXT/B.T. JHP	180 gr	35.5 gr	144.5 gr
.40/10 mm	Hornady FMJ	200 gr	24 gr	176 gr
.41 Rem. Mag.	Winchester JHP	210 gr	31.5 gr	178.5 gr
.44 Mag.	Remington UMC JSP	180 gr	28.5 gr	151.5 gr
.44 Mag.	Winchester U.S.A. JSP	240 gr	36 gr	204 gr
.45 Auto	Remington Golden Saber JHP	185 gr	45 gr	140 gr
.45 Auto	Speer JHP	200 gr	25 gr	175 gr
.45 Auto	Remington FMJ-RN	230 gr	35 gr	195 gr
.45 Auto	Winchester FMJ-RN	230 gr	36 gr	194 gr

GENERAL FOUNDATIONAL QUESTIONS FOR

Would you please state your name and occupation?

What is a criminalist/forensic scientist?

By whom are you presently employed?

How long have you been employed as a criminalist/forensic scientist?

Have your past duties include the examination of firearms and firearms-related evidence?

Please describe the types of firearms examinations you conducted during your _____ years as a criminalist/forensic scientist.

Would you please take a moment to describe your educational background?

Has any of your training included the examination of firearms and firearms-related evidence?

Please describe the nature of that training.

Have you also attended seminars on the subject of firearms evidence and examination?

On more than one occasion?

Are you a member of any professional associations or societies?

Would you name them please?

Do any of these organizations deal with firearms evidence and examination?

Have you been called to testify as an expert witness in courts of law as a result of the various types of testing you have carried out on firearms and firearms-related evidence?

Are there certain aspects of investigations involving shooting incidents that are reconstructive in nature?

Would a *muzzle distance determination* based on a powder pattern on a victim's shirt be a common example of a shooting reconstruction?

Would a *range-of-fire* determination based on a pellet pattern from a shotgun be another example?

Are these fairly routine determinations for people in your field?

Is the reconstruction of crime scenes, accident scenes, and certain events that took place at such scenes one of the common, recognized objectives of criminalistics and forensic science?

Regarding shooting incidents, aside from the previous examples, can you give us some additional examples of the reconstructive aspects of such cases.

Sample answers to this question:

- The manner in which a firearm was discharged (e.g., impact versus normal discharge).
- The approximate range from which a firearm was discharged (e.g., powder pattern).
- The position of the shooter based on scene geometry and bullet path.
- The position/orientation of a victim based on wound path and projectile-struck objects.
- The position/orientation of a firearm at the moment of discharge.
- The number and/or sequence of shots (e.g., two shots in tempered glass).
- The direction of fire (bullet holes in glass, wood, sheet metal).

Do you have any special training in the reconstruction of shooting incidents? Please describe that training.

Sample answers to this question:

- Five-day, 40-hour course at the Gunsite Training Facility, Paulden, AZ.
- Past workshops and/or presentations at the annual training seminars of The Association of Firearm and Tool Mark Examiners.

Optional questions

If one or more special shooting reconstruction courses have been attended, did you successfully complete them?

Would you describe in general terms what is involved in attempting to reconstruct a shooting incident?

Is it appropriate to consider the accounts of the various actors, participants, or witnesses in a given case?

Why?

How did you start your evaluation in this case?

Specific Foundational Questions

When were you first contacted in this case?

Who contacted you in this matter?

What were you asked to do?

Did you review any documents or other materials in this undertaking?

What did you study? *List or describe the documents.*

Did you examine any physical evidence related to this case?

Could you, in very general terms, give us a brief description of the physical evidence you personally examined? *Note: Specific details regarding certain items to be gone into later.*

Optional Questions

Did you go to the scene?

When?

Who was present?

What was your purpose in going to the scene?

Would you give us a brief overview of your activities at the scene?

Did you carry out any ballistic or other type of testing at your laboratory related to this case?

If yes, what sort of testing did you carry out at your laboratory?

When were these tests carried out?

What was their purpose in general terms?

[Specific questions to follow consultation with attorney(s).]

DETERMINATION OF ISSUES IN QUESTION

Forensic scientists and crime scene investigators typically are not responsible for interviewing participants in a shooting incident. This is repeatedly a problem because the specific questions that should be asked of a subject are often missed by those not trained in the analysis of physical evidence. To this end, the following questions are designed to assist the interviewers of shooting incident participants in gaining as much useful information as possible.

No case is the same. This list of questions and topics is designed to cover lines of investigation or questioning that are often missed in initial interviews of victims, witnesses, or suspects, and that later become important. Some questions apply to semiautomatic firearms, some to revolvers, and some to long guns, so some discretion and basic knowledge on the part of the interviewer is required.

The questions can also give the interviewer an idea of what might be important to include in a search warrant. Some of these questions may seem tedious, but all are derived from one case or another where having the answer to a question was critical. Additionally, many of these questions lock an interviewee into a particular story or version of events, hopefully at a time when the event is most fresh in their minds. This may be a critical factor later on in examination of the physical evidence.

Please keep in mind that any piece of firearms evidence could become important at a later date. This includes ammunition, fired casings, magazines, gun manuals, silencers, and internet articles on, for example, firearms, ammunition, and/or silencers and suppressors.

Officer-involved shootings add an additional layer of scrutiny to the investigation. *Always* ask the questions listed in the Officer-Involved-Shooting (OIS) section, whether it seems important at the time or not.

General Questions

Describe the storage and condition of the gun prior to the incident.

Was the gun previously cleaned, oiled, dirty, rusty, loaded, or unloaded?

What *exactly* did you do to the gun (if anything) after the event?

Did you unload, reload, or “clear” the gun?

Did the gun malfunction in any way?

Are you right-handed or left-handed?

Please state your height and weight.

Are there additional magazines for this gun or any other? If so, where are they?

Was the magazine separate from the gun before the incident?

At what point was the gun loaded?

When was the magazine loaded?

How exactly did you load the magazine? (Use visual demos if needed to show if it was fully topped off or loaded with only one.)

What are the source and type(s) of ammunition in the gun (brand, source, bullet weight, type)?

Where did the ammunition come from?

Where was the ammunition purchased/obtained?

In the past, when loading and unloading a semiautomatic pistol and magazine, was the top cartridge always placed back in the top position in the magazine?

Do you load cartridges in a magazine or cylinder in a certain order (if different types of ammunition are involved)?

In what manner was the gun held (e.g., one hand, two hands, arms extended)?

How were you standing when each different shot was fired?

Have the individual demonstrate any positions, and measure approximate height above ground level and any upward or downward angles if possible

How did the gun discharge, by what means of discharge (e.g., double action, single action, dropped, "slamfired")? *You may have to educate the interviewee.*

What was the manner in which the gun was sighted, if at all? *Note the settings of any optical sight on the firearm and secure them.*

Was the gun held upright, or rotated ("gangsta style," left- or right-handed)?

When fired, was the firearm pitched up or down?

What was the conduct of the shooter/participants relative to the firearm after discharge (e.g., gun recocked, reloaded, action cycled, magazine removed, touched in any way)?

Who *exactly* handled the firearm *before the shooting*?

Who *exactly* handled the firearm *after the shooting*?

Who loaded the gun?

When was the gun loaded?

Did you set the gun down anywhere?

Was the gun placed in a vehicle, under a seat, in a bag, and so forth?

What were the general weather conditions at the time of the shooting (if applicable)?

Was it extremely windy, rainy, or otherwise?

Have the shooter make diagrams and drawings of the shots and direction of fire, with their location and all other participants locations.

Do you recall seeing any intervening materials or objects in the area you were firing (stools, chairs, cars, trees, fences, etc.)?

Did you see bullets impact any surfaces or objects during the event?

Vehicle Shootings

Please state *exactly* where each occupant of the vehicle was?

Were any of the occupants moving, or sitting in orientations other than seated, and facing forward?

Were windows up or down (exactly which ones)?

When shots were fired, was the vehicle in motion or stationary?

How fast would you estimate the car was traveling at the time shots were fired?

Was the car traveling straight or turning (directions) when shots were fired?

Did you see any bullet impacts on the vehicle?

Long-Range Shooting Specials

Did you hear a shot?

Did you hear the sound of a bullet passing by?

Did you see the shots being fired, and was there a separation between the "puffs" of GSR/smoke and when you heard the report? *Use video or audio tapes to have the witness demonstrate such sound separations.*

INVESTIGATION AND ANALYSIS OF BURST FIREARMS: HIGH-PRESSURE EVENT/METALLURGICAL FAILURE/BORE OBSTRUCTION

Failure/Burst of Firearm

Firearm's design limits exceeded:

- Improperly loaded ammunition
- Too much of an otherwise appropriate propellant
- Acceptable charge weight but wrong propellant
- Smokeless powder in black powder firearms

Firearm weak:

- Design shortcoming
- Manufacturing defect or shortcoming

Firearm Weakened

- By misuse/abuse/improper care
- By inappropriate modification(s)
- By inappropriate parts substitution

Obstruction of the bore:

- Squibbed bullet/shot charge (shotguns)
- "Pulled" bullet in chamber throat or leade
- Dirt/mud in muzzle
- Insertion of foreign object(s) ahead of cartridge
- "12-20" obstruction (12-gauge shotguns)

Ammunition-Related Bursts

Design limits of firearm/cartridge case exceeded:

- Improper propellant
- Improper amount of propellant
- Oversized projectile
- Overweight projectile
- Case dimensions out of limits (e.g., thick neck "chucked up" in throat of chamber at moment of discharge)
- Mismatched ammunition
- Modern (high-pressure) cartridge in older gun not designed to take higher pressures of contemporary loading
- "s.e.e." event (controversial)

Weak cartridge:

- Excessively soft brass
- Head separation (multiple reload—stretched case)
- Modern load in old-style cartridge case (balloon-head cartridges)

Firearm-Related Cartridge Failure

- Excessive headspace
- Fired out-of-battery
- “Slamfire” (broken firing pin; irregular, raised breechface; high primer)
- Pierced primer
- Firing pin problem
- Incorrect (soft) primer
- Oversized/rough firing pin aperture/deformed breechface

Background Information and Items to Be Sought

- Make, model, and serial number of burst firearm
- Age of firearm
- Original owner: yes/no
- Previous owner if “no”
- Prior use of firearm
- Brands and types of ammunition previously discharged in firearm
- Repair/maintenance history of firearm
- Detailed description of events leading up to burst
- Burst firearm to include all parts and pieces (may require metal detection at the site)
- Burst cartridge case to include all fragments (may require metal detection at the site)
- Any previously discharged cartridge cases from incident pistol (to include any from scene)
- Any (all) remaining (unfired) ammunition, including ammunition box if available/locatable, spare magazines, magazine in gun at time of incident
- Chain-of-custody information regarding firearm from time of incident to present
- Names, titles, occupations of anyone who has examined/inspected burst firearm

Glossary

ACP Abbreviation for *Automatic Colt Pistol*. Normally used to designate a cartridge, as in .45 ACP.

AFTE Abbreviation for the The Association of Firearm and Tool Mark Examiners.

AP Abbreviation for *Armor-Piercing Ammunition*.

API Abbreviation for *Armor-Piercing-Incendiary Ammunition*.

Accelerator® Cartridge A type of Remington centerfire ammunition utilizing a substitute bullet mounted in a nylon sabot.

Accidental Discharge Along with *Negligent Discharge*, a broad term having limited forensic application. We prefer to break down reported “unexpected” discharges into several categories: mechanical failure, handler induced, and inadvertent. Experience suggests that all scenarios in reality cannot be covered by these definitions, and some investigations are unique unto themselves.

Mechanical failure: The gun and/or ammunition is the source of the discharge, for example, a compromised or inadequate safety system, high primer, a broken firing pin protruding from the bolt, and so forth. Normal operation of the firearm results in a discharge due to mechanical failure.

