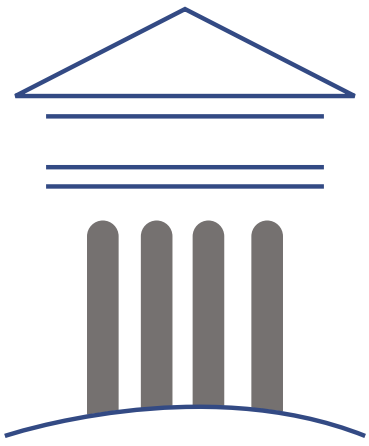
Advanced Ballistics
Lesson: 2199

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Objectives

In this lesson, you will learn

1. The definition of ballistics.
2. What factors affect trajectory.
3. The factors that affect a bullet's reaction to wind.
4. The effect of shooting uphill on a bullet's impact.

Introduction

Ballistics is the science of the motion of projectiles. Interior ballistics deal with the movement of a projectile through the gun barrel; exterior ballistics deal with the projectile's motion between muzzle and target; and terminal ballistics deal with the effects of the projectile on the target. Ballistics was a technical art long before firearms existed. In fact, the development of specialized projectiles and throwing instruments can be traced back to the Stone Ages. Ballistics became a science with the development of firearms, because firearms completely changed the nature of warfare.

The development of ballistics as a science was tightly interwoven with the development of firearms and bullets as we know them today. It is not possible to discuss any one of these topics without involving the others because of their strong interactions. The first section of this lesson is an overview section. In this section, we will briefly recount the development of ballistics and the development of the bullet, and show how these developments related to key events in the development of firearms.

The Development of Ballistics

No one knows exactly when or where the first gun was invented, but the documented history of firearms in the Western Hemisphere extends back more than 650 years. The earliest written records come from both Italy and England in the year 1326. The English records show drawings of large, vase-shaped guns about 4'-5' tall, resting on wooden platforms, and firing large arrows several feet long and several inches in diameter. Strange as it now seems, these large arrows were not unusual projectiles for that time. Large crossbow-like weapons called ballistics have been used from the time of the ancient Greeks to shoot huge arrows. These weapons, together with catapults throwing huge stones, were the largest weapons of war in the Middle Ages.

History shows that arrows were not used very long as firearms projectiles. Small cannon tubes firing lead, iron, or stone balls weighing 1-2 pounds appeared in the mid-1300s. In the late 1300s, the first of the huge bombards appeared. These were giant cannons with bores many inches in diameter. They fired stone or iron balls, weighing from several hundred pounds to a ton, to ranges sometimes exceeding a mile. These huge guns were improvements on the catapults and trebuchets of the Middle Ages and were very effective in sieges against fortified cities and castles.



***Figure 1**: The earliest firearms were hand-held cannons or handguns.*

The development of small firearms also began in that same period, and the first handguns (guns that could be carried and fired by a single person) appeared well before the year 1400. Actually, these were hand cannons, as shown in Figure 1, with short barrels and bores about 1" in diameter. They were equipped with tillers (the name used for a crossbow stock) to aid in pointing, but they were designed to be fired from a city or castle wall or other fixed rest. Another full century would pass before the first basic shoulder stocks would appear.

Relatively few guns were actually used before roughly 1500 A.D. The huge bombards, while very effective against fortifications, were very difficult to load—and enormously expensive as well. Handguns were effective more from the fear generated by their reports than because of their actual firepower. In terms of accuracy, range, penetration, and rate of fire, longbows and crossbows were much more effective than handguns. Consequently, these early years witnessed more active developments of artillery pieces than of arms for personal combat.

Ballistics was a technical art practiced by gunners in that time. Gunnery was a completely closed profession. A bombard gunner, for example, learned by trial and error how to change and aim a gun to get the range and energy needed to hit a target. This secret knowledge was carefully guarded and handed down, but the secretive practice survived only as long as there were few guns in each European army.

In the late 1400s, metalcasting and metalworking began to improve rapidly in Europe. This was paralleled closely by the development of smaller, lighter mobile artillery and then by firearms that could be carried and fired by a single soldier. Although the sword, axe, and bow would remain the principal weapons of European armies for at least another 100 years, the development of firearms for the common soldier was definitely underway by the year 1500. These events spelled the end of gunnery as a closed profession. Many more gunners were needed as artillery pieces became smaller and more numerous. Guns began to be used on open battlefields against moving targets. The art of ballistics had to be improved, both to handle the new battlefield situation and to provide a systematic method for training gunners.

The development of ballistics as a true science began at that time and continues to the present day. The names of some of the great scientists and mathematicians in history are associated with the development of ballistics, including Leonardo daVinci, Galileo, and Isaac Newton. From the earliest days of firearms, rulers were very interested in ballistics for a simple reason — battles were won by armies with the best guns and gunners. The best brains and skills available were put to work on the problems of designing better guns and more effective ways of using them. In those days, just as at the present time, governments spent money willingly to gain more powerful and more effective armament. It is worth noting that this money and effort spurred the development not only of firearms and ballistics, but also of all the mechanical arts, mathematics, and physical sciences—in particular mechanics, dynamics, and aerodynamics.