Handler induced: The handler of the gun is the source of the discharge. The firearm functions correctly as designed, but is discharged by the pull of the trigger with a negative result when one or more of the four fundamental *Firearms Safety Rules* is violated. Examples include an involuntary/sympathetic discharge during a struggle or a slip-and-fall scenario. Another example is a discharge while the handler has a finger on the trigger while holstering.

Inadvertent: Some unintended event creates a condition that results in discharge. The gun functions as designed and the handler does not violate any of the four standard *Firearms Safety Rules*. An example is the loss of control of the hammer on a revolver during an attempted letdown from the fully cocked position, wherein the handler still has the trigger retracted. Another example is a branch, rope, or other environmental object causing the mechanism to discharge a cartridge. This definition excludes the discharge being the result of the handler’s finger simply pulling the trigger or being in the trigger guard.

Acetic Acid A chemical reagent used in the Modified Griess Test for nitrite residue detection. Acetic acid forms nitrous acid in reacting with nitrites in gunpowder residues; the nitrous acid in turn reacts with the other constituents in this reagent to form an azo-dye. Acetic acid may also be employed with the sodium rhodizonate test to solubilize lead residues and make them reactive with this reagent.

Ammunition The material fired in and from any weapon or firearm such as cartridges, bullets, and shot. One or more loaded cartridges consisting of a primed case and propellant, with or without one or more projectiles.

Angle Finder A device designed to measure or display vertical or azimuth angles, or both.

Angle of Deflection The angle formed between the path of the departing projectile subsequent to an impact and the pre-impact path of the projectile’s flight.

Angle of Departure The angle formed between a horizontal line and the centerline of the bore at the moment the projectile leaves the muzzle of the firearm. *Note:* This angle is related to the initial angle at which the projectile departs relative to the surface of the earth.

Angle of Elevation The vertical angle formed between the target and the axis of the barrel bore. *Note:* This angle is related to the initial angle at which the projectile departs relative to the line of sight (LOS) to the target. Over level terrain between the gun and the target, this angle will also be the angle of departure relative to the horizontal plane.

Angle of Fall In shooting scenes, the arrival angle relative to the horizontal plane of a bullet descending from a long-range flight. This angle is the same as the vertical angle component of any bullet path at a shooting scene.

Angle of Incidence In ricochet events, the intercept angle described by the pre-impact path of the projectile and the plane of the impact surface at the impact site when viewed in profile. The angle formed between the path of the projectile prior to impact and the plane of the impacted surface. *Note:* In this text, this definition differs from the

NATO definition. To convert from the forensic definition used here to the corresponding NATO angle, use the equation $[90^\circ - \text{F.A.}] = \text{NATO} \supseteq$.

Angle of Ricochet Using the same coordinate system as for the angle of incidence, the path taken by the ricocheted projectile as it departs the impacted surface, with one qualification: the plane of the impact site is the surface *prior* to bullet impact, even though in some situations the bullet is departing a much modified surface (e.g., water, sheet metal, soil). Also, the angle formed between the path of the departing projectile subsequent to impact and the plane of the impacted surface. *Note: Departure angle or angle of departure* has been used to describe ricochet angle but this is discouraged because these terms also apply to a gun barrel's launch angle relative to the horizontal plane.

Annulus The ringlike space between the exterior surface of the primer and the primer pocket or battery cup on the base of a cartridge.

Antimony (Sb) A metal frequently used to harden lead by alloying. Percentages of antimony in lead shot and lead bullets typically range from 0.5 to 3%.

Antimony Sulfide (Sb_2S_3) A component of most common priming mixtures that serves as a fuel.

Anvil (1) An internal metal component in a boxer-primer assembly against which the priming mixture is crushed by the impact of the firing pin. (2) A metal feature in the primer pocket of a Berdan-primed cartridge case, against which the priming compound is crushed by the impact of the firing pin. (3) The breech end of the chamber in a rimfire firearm against which the rim is crushed by the firing pin's impact.

Anvil Mark A microscopic mark impressed on the forward face of the rim of a rimfire cartridge case as it is forced against the breech end of the barrel by the impact of the firing pin. These marks are characteristic of the breech under the firing pin and have been used to match a cartridge case to a specific firearm.

Apogee In exterior ballistics, the highest point in a bullet's flight path. For trajectories in air, this point will always be slightly displaced downrange of the true midpoint of the trajectory.

Armor-Piercing Bullet A bullet containing a hardened core composed of a substance other than lead or lead alloy; any bullet manufactured, represented, or designed to be metal or armor piercing.

Assault Rifle A rifle of intermediate caliber capable of both semiautomatic and fully automatic fire by means of a selector.

Assault Weapon A media and/or legislative term applied to almost any military-style, semiautomatic rifle or carbine. Some states legislatures have defined as assault weapons rifles having pistol grips, extended box magazines, flash suppressors, and so forth, or they have simply identified specific firearms as such. There is no scientific or technical definition for the term. Assault weapons are not fully automatic.

Automatic Weapon Any firearm that discharges multiple shots with a single actuation of the trigger. In common usage, the term is often applied erroneously to an auto-loading, semiautomatic, or self-loading firearm.

Azimuth Angle An angle or bearing lying in the horizontal plane, usually described on the basis of compass direction or with north, south, east, and west descriptors. In shooting reconstruction, an arbitrary north-south or east-west reference line may be chosen as a reference for azimuth angles related to that line.

BB The designation of spherical shot having a diameter of .180 inch used in shotshell loads. The term *BB* also designates steel or lead air rifle shot having a diameter of .175 inch. Although the two definitions cause some confusion, they have coexisted for many years.

BC Abbreviation for *Ballistic Coefficient*.

BHN Abbreviation for *Brinell Hardness Number*, a system of hardness measurements commonly applied to lead alloys.

Back-Spatter The short-range ejection of small droplets of blood and possibly other biological debris back along the path of a penetrating projectile or shot charge. Such bio-matter is often deposited on and in the bore of the responsible firearm when the firearm is either in contact with the injury site or in very close proximity to it at the moment of discharge.

Backthrust The force exerted on the breechblock by the head of the cartridge case during propellant burning.

Ballistic Coefficient A mathematical expression of a bullet's ability to counter atmospheric resistance (aero-dynamic drag), as compared to a specified "standard" reference projectile. Also, a form-fitting factor for a particular bullet's exterior ballistic behavior as compared to that of the standard bullet for which well-established performance data is known. Generally abbreviated as *BC*. *BC* values related to the G_1 standard bullet are used with nearly all contemporary exterior ballistic programs. They are defined by the equation w/id^2 , where: w = mass in pounds,

i = coefficient of form (i.e., a form factor), and d = bullet diameter in inches. The G_1 standard bullet weighs 1 pound, has a form factor of 1 and a diameter of 1 inch, and therefore has a BC of 1.00.

Ballistics The science and study of projectiles in motion, usually divided into three parts: (1) interior, which studies the projectile's movement inside the gun; (2) exterior, which studies the projectile's movement between the muzzle and the target; and (3) terminal, which studies the projectile's movement and behavior in the target.

Ballistic Soap A glycerin-type soap designed to simulate muscle tissue for use in wound ballistics studies of projectile behavior—most commonly penetration depth and projectile deformation or expansion.

Ballistic Tip® A trademark of the Nosler Bullet Company for jacketed rifle bullets possessing specially designed and mounted plastic tips of various colors. The color denotes the caliber of the bullet.

Balloting (bullet) The movement of a bullet through the bore of a firearm with a bumping, buffeting action; a yawing of a bullet while traveling through the bore, resulting in incomplete, intermittent rifling impressions often extending onto the ogive of the bullet.

Ball Powder Any of a series of double-base powders originally developed by Olin in the 1930s, having a spherical or flattened spherical shape. Examples include Winchester's 231, 748, and 760 powders. Ball powders are now manufactured in many countries other than the United States.

Barium Nitrate A component of most priming mixtures that acts as an oxidizer of the particular fuel in such mixtures.

Barrel/Cylinder Gap The distance from the face of a revolver's cylinder to the face of the barrel, normally somewhere in the range of .003 to .006 inch, depending on the manufacturer's specifications. The source of certain gunshot residues possessing important reconstruction properties.

Barrel Length For shoulder arms and most handguns, the distance between the muzzle of the barrel and the face of the breechblock or bolt. For revolvers, the overall length of the barrel only, including the portion within the frame.

Barrel Time See *IBT*.

Battery As applied to firearms, the position of readiness for firing. A firearm is "in-battery" when the locking mechanism is fully closed and the action is ready to be fired or the breechblock is fully forward against a chambered cartridge.

Bearing Surface The area of a bullet that actually contacts the bore of a firearm during its passage through the barrel.

Belted Case A case having a raised band, or belt, around the base just ahead of the extractor groove. It provides positive headspacing on cartridges with long, sloping shoulders, the belt allowing the cartridge to feed and function more reliably than a rimmed case. Contrary to the common misconception, the belt adds little or nothing to the strength of the case.

BenchKote® A special absorbent paper with a plastic backing manufactured by Whatman.

Berdan Case/Primer A primer/case system, designed by Col. Hiram Berdan, having two or more flash holes and an anvil formed into the primer pocket of the cartridge case. Although widely used throughout the world, this system has never been popular in the United States largely because of the difficulty in reloading Berdan cases.

Berdan Primer An ignition component consisting of a cup, an explosive mixture, and a covering foil or paper disc. The anvil is an integral part of the cartridge case head in the bottom of the primer pocket. One or more flash holes are drilled or pierced through the bottom of the primer pocket into the propellant cavity of the case.

Bevel-Base Bullet A bullet possessing a beveled edge at its heel. This feature assists the seating of such bullets in the cartridge case at the time of manufacture or during reloading.

Billiard Ball Effect The divergence of pellets from the axis of the wound channel, caused by collisions between pellets in a shot string as they move into and through tissue or organs. The resultant scatter of pellets can give the appearance of a distant shot when viewed in X-rays.

Birdshot A general term used to indicate any shot smaller than buckshot. Popular sizes range from 0.09 inch to 0.13 inch in diameter.

Birefringence An optical property of materials that possess two or more refractive indices when viewed with a polarizing microscope.

Black Powder A mechanical mixture of potassium nitrate, charcoal, and sulfur, usually with proportions of 75/15/10. For sporting arms use, various granulations are available. These are designated f_g , ff_g , fff_g , and $ffff_g$, largest to smallest, respectively. Although obsolete for over a century, the propellant is still in popular use with antique and replica firearms of the 18th and 19th centuries.

- Black Talon®** A trademark of the Olin-Winchester Corporation, denoting a group of high-performance handgun projectiles coated with a black copper oxide. Upon expansion in tissue, the petals of the bullet's jacket have a unique talon-like shape.
- Blowback Operation** An automatic or semiautomatic firearm design that directly utilizes the breech pressure exerted on the head of the cartridge case to actuate the mechanism. In blowback-operated semiautomatic pistols, the slide is not locked to the barrel or frame and begins its rearward movement as the bullet accelerates down the bore.
- Blown Primer** A primer that is separated completely from the cartridge or shotshell after firing because of severe expansion of the primer pocket and head. This is usually the consequence of greatly elevated pressures during discharge.
- Boattail-Base Bullet** A tapered section between a bullet's bearing surface and base, intended to reduce the effects of aerodynamic drag, thus giving the bullet a higher ballistic coefficient than that of a comparable flat-base bullet.
- Bolt Action** The working mechanism of a firearm in which the breech closure operates in line with the bore in a manually reciprocating manner to cock, load, and unload as well as to extract the fired cartridge case from the chamber.
- Bolt-Locking Lug(s)** The protrusion or protrusions from the surface of the bolt body that lock into mating recesses in the receiver, barrel, or barrel extension to resist rearward thrust of the chamber pressure.
- Bore** The interior of a barrel through which the projectile or shot charge passes.
- Bore Diameter** The inside diameter of the barrel prior to its rifling. In a barrel with an equal number of grooves, the bore diameter refers to the measurement from the top of one land to the top of the opposing land.
- Bottleneck Cartridge** A cartridge case having a main body diameter and a distinct angular shoulder stepping down to a smaller diameter at the neck portion of the case.
- Bow Effect** The flow pattern of abrasive materials in soil, sod, and/or sand around the nose, ogive, and/or bearing surface of a bullet generated during penetration and ricochet. This characteristic pattern is uniquely associated with ricochets from soil, sand, or sod that have yielded to the bullet's impact and allowed the bullet to enter into the substrate to some depth before departing it. The bow effect is most noticeable on the ogive of the bullet, but may extend back along the bearing surface as well. It takes its name from its similarity to the flow pattern of water off the bow of a boat.
- Boxer Case/Primer** A primer/case system, designed by Col. Edward Boxer, having one flash hole located in the center of the primer pocket and a separate anvil pressed into the primer cup. Because of its ease of reloading, the Boxer system is best-suited to hand loading. Invented by an Englishman, this system is most prevalent in the United States, while an American system (Berdan's) is commonly used in England and Europe.
- Boxer Primer** An ignition component consisting of a cup, explosive mixture, anvil, and a covering foil or paper disc that forms the completed primer ready for assembly into the primer pocket of a cartridge case. A central flash hole is pierced through the bottom of the primer pocket into the propellant cavity of the cartridge case. Boxer primer is used in modern commercial centerfire ammunition made in Canada and the United States and is now available from manufacturers in many other countries.
- Breech** The part of a firearm at the rear of the bore into which the cartridge or propellant is inserted.
- Breechblock** The locking and cartridge head-supporting mechanism of a firearm that does not operate in line with the axis of the bore. Examples include Sharps, Martini-Henry, and Spencer rifles.
- Breech Bolt** The locking and cartridge head-supporting mechanism of a firearm, such as in a common bolt action rifle, that operates in line with the axis of the bore.
- Breechface** That part of the breechblock or breech bolt that is against the head of the cartridge case or shotshell during firing.
- Breechface Marks** Negative impressions of the breechface of the firearm found on the head of the cartridge case and/or in the primer around the firing pin impression after discharge.
- Brinell Hardness Number** A system of hardness measurement used for lead and lead alloys in which pure lead is BHN 4. See also *BHN*.
- Buckshot** Lead pellets ranging in diameter from .20 to .36 inch normally loaded in shotshells. These pellets are sometimes plated with copper or nickel.
- Bulged Barrel** A barrel with an abnormal enlargement of its bore.
- Bullet** A nonspherical projectile fired from a firearm. A complete, loaded cartridge is not a "bullet"; the bullet is one part of it. It emerges from the muzzle of a pistol or rifle.

- Bullet Drift** The lateral deviation in a bullet's flight through the atmosphere due to rotational effects. A bullet fired from a right-twist firearm will drift right; it will drift left from a left-twist firearm. This effect is only noticeable and significant in long-range fire (e.g., 1000 yards).
- Bullet Drop** The vertical distance a bullet has fallen, under the influence of gravity, at any point in its flight path. The distance is measured from a point on its path to the straight line from the axis of the bore to the target.
- Bullet Path** The vertical distance, normally expressed in inches, above or below a firearm's line of sight. Also, the path followed by a bullet in its flight to a target.
- Bullet Pull** The amount of pull, normally measured in pounds, needed to pull a bullet from the case mouth. Also referred to as *neck tension*.
- Bullet Upset** In interior ballistics, the change of bullet's form due to chamber pressure. In exterior ballistics, the expansion of a bullet upon impact with the target.
- Bullet Wipe** The discolored area on the immediate periphery of a bullet hole, caused by the transference of residues from the bullet's bearing surface. The dark gray or black residues typically contain carbon, lead, bullet metal, and possibly other constituents such as lubricant and primer. Bullet wipe occurs at any range of fire as long as the bullet has not passed through some intermediate object.
- Bullet Yaw** An instability caused by the eccentricity or imbalance of the bullet in flight. Yaw is usually at its greatest in the initial portion of the flight, after which the bullet "goes to sleep" and becomes fully spin-stabilized. Yaw occurs after elongated bullets strike an object or when they enter media other than the atmosphere.
- Burning Rate** The relative quickness of deflagration of a given powder as compared to a known standard. Burning rate is extremely important in determining a powder's suitability for a given cartridge.
- CUP** Abbreviation for *copper units of pressure*, firearm discharge pressure measured in copper units in a copper crusher testing system. There is no direct correlation between CUP and pressure expressed in pounds per square inch (PSI), and no conversion factor to extrapolate one from the other. CUP values provide a means of testing and evaluating peak pressure generated during the discharge of a suitably modified firearm.
- Calcium Silicide** A component of some priming mixtures that serves as a fuel.
- Caliber** The diameter of a projectile, commonly expressed in hundredths or thousandths of an inch in the United States, although it may also be expressed in millimeters for small arms. *Caliber* may also refer to bore or groove diameter, again either in inches or millimeters. Also, the specific cartridge(s) for which a firearm is chambered. *Caliber* may refer a unit of measure. For example, a bullet can be described as three calibers in length when its length is three times its diameter.
- Cannelure** One or more circumferentially cut or pressed grooves around the shank of a bullet. Cannelures provide an area into which the case mouth may be securely crimped and/or lubrication may be deposited. They may also have product identification value.
- Cantering** The tipping or tilting of a gun to one side at the time it is fired.
- Cap-and-Ball** A muzzle-loading firearm (most commonly a revolver) using percussion cap ignition and firing round lead balls.
- Carbine** A rifle of relatively short length and light weight originally designed for mounted troops.
- Cartridge** A single, complete round of ammunition. Modern cartridges normally consist of a case, a bullet, a primer, and a powder charge. See *Ammunition*.
- Cartridge Case** The container for all components that make up a cartridge. Also referred to simply as *case*, *shell*, *casing*, and *hull*.
- Cartridge Cook-Off** The firing of a cartridge by extreme overheating in a firearm chamber, without operation of the firing mechanism. Usually associated with closed-bolt machine guns after prolonged bursts of fire. Cook-off is believed to be due to one or more components in the primer (e.g., tetracene) undergoing thermal initiation at about 320 degrees F (160 degrees C).
- Case Cannelure** One or more circumferential rings around a cartridge case typically used by manufacturers to denote a certain type of load or product line.
- Case Head Separation or Rupture** A generally circumferential separation in the side wall of a cartridge case. It may be complete or partial.
- Cast Bullet** A bullet produced by pouring molten lead (or lead alloy) into a mold.
- Celsius Temperature Scale** The temperature scale setting the freezing point of water as 0 degrees and the boiling point as 100 degrees, with equal divisions between and extending beyond these reference points. The conversion of Celsius to Fahrenheit is $^{\circ}\text{F} = 9/5^{\circ}\text{C} + 32$.

Center of Gravity In ballistics, the point through which the resultant force of gravity on a projectile passes. This is a fixed location for a particular projectile.

Center of Pressure The focal point of the sum of the aerodynamic forces acting on a projectile in flight at any one moment in time. This is a fictitious entity that can be defined as that point where the observed normal force must act to produce the observed overturning moment. For nearly all spin-stabilized projectiles, this point is forward of the center of gravity. Unlike the center of gravity, the center of pressure is *not* a fixed location for a particular projectile as it moves through the atmosphere and loses velocity and/or experiences changes in stability.

Chamber Marks Individual microscopic markings engraved and/or imprinted on a cartridge case by the chamber wall as a result of any or all of the following: (1) chambering, (2) expansion during firing, (3) extraction. Chamber marks produced during discharge are generally most noticeable in firearms that utilize the blowback method of operation.

Chilled Shot Lead shot containing more than 0.5% of an alloying metal, usually antimony, to increase its hardness. Also called *hard shot*.

Chisum Trail An elongated transference of bullet metal at the departure end of low incident angle ricochet marks on smooth, flat, unyielding surfaces. This asymmetrical elongated transference will be on the left side of ricochet marks for bullets fired from left-twist firearms and on the right side for bullets fired from right-twist firearms. It is caused by the right or left edge of a flattened bullet remaining in contact with the surface after the main body has lifted off the surface. The authors named this phenomenon after Criminalist Jerry Chisum, who first described it.

Choke An interior constriction at or near the muzzle end of a shotgun barrel for the purpose of controlling shot dispersion. Markings by U.S. manufacturers typically utilize the following symbols:

Full Choke = FC Full (greatest constriction)

Improved-Modified = Imp. Mod. (less constriction than full)

Modified = Mod. (less constriction than improved-modified)

Improved-Cylinder = IC, Imp. Cyl. (less constriction than modified)

Skeet = Skeet, Sk (less constriction than improved-cylinder)

Cylinder Bore = Cyl. (least constriction or no constriction)

European markings are normally as follows:

Full Choke = *

Improved-Modified = **

Modified = ***

Improved Cylinder = ****

Cylinder = CL

Chronograph (Ballistic) An instrument used in determining the velocity of a projectile. Most are based on the time taken by a projectile to traverse a known distance between two points monitored by some form of detection system.

Clip A device that holds ammunition to be charged into a magazine. Clips may be inserted into the firearm and remain there during firing, as with the M1 Garand, or they may be used only to aid in charging the magazine, as with the 1903 Springfield, M14 or M16 rifle. This latter type is referred to as a "stripper" clip, while the former is referred to as a "charger" or "en bloc" clip.

Cocking Indicator Any device to indicate that a firearm hammer or striker is cocked.

Concentric Fractures Fractures or cracks in glass or other similar brittle or ceramic material with a generally circular form around the bullet hole or impact site in such materials.

Cone Fracture The characteristic cone shape of the exit side of a projectile hole through a relatively brittle medium (e.g., glass, bone) caused by *spalling* around the exit.

Cordite An early extruded, smokeless double-base propellant widely used in England, particularly in early .303 British cartridges. Cordite is distinguished by its length, which normally runs the full length of the powder chamber. Invented in 1889, cordite served as the basis for many current extruded propellants.

Corrosive Primer Any primer using potassium chlorate in its priming compound. When fired, a portion of primer will become potassium chloride, similar to common table salt, and be deposited in the barrel, causing corrosion (rusting) upon standing. Cleaning with normal powder and copper solvents will not remove the corrosion-causing residues left in the bore, but they can easily be removed with warm water followed by standard cleaning and oiling. Corrosive priming mixtures were used in most U.S. military ammunition prior to 1952.

- Crack Rule** Also known as the “T” test, referring to the halting of the propagation of one or more radial fractures during a projectile’s impact in plate glass or other similar material by a fracture from a previous shot.
- Criminalistics** In an early definition, “That science which applies the physical sciences in the investigation of crimes.” Derived from the German word *kriminalistik*, criminalistics has taken on a broader definition and is more properly defined as the science of recognizing, identifying, individualizing, and evaluating physical evidence as it relates to some law-science matter. Also, the reconstruction of events based on the analysis of physical evidence. Criminalistics draws upon the physical and natural sciences to accomplish its mission.
- Crimp** A turning inward of a case mouth to increase its tension on a bullet. Crimping is necessary when loading for revolvers, tubular magazines, and some rifles with extremely heavy recoil.
- Crimped Primer** A primer that has been staked, stabbed, or otherwise crimped into the primer pocket; commonly found on military cartridge cases. In reloaded cases of this type the remnants of the crimp will have been removed by swaging or reaming before the new primer is seated.
- Critical Angle** The incident or intercept angle at and above which a projectile at a given impact velocity no longer ricochets from the impacted surface.
- Crown** The point of the bore where the rifling terminates at the muzzle.
- Cupronickel** An alloy of copper and nickel, also known as “German silver.” Cupronickel was once used extensively as a jacket material, despite its tendency to leave metal fouling in the barrel. In the United States it has been replaced almost entirely by gilding metal, a copper-zinc alloy.
- Cut Cannelure** A smooth cannellure cut or formed in a jacketed bullet that lacks any knurling but otherwise serves the usual purpose of crimping the cartridge case into the bullet and/or identifying the bullet’s manufacturer.
- Cylinder** The rotatable part of a revolver that contains the firing chambers.
- Cylinder Flare** The circular gray-to-black deposit around the front margin of the chamber or chambers of a revolver composed of gunshot residues deposited during discharge. Also called *halo* or simply *flare*.
- Cylinder Gap** In a revolver, the maximum space between the cylinder and the barrel. Also called the *cylinder-barrel gap*. The cylinder gap is a source of high-energy gunshot residues with unique reconstructive value. Cylinder gap values of 0.004 to 0.006 inch are normal.
- Decibel** A unit of intensity of sound, equal to 20 times the common logarithm of the ratio of the pressure produced by the sound wave to a reference pressure. Abbreviated as *dB* and described by the formula $dB = 20 \log(P/P_0)$, where $P_0 = 0.0002 \text{ dynes/cm}^2$.
- Deflagration** (1) A rapid but controlled burning of a solid fuel or propellant, producing large volumes of gas and heat. (2) A rapid combustion reaction that is propagated at a subsonic rate by heat transfer into the reacting material. This reaction is accompanied by a vigorous evolution of heat and flame. Deflagration is usually dependent on fuel and oxidizing agent being in very close contact, either from having the fuel as a finely divided mixture with the oxidant (such as black powder) or by combining the two in the same chemical compound or mixture (such as nitrocellulose propellants). Deflagration depends on the surrounding gas pressure, in that increases in pressure increase burning rate.
- Deflection** As differentiated from ricochet, a deviation in the projectile’s normal path through the atmosphere as a consequence of an impact with some object. This term is further refined for two types of impactive events in a projectile’s normal flight path:
- Deflection as a consequence of a ricochet* describes any lateral component of the ricocheted projectile’s departure path relative to the plane of the impacted surface as viewed from the shooter’s position and with the plane of the surface normalized to a horizontal attitude. The angle formed between the path of the departing projectile subsequent to impact and the pre-impact plane of the projectile’s path.
- Deflection as a consequence of perforating or striking an object* describes deviations in any direction from the projectile’s normal flight path as a consequence of perforating or striking an object rather than rebounding off a surface. For example, a bullet may be *deflected* by passage *through* a tree branch, a windshield, or a panel of sheet metal. These are not ricochet events. Since such deflection can occur in any direction (up, down, right, or left), clock position is used to describe it. As viewed from the shooter’s position (or position directly behind the projectile at impact), 12 o’clock is straight up relative to the horizontal plane at the location of the event; 3 o’clock is to the right; 9 o’clock to the left, and so forth.
- Density** A physical property of all matter that is equivalent to the mass (sometimes weight) per unit volume. For example, pure lead has a density of 11.34 grams per cubic centimeter.
- Departure Angle** See *Angle of Departure*.

Design Defect A flaw or shortcoming in the design of a product. See also *Manufacturing Defect*.

Deterrent Coating A chemical coating applied to propellant particles to bring their burning rates and characteristics into line with the manufacturer's specifications for that particular powder type.

Detonation (1) An extremely rapid chemical rearrangement normally associated with high explosives resulting in the near-instantaneous production of large volumes of gas. (2) An extremely rapid exothermic decomposition reaction that proceeds at a rate greater than the speed of sound within the reacting material (unlike *deflagration*). The normal mode of initiation is shock (such as a blasting cap or high-level mechanical shock) or initial combustion that, because of the peculiarities of confinement or other circumstances, accelerates to such a degree that a shock wave is formed. Behind the shock wave is a reaction zone where material is converted into gaseous products at high temperature and pressure.

Dicing The characteristic failure in tempered glass that takes the general form of small square or rectangular pieces.

Disconnecter A device intended to disengage the sear from the trigger. In a manually operated firearm, it prevents firing without pulling the trigger. In a semiautomatic firearm, it prevents full automatic firing.

Disk-Flake Powder An extruded form of smokeless powder cut into thin circular disks that may have a central perforation (see *Perforated Disk-Flake Powder* and *Unperforated Disk-Flake Powder*). Such propellants are most commonly used in pistol and shotgun ammunition and may be of either single- or double-base formulation.

Dithiooxamide (DTO) A specific colorimetric reagent (also known as *rubeanic acid*) that reacts with copper ions to produce a dark greenish-gray product.

Doppler Radar A continuous-wave radar, used chiefly to make precise speed measurements, that works on the basis of the Doppler effect—that is, a change in observed wave frequency caused by motion. By measuring the difference in frequency, Doppler radar determines the speed of the object or projectile observed.

Double Action A handgun mechanism in which a single pull of the trigger accomplishes two events: the cocking and the release of the hammer.

Double-Base Powder A powder that uses both nitrocellulose and nitroglycerine as the propellant base, as opposed to a single-base powder, which uses only nitrocellulose. Double-base powders generally have a higher energy content and so possess higher flame temperatures and can be somewhat more erosive than comparable single-base powders. See also *Single-Base Powder*, *Triple-Base Powder*.

Doubling The unintentional firing of a second shot. Doubling is usually associated with semiautomatic firearms in which the sear fails to capture or hold the hammer or striker.

Drag Coefficient An experimentally derived correction or fitting factor denoted as C_D in the drag equation, $F = \frac{1}{2}\Delta V^2 AC_D$, necessary to make the drag force, F , fit the data for a bullet of cross-sectional area, A , traveling at velocity, V , in an atmosphere of density, Δ . C_D is not a constant and varies with velocity and atmospheric density.

Drag Force The force, F , in pounds in English units derived from the formula $F = \frac{1}{2}\Delta V^2 AC_D$, where A is the bullet's cross-sectional area in square feet, V the velocity in feet per second, Δ the density of the atmosphere (in mass units), and C_D the drag coefficient.

Dram Equivalent The traditional method of correlating relative velocities of shotshells loaded with smokeless propellant to shotshells loaded with black powder. The referenced black powder load chosen was a 3-dram charge, with 1 1/8 ounce of shot and a velocity of 1200 fps. Therefore, a 3-dram load of smokeless powder would be equivalent to 1 1/8 ounces of shot having a velocity of 1200fps, or 1 1/4 ounces of shot having a velocity of 1165fps. A 3 1/4-dram-equivalent load might have 1 1/8 ounces of shot and a velocity of 1255fps. Abbreviated as *dram equiv.*

Draw Mark A longitudinal scratch on a cartridge case caused by foreign material on either the draw punch or the die during fabrication.

Drop See *Bullet Drop*.

Drop-Fire The discharge of a loaded firearm as a result of impact from being dropped. This may be the consequence of a design shortcoming, a compromised safety system, or the failure of the handler to engage the appropriate safety device.

Dry Firing The release of the firing pin on an unloaded chamber of a firearm.

Dum-Dum A term applied to some early expanding bullets for the .303 service cartridge loaded by the British arsenal at Dum-Dum, India, prior to 1899. Frequently used (incorrectly) by the media and others unfamiliar with firearms to indicate any expanding bullet.

Duplex Load A cartridge case containing two projectiles or two sizes of shot with a single powder charge. Also, a cartridge case containing a single projectile with two types of powder.

- Effective Range** The maximum distance at which a projectile can be expected to be useful in its intended purpose.
- Ejection Port** An opening in the receiver to allow ejection of the fired cartridge case.
- Ejection Port Marks** Indented or striated marks at one or more locations on a cartridge case resulting from the bullet striking one or more areas on the ejection port during egress. Such marks may bear reproducible patterns of striae.
- Ejector** A portion of a firearm's mechanism that ejects or expels cartridges or cartridge cases from a firearm.
- Ejector Mark** A small, impactively produced mark in the head of a cartridge case formed through violent contact with the ejector, normally associated with semiautomatic and fully automatic firearms. Such marks can be produced during the extraction-ejection process of manually operated firearms but usually only through vigorous manipulation of the gun's mechanism.
- Energy** The capacity for performing work. In ballistics, energy is normally expressed in kinetic units of foot-pounds (ft-lbs) in the American and English systems of measurement, and in kilogram-meters (kg-m) or joules in the metric system. One foot-pound is equivalent to the energy required to lift one pound one foot against the force of gravity. To convert ft-lbs to kg-m, multiply ft-lbs by 0.1382 or by 1.355 to obtain the equivalent energy in joules.
- Erosion** The wear, usually in the throat area of a barrel, caused by extreme heat and friction. Erosion occurs in all firearms, but is aggravated by rapid fire, large case capacity, or the use of propellants with elevated flame temperatures.
- Explosion** An extremely rapid chemical or mechanical action resulting in the very quick production and expansion of gases.
- Exterior Ballistics** The branch of ballistics that deals with the projectile's flight, from the time it leaves the muzzle of a firearm to the time it makes impact with the target.
- Extraction Groove** A groove cut or formed in the side wall of a cartridge case just forward of the face of the head and rim for the purpose of extraction.
- Extractor** A mechanism for withdrawing the cartridge or cartridge case from the chamber of a firearm. This component usually has a hook-like shape that grasps the rim or extraction groove of the chambered cartridge case.
- Extractor Marks** One or more small marks that may occur in several closely related locations on or near the rim of a cartridge. An *extractor override mark* on the rim of a cartridge case occurs during the chambering process. *Extractor gouge marks* can occur on the case wall immediately adjacent to the rim or in the extraction groove during chambering or during discharge-extraction. An *extractor bite mark* is normally associated with semiautomatic and fully automatic firearms and is the result of violent contact between the extractor and the front face of the cartridge rim, producing an indented toolmark at this location.
- Extruded Tubular Powder** A type of smokeless powder formed by forcing the dough-like nitrocellulose composition through a die of specific dimensions and cutting it into particles of specified length. Extruded tubular powders are more or less cylindrical in shape and may have one or more perforations. Common examples of extruded powders are IMR 4350, H4895, and Accurate 3100. (Improperly referred to as *extruded powder*.)
- FMJ** Abbreviation for *full metal jacket*.
- FMJ-BT** Abbreviation for *full metal jacket-boattail*.
- FMJ-RN** Abbreviation for *full metal jacket-round nose*.
- FMJ-TC** Abbreviation for *full metal jacket-truncated cone*.
- Facets** Multiple flat, squarish impressions on the nose and ogive of a bullet that has perforated previously shattered tempered glass. These facets are produced during the bullet's impact with the small, diced pieces of broken glass.
- Far-Zero** The second point at which the bullet path intersects the line of sight. Commonly referred to as *zero* for a given firearm, it is the point at which the point of aim and the point of impact coincide.
- Filler Wad** A cylindrical disk of fibrous material of various thicknesses used to adjust the volume of a shotshell's contents.
- Firearms Safety Rules** (1) All guns should *always* be treated as loaded. (2) Never let the muzzle cover anything you do not intend to shoot. (3) Fingers stay off the trigger until ready to intentionally fire. (4) Know your target and what is beyond it.
- Fireform** To alter the shape of a case by firing it, generally to increase case capacity. Upon firing, pressure forces the existing case out to fit the larger chamber, creating the new dimensions desired. Fireforming is a common technique in making wildcat or improved cases.
- Firing Pin** That portion of a firearm that strikes the primer of the cartridge, causing detonation of the primer composition and ignition of the propellant charge.

- Firing Pin Aperture** The opening in the bolt or breechblock of a firearm through which the firing pin moves during discharge.
- Firing Pin Drag Mark** The toolmark produced when a projecting firing pin remains in, or comes in contact with, the primer, cartridge case, or shotshell during the extraction-ejection cycle in certain firearm designs, such as break-open shotguns and semiautomatic pistols employing the Colt-Browning locking system.
- Firing Pin Impression** The indentation in the primer of a centerfire cartridge case or in the rim of a rimfire cartridge case caused by the impact of the firing pin. Also called *firing pin indent*.
- Firing Pin Scrape Mark** See *Firing Pin Drag Mark*.
- Flare** The circular gray-to-black deposit around the front margin of the chamber or chambers of a revolver, composed of gunshot residues deposited during discharge. Also known as *halo*.
- Flash Holes** (1) One or more holes from the primer pocket to the powder chamber of a cartridge case. (2) A hole in the end of a battery cup primer used in shotshells. (3) A hole in the nipple of a percussion firearm.
- Flash Suppressor** A muzzle attachment designed to reduce muzzle flash. Also called a *flash hider*.
- Forcing Cone** The section of a revolver or shotgun barrel just ahead of the chamber(s) that gradually reduces in size to bore or land diameter. The forcing cone serves to align the bullet or shot charge with the bore while preventing deformation to the projectile(s).
- Frangible** Susceptible to being broken up or shattered into small pieces or particles. This term is often associated with certain special-purpose bullets designed to shatter into many small pieces upon impact with the hard metal backstop of a shooting range.
- Frangible Bullet** A projectile designed to disintegrate upon impact on a hard surface in order to minimize ricochet or significant rebound of bullet fragments.
- Freebore** Essentially, the throat area of a barrel, normally indicating that the rifle in question has an unusually long throat, as is the case in most of Weatherby chamberings.
- Free Fall Velocity** See *Terminal Velocity*.
- Full Metal Jacket** Abbreviated *FMJ*, a bullet having no exposed lead on the frontal portion. FMJs are nonexpanding and used in both rifles and pistols. They are produced in several different configurations: round nose, spitzer, spitzer boattail, and so forth, depending on their intended use. Also called *full-jacketed*, *full patch*, *full metal case*.
- G** The symbol for the accelerative force of the earth's gravitational attraction. The average, sea level value for the earth's gravitational acceleration is 32.174fps (9.807 m/s/s).
- GSR** Abbreviation for *gunshot residue*.
- Gage** An instrument or device for measuring or testing a parameter (such as headspace or trigger pull).
- Gas Check** A protective cup of copper, brass, or gilding metal placed on the base of a cast bullet. Gas checks reduce gas cutting and deformation of the bullet's base due to pressure or hot propellant gases.
- Gas-Operated** In firearms, a gun system that utilizes a portion of the gases produced by the powder's combustion to cycle the action. The U.S. military M1, M14, and M16 are examples of gas-operated weapons.
- Gauge** For sheet metal, a system of thickness measurement. Contemporary automotive sheet metal is typically composed of 0.031- to 0.032-inch (0.79- to 0.82-millimeter) steel, which is designated as 22 gauge. The adjacent gauges of sheet metal have listed thicknesses of 0.0343 inch (21 gauge) and 0.0280 inch (23 gauge).
- Gauge (Shotguns)** An archaic description of the diameter of shotgun bores based on the number of lead spheres just fitting the bore that equal 1 pound. For example, the bore of a 12-gauge shotgun is of such a diameter that 12 lead spheres, each weighing one-twelfth of a pound, would just fit in it. A 20-gauge shotgun (possessing a smaller bore) would require 20 lead spheres of bore diameter to equal 1 pound. (Also spelled *gage*.)
- Gilding Metal** An alloy of 90 to 95% copper and 5 to 10% zinc, now used extensively as a jacket material for bullets. Also termed *commercial bronze*. Neither name is recommended by the Copper Development Association, which prefers *Alloy No. 220* and *Alloy No. 210*, respectively.
- Gold Dot®** A trademark of the Speer ammunition company for a line of jacketed pistol bullets possessing a plated, hollow-point jacket over a lead core. The manufacturing process leaves a characteristic "dot" of the jacketing material at the bottom of the hollow-point cavity.
- Golden Saber®** A trademark of the Remington ammunition company for a line of brass-jacketed hollow-point pistol bullets possessing canted skives on the bullet's ogive.
- Grain** A unit of weight (avoirdupois) equaling 1/7000 of a pound. The most common unit of weight by which bullets and powder charges are measured. There are 7000 grains in a pound and 437.5 grains in an ounce.
- Gravitational Acceleration** See *g*.

- Greenhill Formula** A mathematical formula developed by Sir Alfred Greenhill to determine the twist necessary to stabilize an elongated bullet. The Greenhill formula states that the twist required (in calibers) equals 150 divided by the length of the bullet (in calibers).
- Griess Test** A specific chemical test for the detection of nitrites, typically used by criminalists and firearms examiners in the laboratory to develop patterns of gunpowder residues (nitrites) around bullet holes.
- Groove Diameter** The major diameter in a barrel, which is the diameter of a circle circumscribed by the bottom of the grooves in a rifled barrel.
- Grooves** The area between the lands in the bore of a rifled firearm. The grooves are cut or impressed into the bore's surface.
- Gunshot Residue** Sometimes defined as the total residues resulting from the discharge of a firearm, constituted typically of nitrites and lead as well as unburned and partially burned gunpowder particles, and carbonaceous material, plus metallic residues from projectiles, fouling, and any lubricant associated with the bullet. These are usually observed with the naked eye or through an optical microscope, and detected or visualized by the Griess Test and sodium rhodizonate.
- Hair Trigger** A slang term or shooter's jargon for a trigger requiring very low force to actuate. There is no technical definition or quantified measure for a "hair trigger."
- Half-Cock** The position of the hammer when about half-retracted and held by the sear, intended to prevent release of the hammer by a normal pull of the trigger. This can be the safety or loading position of many guns.
- Half-Protractor** A protractor consisting of a 90-degree angle with gradations for each degree from 0 to 90, and with a zero-edge allowing bullet path measurements in corners and other tight spots inaccessible to full, 180-degree protractors. See *Zero-Edge Protractor*.
- Halo** See *Flare*.
- Hammer Spur** The knob or extension on an exposed hammer that acts as a cocking or decocking aid.
- Hangfire** A delay, sometimes quite noticeable to the shooter or listener, between the impact of the firing pin and the actual ignition of the cartridge. Such delays are typically less than one second in duration and are usually on the order of 0.25 second or less. The causes are typically either a contaminated primer mixture or an improperly seated primer.
- Hard Shot** Also known as *chilled shot*, lead shot that has been alloyed with antimony to make it harder and less susceptible to deformation than pure lead shot of the same size.
- Head** As applied to cartridges, the base area of the case. This area encompasses the primer pocket, the extractor groove, and the rim or belt, extending up to the beginning of the body of the case.
- Head Separation** A circumferential cracking around the body of the case, usually just above the web area. A complete head separation will normally leave the forward portion of the case in the chamber upon extraction. Generally caused by excessive chamber headspace.
- Headspace** (1) The longitudinal dimensions of a cartridge that, when correct, properly position the cartridge in the chamber of a firearm that itself is of proper headspace. (2) The distance from the face of the closed breech of a firearm to the surface in the chamber on which the cartridge case seats. (3) The amount of play between the case head and the breechface in a fully closed action. Insufficient headspace will cause difficulty in chambering, while excessive headspace can result in cartridge-head separation. Headspace problems may be the fault of the gun, the ammunition, or a combination of both. There is a necessary relationship between the headspace of the firearm's chamber and that of the cartridge for the cartridge to perform properly during discharge.
- Headspace Gage** An instrument for measuring the distance from the breechface of a firearm to that portion of the chamber against which the cartridge seats.
- Headstamp** A series of letters, numbers, or characters stamped into the head of a cartridge case to denote caliber, type, manufacturer, supplier, arsenal, and date of production, or other pertinent information.
- High Primer** A primer that has not been fully seated in the primer pocket and extends slightly above the head of the case. High primers create a dangerous condition that can result in slamfires, particularly in semiautomatic firearms.
- Hollow-Base Bullet** A type of bullet having a hollow cavity in its base designed to improve bore obturation during discharge. This design also moves the bullet's center of gravity forward compared to that of a bullet of the same caliber and dimensions with a solid base.
- Hollow-Point Bullet** A type of bullet having an opening in the nose. Hollow points may be of either the hunting or the target style. Contrary to popular opinion, hollow points are not always designed to expand on impact. Match-grade hollow-point target bullets, for example, rarely exhibit any expansion when fired into tissue or tissue simulant.

Hydra-Shok® A trademark of the Federal Cartridge Company for a line of hollow-point pistol bullets containing a unique central post of lead in the hollow-point cavity.

IBT Abbreviation for *ignition-barrel time*, the elapsed time from the contact of the firing pin with a cartridge primer to the emergence of the projectile(s) from the muzzle of the firearm. Sometimes simply called *barrel time*.

IMI Abbreviation for *Israel Military Industries*.

IMR Abbreviation for *Improved Military Rifle*. A series of single-base extruded tubular powders developed by DuPont, currently manufactured by IMR.

Ignition Temperature The minimum temperature at which a combustible substance will ignite.

Ignition Time The interval between the impact of the striker or firing pin on the primer and a rise in pressure sufficient to start the bullet from its seated position in the cartridge case. The elapsed time from the moment of firing pin contact on the primer to the point on the x (time) axis equal to the point where the pressure time curve indicates that propellant burning has initiated.

Incendiary Bullet A bullet containing a chemical compound that ignites on impact with the intended purpose of starting a fire.

Incident Angle The intercept angle ($\angle I$), described by the pre-impact flight path of the projectile and the plane of the impact surface at the impact site when viewed in profile.

Inclinometer A device for measuring or displaying the angle of a surface relative to the horizontal or vertical plane.

Inertia Firing Pin A type of firing pin in which the forward movement is restrained until it receives the energy from a hammer blow. It is slightly recessed in the breechface before being struck by the hammer and is shorter than the housing in which it is contained. On hammer impact, it flies forward using only its own kinetic energy to strike and fire the primer.

Ingalls' Tables A set of ballistics tables computed by Col. James Ingalls in which the drag characteristics of a "standard" projectile are used as a reference for comparison of other small arms bullets. The standard projectile for the Ingalls' tables is the G₁ bullet. The ballistic coefficients of almost all U.S.-manufactured bullets can be referenced to Ingalls' tables, with only a slight degree of error.

Instrumental Velocity The velocity of a projectile as registered on a chronograph; the average velocity of a projectile as it traverses the distance between the "start" and "stop" screens of the unit. If an actual muzzle velocity is needed, the instrumental velocity must be corrected to the muzzle. With modern chronographs, given their short screen spacings and a "start" screen only a few feet in front of the muzzle, this is generally unnecessary, and the corrections rarely amount to more than a few feet per second.

Interior Ballistics The branch of ballistics dealing with events occurring between the detonation of the primer and the projectile leaving the muzzle. Also referred to as *internal ballistics*.

Involuntary Discharge A situation in which grasping, struggling, or pulling with one hand results in an involuntary contraction of the fingers of the opposite hand; when the opposite hand is holding a firearm in the shooting configuration with a finger on the trigger, the gun fires. Involuntary discharge has also been claimed to occur as the result of a startle reaction with the same improper gun handling.

JHP Abbreviation for *jacketed hollow-point bullet*.

Jacket An outer sheath covering the interior portion (core) of a bullet. Many materials, including mild steel and cupronickel alloy, have been used in making jackets; today 95/5 gilding metal (Cu/Zn) is the standard in the United States.

Jacketed Bullet A bullet having an outer jacket composed of a metal or metal alloy such as copper, gilding metal, brass, mild steel, cupronickel, or aluminum.

Jam A malfunction of a firearm that prevents the action from operating; a jam may be caused by faulty parts and/or ammunition, improper maintenance, or improper use.

Kernel An industry term for a single, individual particle of powder. Sometimes also referred to as a grain, but not to be confused with the unit of weight (see *Grain*). Forensic examiners typically use *powder particle* rather than *kernel*.

Keyhole An elongated bullet hole, indicating that the bullet was not traveling point on or fully nose forward at impact. Also, a slightly "out-of-round" hole, or a complete profile image of the bullet, where the projectile actually went through the target sideways. This is the result of a stability problem or the consequence of a deflected or ricocheted bullet.

Keyholed Bullet A bullet that strikes or enters a medium in a yawed or destabilized orientation.

- Kinetic Energy** The energy of a body with respect to the motion of that body given by the formula $\frac{1}{2}mv^2$, where m = mass of the projectile and v = projectile velocity.
- Knurled Cannelure** A cannellure with a series of small regular ridges or rectangles to help prevent slippage of the bullet while held in the cartridge case. The style and spacing of the knurling also relates to the source of the bullet's manufacture.
- LCB** Abbreviation for *lead core bullet*.
- LRN** Abbreviation for *lead round nose*.
- LUP** Abbreviation for *lead units of pressure*, relating to the pressure measured in a lead crusher testing system. Most often used in low-pressure firearms such as shotguns. There is no direct correlation between LUPs and pressure expressed in pounds per square inch (PSI), and no conversion factor to derive one from the other.
- Lagtime** The time difference between the sound of the arrival of the bullet (i.e., the sound of impact or of passage) at a specific downrange location and the arrival of the sound of the shot at that location. This interval is useful in calculating the range of fire when the approximate muzzle velocity and ballistic coefficient of the bullet are known.
- Lamel Powder** A type of smokeless propellant in which the individual particles are thin square, diamond, and/or parallelogram-shaped flakes. In some samples the shape and dimensions of the particles are closely controlled, while others may show considerable variation. This type of powder is typically found in European and Scandinavian small arms ammunition and is also available as an imported canister powder. Examples include Alcan 5, 7, and 8.
- Laminated Glass** A "sandwich" of glass layers that combines alternate layers of plastic material and single-strength (plate) glass. The outside layer may break when hit by an object, but the plastic layer stretches. This holds the broken pieces of glass together and keeps them from flying in all directions. Used in automobile windshields.
- Lands** The raised portions of a bore remaining after the cutting or forming of the grooves in a rifle barrel. Commonly referred to as *rifling*.
- Laser Photography** As used in this text, the open shutter time exposure and recording of laser beams in darkness or subdued light.
- Lead-Core Bullet** A jacketed bullet having a lead or lead alloy core.
- Leade** The minute portion of a barrel's rifling that slopes from the unrifled throat to the full-depth rifling. Although frequently referred to as the *throat*, there is a definite difference between the two.
- Leading** A buildup or accumulation of lead in the barrel of a firearm, caused by the use of cast or swaged lead bullets. This can be controlled to a considerable degree by the use of harder alloys, better lubricants, or lower velocities. Leading causes no permanent harm to a firearm, but is detrimental to accuracy and can be difficult to remove.
- Lead-In Mark** A visible, thin, elongated deposition of bullet wipe transferred to a surface as a bullet first makes contact with the surface at a shallow incident angle. The lead-in mark is useful in establishing the direction of fire and travel of the projectile. Also, the dark, elliptical transfer of material from a bullet as it makes its initial contact with a surface at a low incident angle.
- Lead Round-Nose Bullet** A lead bullet with a radiused nose. Technically, the radius of the nose is one-half of the bullet's diameter.
- Lead Splash** The production and dispersal of vaporized and fine particles of lead as a result of impact. Lead splash is related to bullet design and composition, the nature of the surface struck, and the energy associated with the impact. The geometry of the deposition of lead splash can provide information on the direction of fire. The amount of lead splash is a function of impact velocity.
- Lead Styphnate** An impact-sensitive initial detonating agent used in common priming mixtures. Also known as *trinitroresorcinat*e, it is one source of particulate and vaporous lead in gunshot residue and bullet wipe.
- Line of Departure** A straight line projecting through the axis of the bore to infinity. The direction in which a projectile is moving when it leaves the muzzle of a firearm. While this is the initial direction of the bullet's velocity, it should be clearly understood that the bullet falls away from this line immediately on leaving the muzzle, primarily because of gravity and other outside forces acting on it.
- Line of Sight** Abbreviated *LOS*, a straight line passing through the sights of a firearm to the target.
- Locked Breech System** In more powerful firearms, the condition of the action in which the bolt or breechblock is solidly secured in a fixed relationship with the chamber so as to resist being driven back by chamber pressure.
- Locking Lug** The protruding lug that engages the receiver to lock the action closed during firing. Locking lugs are normally situated on a firearm's bolt in a bolt-action rifle, although there are exceptions.
- Lock Time** The interval between the sear's release of the striker or firing pin and the subsequent impact on the primer.

- Lot Number** A designation generally used by American sporting ammunition manufacturers to indicate production date, conditions, and components used to load a batch of ammunition.
- Lubaloy®** An Olin-Winchester process resulting in a thin copper plating on lead bullets.
- Lube Grooves** See *Cannelure*.
- M2 Bullet** The U.S. military designation for the 152-gr FMJ flat-based bullet loaded in .30-06 cartridges.
- M80 Bullet** The U.S. military designation for the 147-gr FMJ-BT bullet loaded in 7.62 NATO cartridges.
- M193 Bullet** The U.S. military designation for the 55-gr FMJ-BT bullet loaded in 5.56mm cartridges.
- M855 Bullet** The U.S. military designation for the 62-gr FMJ-BT bullet loaded in 5.56mm cartridges. This bullet contains a hardened-steel penetrator in its nose.
- Machine Gun** An automatic weapon firing a full-size (rifle caliber or larger) cartridge, usually fired off a bipod, tripod, or other fixed mount. Machine guns may be clip-, magazine-, or belt-fed depending on the design and intended use. They are most often employed as a crew-served weapon.
- Mach Number** The number obtained by dividing the speed of the projectile by the speed of sound at the time and location of the shot.
- Magazine** An ammunition reservoir from which cartridges are fed into a firearm's chamber. Magazines may be integral, as in the 1903 Springfield rifle, or may be detachable, as in M14 and M16 rifles. Although the terms are frequently used interchangeably, a clip and a magazine are not the same thing.
- Magazine Follower** A spring-actuated device to push cartridges in a magazine to the feeding position.
- Magazine Lip Marks** Thin, often curvilinear marks on the body and/or rim of a cartridge case at positions of approximately 10 o'clock and 2 o'clock, produced by the lips of a magazine as the cartridges are stripped from the magazine by the firearm's mechanism.
- Magazine Safety** A feature in some semiautomatic firearms in which the removal of the box magazine renders the firearm incapable of being fired by a normal pull of the trigger.
- Magnum** A designation sometimes attached to a cartridge of greater capacity or power than others of similar caliber. This can be misleading, as magnum cartridges are not always the most powerful in their respective bore sizes. In rifles, the term usually refers to one of the belted cartridges based on the original Holland & Holland magnums. Today, belts are used more for sales appeal than for any true ballistic function. In shotshells, the term denotes a heavier charge of pellets.
- Manufacturing Defect** An individual product that does not match the manufacturer's specifications. See also *Design Defect*.
- Mass** A constant property of matter that reflects the amount of material present. It is related to weight through the formula $m = W/g$, where W = weight and g = gravitational accelerative force acting on mass m .
- Meplat** The diameter of a flattened tip at the nose of a bullet. A term for the blunt tip of a bullet, specifically the tip's diameter.
- Mercuric Primer** Any primer that uses mercury fulminate as a component in its priming compound. While no longer in use, surplus U.S. military ammunition, old commercial ammunition, and some foreign ammunition may still be encountered that is loaded with such primers.
- Mikrosil™** A two-part silicon rubber casting material designed specifically for forensic use in casting toolmarks, the bores of gun barrels, and a variety of other surfaces and objects.
- Mil** The angle created by 1 unit at 1000 units of distance.
- Mild Steel** A carbon steel containing a maximum of 0.25% carbon.
- Minute of Angle** A unit of angular measurement equaling 1/60th of a degree. One minute of angle works out very close to 1 inch per 100 yards, making it a convenient measurement for shooters to describe accuracy, sight elevation, or windage deflection. Also referred to as MOA or *minutes*. One minute of angle = 1.0472 inches at 100 yards.
- Misfire** The complete failure of a cartridge to fire after being struck by the firing pin or striker. The causes are, among others, a contaminated primer and/or contaminated powder.
- Momentum** A quantity of motion expressed in American units of "pound-seconds," obtained by multiplying a bullet's mass by its velocity (i.e., mv). In some instances, momentum may be a better indicator than kinetic energy of a bullet's injury-producing potential and its penetrative ability.
- Momentum Transfer** The transfer of momentum of one object to another object as the two collide or impact each other. When a projectile of mass m and velocity V strikes and comes to rest in an unrestrained object of mass M , the conserved momentum is given by the expression $mV = (m + M)v$. This is useful and applicable to claims of bullets knocking gunshot victims over or spinning them around.
- Muzzle** The end of a firearm's barrel; the point from which the bullet exits.

Muzzle-Brake (Compensator) A device at the muzzle end, usually integral with the barrel, that uses the emerging gas behind a projectile to reduce recoil.

Muzzle Pressure The gas pressure remaining as the bullet exits the muzzle. High muzzle pressures are associated with greater muzzle blast and higher peak decibel values.

Muzzle Velocity The initial velocity of a projectile as it exits the muzzle.

2-NN Abbreviation for 2-nitroso-1-naphthol, a colorimetric reagent for copper residues in suspected bullet holes and bullet impact sites.

Neck In a cartridge case, the parallel-sided portion that grips the bullet. In a bottle-necked case, the area immediately ahead of the shoulder.

Negligent Discharge See *Accidental Discharge* and related definitions.

Nitrocellulose Also known as *cellulose nitrate* and *cellulose hexanitrate*, the principal ingredient of single-base, double-base, and triple-base propellants.

Nitroglycerin Also known as *glycerol trinitrate*, a high explosive and ingredient of double-base and triple-base propellants.

Noncorrosive Primer A primer that contains no potassium chlorate or similar compounds in its primer mixture. See *Corrosive Primer* and *Mercuric Primer*.

Nonmercuric Primer A primer that contains no fulminate of mercury or other mercuric compound in its priming mixture. A mercuric primer may or may not be corrosive, depending on whether or not it contains potassium chlorate. See *Mercuric Primer* and *Corrosive Primer*.

Nyclad® Bullet A nylon-coated lead bullet, originally trademarked by Smith & Wesson but now owned by Federal.

OAL Abbreviation for *overall length*, the total length of a loaded cartridge.

Obturation The sealing of a bore and chamber by pressure. During the firing process, pressure swells the case within the chamber, preventing gas from leaking back into the action. The same pressure applied to the base of the projectile causes it to swell or upset, filling and sealing the bore.

Ogive French for *pointed arch*, the radiused portion between the bearing surface and the meplat or tip of the bullet. This radius is often measured in calibers, where “caliber” is a unit of measure based on the diameter of the particular bullet.

Out-of-Battery Discharge A discharge that takes place when the firearm’s locking mechanism is not fully closed. Unlike a slamfire, an out-of-battery firing is normally the result of the shooter intentionally pulling the trigger. On firing, the unsupported case may rupture and vent gasses back into the action. This is a very hazardous situation for the shooter and can damage or destroy the rifle.

Over Powder Wad The wad between the propellant and other components in a shotshell.

PPK From the German *pistole, polizei, kriminal* (criminal police with plainclothes and pistol).

PSI Abbreviation for *pounds per square inch*.

Parabellum From the Latin, *for war*, typically associated with the 9mm Parabellum cartridge.

Partition Bullet A bullet designed for controlled expansion, having a jacket divided into two chambers that enclose the bullet’s forward and rear cores. It is designed so the first chamber expands and the rear chamber holds together for improved penetration.

Patched Ball (1) For modern cased ammunition, a full-metal-jacketed (FMJ) bullet. (2) For muzzle-loading firearms, round or conical lead projectiles that utilize cloth or other material that acts as a gas seal or a guide for the projectile. (3) Early fixed ammunition using paper as a gas seal for the projectile (a paper-patched bullet).

Pattern The distribution of shot fired from a shotgun. Among firearms manufacturers, pattern is generally measured as a percentage of pellets striking in a 30-inch circle at 40 yards. Some skeet guns are measured with a 30-inch circle at 25 yards. A *blown* pattern is one that displays an erratic distribution of pellets.

Perforated Disk-Flake Powder An extruded form of smokeless powder cut into thin, circular disks and possessing a small, central perforation to modify its burning characteristics.

Phantom Safety A situation in which the handler incorrectly senses or believes that a manually operated safety system has been engaged. This claim or theory usually arises with traditional single-action revolvers and postulates that the trigger sear was perched rather than seated in the safety or quarter-cock notch of the hammer.

Physical Match The examination of two or more objects, through physical, optical, or photographic means, to determine whether the objects were either one entity or were once held or bonded together in a unique arrangement.

- Pierced Primer** A primer that, on firing, is pierced by the firing pin. This allows gas to flow back into the action, which can be injurious to the shooter. A potentially dangerous situation, normally indicating excessively high pressures, but not unique to this cause.
- Pinch Point** In painted metal surfaces, a small area of surviving paint that was pinched between the initial contact point of a low incident angle bullet and the painted metal surface. The pinch point establishes the entry side of an impact or ricochet mark and thereby the bullet's direction of travel.
- Plate Glass** A flat glass having an extremely clear, smooth surface. Also known as *single-strength glass*. Also, common flat glass lacking any special treatment or construction.
- Plinking** Informal shooting, not following any organized rules of competition or at any designated distance; shooting "just for fun."
- Plumb Line** A simple device to indicate vertical direction, made by suspending a small mass of lead or other heavy material, free hanging and still, on a string line.
- Point-Blank Range** The range at which a shooter can obtain a hit in the vital zone of a particular target or game animal, without holding over or under the target.
- Point of Aim** The place or point on a target that intersects the straight line generated by the alignment of the front and rear sights of a firearm. The exact point on which the shooter aligns the firearm's sights.
- Point of Impact** The point at which a projectile hits a target or other downrange object.
- Polygonal Rifling** A rifling system wherein the lands and grooves have rounded profiles with no distinct driving or trailing edges, as contrasted to the sharp edges between lands and grooves found in traditional rifling systems. The most common firearms utilizing polygonal rifling are the various models and calibers of Glock pistols.
- Port Pressure** In gas-operated firearms only, the amount of pressure remaining in the bore as the bullet passes the gas port. If port pressures are too high, damage can result from the violent cycling of the action. It is important to understand that this can occur even when chamber pressures are within acceptable limits. Port pressure can be controlled by proper powder selection.
- Powder Patterning** The orderly process of preparing powder patterns at selected standoff distances on some form of witness panel material with a specific gun-ammunition combination.
- Powder Stippling** Small hemorrhagic marks on the skin produced by the impact of gunpowder particles or, in inanimate objects, small pits or defects caused by the impact of unburned and partially burned powder particles.
- Powder Tattooing** The embedding of partially consumed and unconsumed powder particles in the skin with accompanying hemorrhagic marks associated with living skin.
- Primer** A cartridge ignition component, consisting of a brass or gilding metal cup, priming mixture, anvil, and a foil or paper disc, which ignites the propellant in the cartridge when struck with sufficient force.
- Primer Cratering** A circumferential rearward flow of primer metal surrounding the indentation of a firing pin in a fired primer cup.
- Primer Residue** Residue created from priming mixtures, typically constituted of very small particles containing lead barium and antimony, detected by scanning electron microscopy. These residues are far too small to be observed with the naked eye. There are now many other types of elements being used in priming mixes, which make this type of analysis very complex.
- Primer Setback** The condition in which a primer moves partially out of its proper location in the primer pocket of a metallic cartridge or shotshell during firing.
- Print-Through** A condition in which the impressions of the lands in a jacketed bullet print through the jacket and can be seen on the separated lead core.
- Proof Cartridge** A special high-pressure load used to test the strength of a newly manufactured or rebuilt firearm; also referred to as a *blue pill load*. Pressures in these rounds may run as much as 40% higher than standard for a given cartridge.
- Pyrodex®** A Hodgdon trade name for a black powder substitute with similar burning characteristics. Pyrodex comes in several granulations for use in percussion revolvers, small- and large-caliber rifles, and shotguns.
- QE** Abbreviation for *quadrant elevation*, a military term for the elevation of the muzzle of the firearm above the horizontal plane, usually expressed in *mils*.
- RF** Abbreviation for *rimfire*.
- Radial Fractures** The fractures or cracks that radiate out from an impact site in noncrystalline materials such as glass, ceramics, bone, and certain plastics.

Recoil The rearward movement of a firearm as a result of discharge.

Recoil Operation

Short recoil: A firearm mechanism (action) in which the breechblock remains locked to the barrel only while the pressure is high. This involves a barrel travel of only about a half inch. The device locking the breechblock to the barrel is then released and the two components separate. The barrel may remain stationary and await the return of the breechblock, but in most modern designs the barrel has its own spring and goes forward into battery.

Long recoil: A system in which the bolt and barrel recoil a greater distance than the length of the unfired cartridge. The breechblock is then held to the rear while the barrel is driven forward by its own spring. When the barrel is fully forward, it trips the catch, releasing the breechblock, which then feeds the next cartridge into the chamber.

Reference Ammunition Ammunition used in test ranges to evaluate barrels, ranges, and other velocity- and pressure-measuring equipment. May also be used as a control sample by which other characteristics are compared, such as accuracy and pattern.

Rib Marks A series of raised and depressed features on the edges of radial and concentric fractures in bullet-struck glass and other comparable materials. Radial fractures start at right angles to the back side (exit) surface of the fracture and turn toward the source of breaking force. Rib marks on concentric fractures start at right angles to the front side (entry) surface.

Ricochet To change the normal path by impact, typically without perforation or penetration; the glancing rebound of a projectile after impact with a surface. Ricochet is typically a *surface* phenomenon.

Rifling The series of spiral grooves, cut or pressed into the bore of a firearm, designed to impart spin to a projectile.

Rifling Twist The direction (right or left) and rate of turn of the rifling helix, usually expressed as 1 turn in x inches or y mm.

Rimfire Any cartridge having its priming mixture contained within its rim. For all practical purposes, rimfire cartridges are nonreloadable.

Ringed Barrel A barrel from a firearm that has been fired while containing an obstruction. The resultant excessive radial pressure causes a circumferential bulge in the barrel.

Round Military terminology for a single loaded cartridge.

SAAMI Abbreviation for the *Sporting Arms and Ammunition Manufacturers Institute*.

S.E.E. Abbreviation for *secondary explosive effect*, a condition that can occur when slow-burning tubular powders such as IMR 4831 are used at greatly reduced charge weights in large-capacity bottlenecked cartridges. Rather than burning in a normal fashion, the powder detonates, as though it were a severe overload. Also known as *high pressure excursion*.

SS109 A European designation for the 62-gr M855 FMJ-BT bullet loaded in 5.56 mm cartridges. The SS109 contains a hardened steel penetrator in its nose.

S.W.A.T Acronym for Special Weapons and Tactics/Training or Special Weapons Assault Team.

S&W Abbreviation for Smith & Wesson.

SWC Abbreviation for *semi-wadcutter bullet*.

SXT® Abbreviation for *Supreme Expansion Technology*, a Winchester trademark for certain pistol bullets.

Sabot French for *shoe*, in weapons systems a device used to center a subcaliber projectile in a bore for firing. The sabot normally disengages from the projectile shortly after it exits the muzzle, falling to the ground a short distance in front of the gun.

Safety Mechanism A device on a firearm that, when set to "On," provides protection against accidental discharge under normal usage. When the safety is set to "Off," the firearm can be discharged by a normal pull of the trigger.

Manual safety: a safety mechanism that must be manually engaged and subsequently disengaged to permit normal firing.

Automatic safety: a safety mechanism that goes to the "On" position when the action of the gun is opened.

Passive safety: a safety mechanism that is in place (or "On") until the trigger is pulled. An example is the transfer bar system in some revolvers.

Schlieren Photography German *streaks*, Schlieren is a special type of photography using a point (spark) source of illumination that exposes a bare sheet of film mounted on a flat surface. Objects and disturbances in the

- atmosphere between the spark discharge and the film are recorded as shadows. Schlieren photography is used to capture the supersonic shock wave and/or air turbulence created by bullets in flight.
- Sear** An internal component in a firearm designed to retain the hammer or striker in the cocked position. When released, it permits the hammer to fall or the striker to fly forward, firing the cartridge in the chamber.
- Sectional Density** A bullet's weight in pounds divided by its diameter in inches squared. High sectional density is essential to producing a good ballistic coefficient and deep penetration.
- Selective Fire** The capability of some automatic weapons to fire in either automatic or semiautomatic mode at the firer's discretion. These weapons normally have a switch or selector lever to facilitate the operator's choice.
- Semiautomatic Firearm** A firearm that fires, extracts, ejects, and reloads once for each pull and release of the trigger. Also referred to as *self-loading* or *auto-loading*.
- Semi-Jacketed Bullet** A bullet with a partial jacket, exposing a lead nose.
- Semi-Wadcutter Bullet** A projectile with a distinct, short, truncated cone at the forward end.
- Shallow Angle Impact** An impact of a projectile with a surface at an oblique angle. While there is no numerical definition associated with this term, it implies several physical evidence observations and expectations: (1) Damage to the bullet will be primarily on the ogive and bearing surface as opposed to the nose. (2) There is significant potential that the outcome of the terminal ballistic event will be ricochet.
- Shock Wave** The disturbance of air surrounding and behind a supersonic bullet caused by compression of the air column directly in front of it.
- Shot Collar** A plastic or paper insert surrounding the shot charge in a shotshell to reduce distortion of the shot when passing through the barrel. The most common shot collars are the plastic inserts found in some Winchester shotshells.
- Shotcup** A wad, or shot protector. Many shotcups are made of plastic; they are designed to reduce pellet deformation during barrel travel.
- Sight Picture** The visual image observed by the shooter when the firearm sights are properly aligned on the point of aim.
- Sight Radius** The distance between the rear sight and the front sight on a firearm.
- SilverTip®** A Winchester trademark most frequently associated with a line of hollow-point pistol bullets jacketed with either nickel-plated gilding metal or aluminum.
- Sine Function** In a right triangle, the ratio of the side opposite a given angle and the hypotenuse.
- Single-Action Firearm** A firearm with an action requiring the manual cocking of the hammer or striker before sufficient pressure on the trigger releases the firing mechanism. In such firearms, pulling the trigger accomplishes the singular act of releasing the hammer or striker from its fully cocked position.
- Single-Base Powder** Any smokeless propellant which uses nitrocellulose as its only explosive base. See also *Smokeless Powder*, *Double-Base Powder*, and *Triple-Base Powder*.
- Single Strength Glass** See *Plate Glass*.
- Skid Marks** Rifling marks formed on the bearing surface of bullets as they enter the rifling of the barrel before being fully aligned and gripped by it. Skid marks have the appearance of a widening of the land impressions at their beginnings. They are typically associated with revolvers because of the bullet's movement from the unrifled cylinder into the forcing cone of the barrel.
- Skive** A small slit or cut in the ogival portion of a jacketed bullet for the purpose of improving expansion.
- Slamfire** An accidental discharge that occurs during the feeding cycle, with no manipulation of the trigger by the shooter; most frequently associated with semiautomatic firearms in combination with poorly assembled ammunition. The most common causes in hand-loaded ammunition are a high primer, improperly set headspace (insufficient resizing), or a combination of the two. Other causes include incorrect primer, a broken and protruding firing pin, or a badly worn sear. These are extremely serious conditions that can damage or destroy the firearm and injure the shooter.
- Slide** A member attached to and reciprocating with the breechblock in a semi- or fully automatic firearm.
- Slide Drag Mark** A mark that occurs in a semiautomatic pistol when a live cartridge is at the top of the magazine and the slide is retracted. The lug on the underside of the slide drags across the 12 o'clock position on the cartridge case, leaving a striated mark. This mark *cannot* occur when a cartridge is manually inserted in the firing chamber and the slide is released, or when a loaded magazine is inserted in the firearm with the slide locked back.
- Slide Scuff Mark** A mark that occurs in a semiautomatic pistol when a live cartridge is at the top of the magazine and the retracted slide, on release or forward movement, impacts the 12 o'clock edge of the cartridge head, producing a

small, indented mark at this location. The mark also occurs during the normal chambering of a live cartridge during firing. It *cannot* occur when a cartridge is manually inserted in the firing chamber and the slide is released.

Slide Stop A device to retain the slide in an open or rearward position.

Smokeless Powder A propellant powder composed primarily of nitrocellulose (single-base) or nitrocellulose and nitroglycerine (double-base). There are triple-base powders as well, but they are not used in reloading powders in the United States. Smokeless powder comes in several forms, such as tubular, ball, and flake.

Snafire The discharge of a loaded firearm through the inadvertent release of the hammer or striker from a partially retracted position. Such discharge may be the consequence of a compromised safety system, the lack of a safety system for such an event, or the handler's failure to engage the appropriate safety system.

Sodium Rhodizonate A chemical reagent used to detect lead by converting it to lead rhodizonate.

Spall A crater formed from chipped or fragmented material as a result of projectile impact in brittle or frangible materials (e.g., concrete, cinderblock, Sheetrock). It is more often seen as a crater on the *exit* side of a bullet impact site but can also be seen as an impact crater in otherwise hard materials.

Spark Photography See *Schlieren Photography*.

Speed of Sound The speed at which sound travels in air; at standard sea level conditions; this is approximately 1115 feet per second but varies with air temperature, altitude, barometric pressure, and relative humidity.

Spitzer German for *pointed*, a sharply pointed bullet with a long ogive, usually of 7 calibers (i.e., a ratio of length to diameter of 7 to 1) or more.

Sprue The opening in a bullet-casting mold that permits entry of the molten metal. Also, the waste piece cast in this opening.

Sprue Cutter Marks The toolmark left on a cast bullet resulting from the cutting off of the sprue.

Squaring A rectangular system of reference for diagramming and measuring projectile strikes to automobiles.

Squib Load or Discharge A cartridge or shell that produces projectile velocity and sound substantially lower than normal. This may result in projectiles and/or wads remaining in the bore.

Steel-Core Bullet A jacketed bullet containing a core, usually composed of mild steel, frequently centered or secured inside the jacket with lead.

Steel-Jacketed Bullet A bullet jacketed with mild steel and often coated or plated with a thin layer of copper as a corrosion inhibitor.

Steel Penetrator A hardened-steel component within a jacketed bullet designed to improve penetration in "hard" targets.

Step-Base Bullet A jacketed bullet having a small, flat recess or "step" in its base.

Stippling See *Powder Stippling*.

Stove-Piping A failure to eject where the fired case is caught in the ejection port by the forward motion of the slide or bolt. The cartridge case protruding out of the ejection port is said to resemble an old fashioned stove pipe.

Sub-machine Gun An automatic or selective-fire weapon chambered for a pistol cartridge. These firearms are normally compact and intended to be used at close-combat ranges.

Swage To form metal under pressure, normally in a press, using a punch or die.

Swaged Bullet A bullet that has been formed by pressing and forming the bullet material in a die.

Sympathetic Discharge See *Involuntary Discharge*.

Sympathetic Firing The simultaneous firing of two or more cartridges chambered in the cylinder of a revolver, one of which is in-battery.

TC See *Truncated Cone Bullet*.

TMJ See *Total-Metal-Jacketed Bullet*.

Tangent In a right triangle, the ratio of the side opposite a given angle to the adjacent leg of the triangle.

Tartrate Buffer An aqueous solution of sodium bitartrate and tartaric acid formulated to provide a pH 2.8 environment for the sodium rhodizonate test reagent.

Tattooing See *Powder Tattooing*.

Tempered Glass A single piece of glass given a special heat and cooling treatment that results in much greater strength, used for glass doors, shower doors, arcadia doors, and side and rear automobile windows. Upon failure, tempered glass shatters and dices into small fragments.

Terminal Ballistics The branch of ballistics that studies a projectile's impact on a target.

Terminal Velocity The final velocity reached by a free-falling object in a specific medium, usually air.

- Throat** The unrifled portion of the bore immediately ahead of the chamber and behind the leade. See also *Freebore*.
- Time of Flight** The time taken by a projectile to traverse two points, or a specific distance. Time of flight is a critical factor in a number of exterior ballistic calculations.
- Total-Metal-Jacketed Bullet** A bullet made by copper plating a lead slug to create a jacket that completely encases the core. This jacket is much thicker than cosmetic copper plating.
- Tracer Bullet** A bullet containing a chemical compound that ignites during discharge and produces visible or infrared illumination during flight. Selected colors such as red, orange, yellow, or green are achieved with certain metallic compounds in the bullet's composition.
- Trajectory** The arched path that a bullet follows in flight. For most shots fired in a shooting incident, a trajectory represents a snapshot in time, showing a relationship between the orientation/location of the firearm and a struck object. See also *Bullet Path*.
- Trajectory Rod** A straight probe or rod, often with centering cones, constructed of inert, brightly colored materials specifically designed for tracking and illustrating the nominal path of a projectile through one or more materials.
- Trigger Pull** The amount of force that must be applied to the trigger of a firearm to cause sear release, measured with hanging weights or an appropriate scale touching the trigger at a point where the trigger finger would normally rest. The force applied is approximately parallel to the bore axis.
- Triple-Base Powder** A propellant composed of nitrocellulose, nitroglycerine, and nitroguanidine generally used in large-caliber military ammunition.
- Truncated Cone Bullet** Abbreviated *TC*, a bullet with a tapered or conical nose profile that has been terminated (by design on the part of the manufacturer) before reaching a certain point.
- Twelve-Twenty Burst** A dangerous situation in which a 20-gauge shotshell is inserted into the chamber of a 12-gauge shotgun followed by a 12-gauge shotshell. The 20-gauge shell represents a serious obstruction at the forcing cone when the 12-gauge shell is discharged, and it will produce a "ringing" of the barrel in this area, at a minimum, or a bursting of the barrel in this area.
- Twist** The direction (right or left) and rate of turn of the rifling helix.
- Twist Direction** The direction of rotation of the rifling, as determined by studying the inclination of the rifling at the top of the bore as one looks through a barrel.
- Twist Rate** The rate at which a firearm's rifling turns within the bore, normally expressed as the distance required for the rifling (and projectile) to make one complete revolution. Depending on the origin of the firearm, this may be written in inches or millimeters. Examples: 1 turn in 12 inches equals 1 turn in 305 millimeters.
- Tubular Powder** See *Extruded Tubular Powder*.
- UMC** Abbreviation for *Union Metallic Cartridge Co.*
- Unintentional Discharge** A situation in which the handler is the source of the discharge. Examples include improper letdown of a hammer, involuntary/sympathetic discharge during a struggle, and a slip-and-fall scenario.
- Unperforated Disk-Flake Powder** An extruded form of smokeless powder cut into thin, circular disks of selected diameters and thicknesses. Examples include Bullseye and Unique.
- Variance** Normal, expected inaccuracy or uncertainty yielding a range of possibilities. Also, a synonym for error of measurement.
- Vector® Ammunition** A unique line of illuminating projectiles manufactured by Hornady that utilize an igniter composition followed by a fine zirconium wire centered in the lead core of open-based pistol bullets. These special cartridges are no longer available.
- Vertical Angle** In shooting scene reconstruction, the vertical component of a projectile's reconstructed flight path; given a minus sign if the path followed by the projectile is downward and a positive sign if upward. A flight path that parallels a level surface has a vertical angle of 0.0 degrees.
- WCF** Abbreviation for *Winchester Center Fire*, a centerfire cartridge designed or produced by Winchester. Examples include the .30 WCF (.30–30), the .38–40 WCF, and the .44–40 WCF.
- WRA** Abbreviation for Winchester Repeating Arms.
- W-W** Abbreviation for Winchester-Western.
- Wadcutter** A bullet having a full-caliber flat nose, intended to cut a clean hole in the target for easier scoring.

- Web** The solid portion of a cartridge case between the primer pocket and the powder chamber. The primer pocket and powder chamber are joined by the flash hole or vent in the web.
- Weight** A property of matter that depends both on the mass of an object or material and on the effects of gravity on that mass, represented by the formula $W = ma$, where W = weight, m = mass, and a = accelerative force of gravity (32.174 fps or 9.807 m/s/s average Earth values at sea level). *Note:* In some formulas the accelerative force of gravity is denoted by g .
- Windage** Lateral correction of a firearm's sights to compensate for the projectile's deflection by wind or drift. Also, the space between an undersized spherical lead ball and the bore of a muzzle-loading rifle.
- Witness Panel** Any one of a variety of materials, such as thin cardstock or poster board, positioned and mounted in such a way as to "witness" or record the position and orientation of a perforating bullet or bullet fragments. Cardstock witness panels are used to record pellet patterns from shogun discharges at selected ranges. The patterns of gunshot residue deposits are also recorded on witness panels of materials selected for this purpose.
- Work Hardening** A change in the grain structure of a metal as a result of repeated stress. In cartridge cases, work hardening most frequently occurs in and around the neck area, from the stresses of repeated firings and resizing, causing brittleness and leading to cracking and splitting of the case.
- Wound Ballistics** A special case in *terminal ballistics* dealing with the behavior of projectiles in tissue and tissue simulants, including bullet performance (threshold velocity to achieve penetration, bullet expansion, fragmentation, deformation, path deviation, and yaw point); penetration characteristics; and velocity loss as a consequence of the perforation of tissue and tissue simulants.
- X-Ray Magnification** The magnification effect for radio-opaque images on X-ray films that result from the conical beam of X-rays from the X-ray source. The effect is that the physical dimensions of the radio-opaque object on the film are always larger than the actual object within the body or subject being examined.
- Yaw** The rotation of a bullet at an angle (usually very slight) to its line of flight. Some yaw is almost always present when a bullet is fired, but this usually dampens out within 200 yards if the bullet is properly stabilized and well balanced. Also, the angle between the longitudinal axis of a projectile and the line of the projectile's trajectory; usually considered to exist before a bullet achieves full gyroscopic stability.
- Yaw Card** A size and thickness of cardstock selected to faithfully record the outline and orientation of a perforating projectile; similar to a witness panel.
- Zero** The adjustment of a firearm's sights to obtain impact at a desired point in relation to a specific point of aim at a given range.
- Zero-Edge Protractor** A protractor with a zero line or edge that lacks any tabs or ears, thus allowing the edge to be placed directly next to the struck surface and the medium used to represent the projectile's flight path.

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