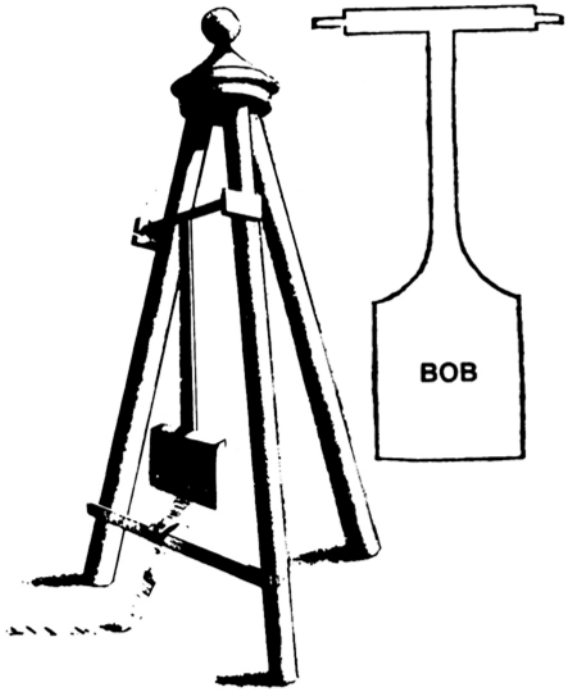


***Figure 2**: The ballistic pendulum was one of the first instruments designed for testing firearms.*

After a bullet leaves the gun barrel, its trajectory is determined by two kinds of forces acting on it: the force of gravity and the force due to the air flow around the bullet as it moves through the air (aerodynamic force). In the early days of ballistics science, almost nothing was known about the aerodynamic force, and very little was known about gravity. For about 200 years after firearms first appeared in Europe, no one knew that the path of a bullet trajectory is a curve. One of the earliest notions was that after a bullet was fired, it traveled a straight line (the direction of the gun bore) until the velocity slowed to near zero, and then it fell more or less straight to the ground. When bombards were developed to throw large bores at low velocity, it became obvious that this idea was wrong, so another answer was conceived. This second notion described the trajectory of a shot by two straight lines — one going out the bore and the other going down into the ground at the strike point of the shot (like two legs of a triangle). These two lines were then joined by a curve near the top of the triangle.

In 1537, Tartaglia, an Italian scientist, wrote a ballistics manuscript in which he said that the trajectory of a bullet was really a continuous curve. Tartaglia was a ballistics consultant to the Italian principality of Verona, and was asked to determine what gun elevation angle achieved the maximum target range. He directed some firing tests to determine this angle, and discovered that it was near 45 degrees. In this process he also noted that the trajectory path was a continuous curve. Tartaglia's work is regarded as the first truly scientific approach to ballistics. He performed systematic experiments and carefully measured the results. This approach continued to be used for several hundred years, until all the necessary knowledge was developed to permit trajectories to be calculated with a reasonable degree of accuracy. Ballisticians constructed firing tables for every gun developed during that period by means of extensive firing tests.

In 1636, nearly a century after Tartaglia published his work, Galileo published results from his famous experiments and was able to give a reason why the trajectory was a curve. Galileo was a ballistics consultant to the arsenal at Venice for a number of years. The famous experiment in which he dropped two cannonballs from the Leaning Tower of Pisa was only one of a long series of experiments having to do with the effects of gravity. Galileo determined that the acceleration of a falling body by gravity is a constant. With this result he was able to show that, if the effects of air drag on a bullet are negated, the trajectory is a type of curve called a parabola.

Galileo's work marks one of the great milestones in the history of ballistics. He published the first analytical descriptions of trajectories and is credited with laying the theoretical foundation for ballistic study. However, it turned out that Galileo's parabolas were not very accurate representations of true bullet trajectories because air drag has a very important effect. Galileo was aware that air drag existed, but there was absolutely no way available for him to measure any of its effects. He thought it was a small effect compared to gravity, and more than 100 years went by before the effects of air drag began to be understood.

Actually, Galileo's method was quite useful for the low-velocity, short-range artillery of that day. It was necessary to know only the elevation angle of the muzzle and the horizontal range of the shot to calculate a parabolic trajectory for a test shot from any gun. These quantities could be measured with good accuracy. Once the parabola was calculated to match the bore elevation angle and the range, a muzzle velocity could be derived from the curve. In a vacuum, this derived muzzle velocity would have been almost exactly correct, but it was in error by a substantial amount due to air drag. In fact, it was always a good deal less than the actual muzzle velocity of the gun, because air drag always acts to slow a bullet. Nevertheless, the derived muzzle velocity could be used to calculate firing tables analytically (range versus elevation angle) for the gun. These calculated tables were in error by several yards at ranges of a few hundred yards, but this accuracy was sufficient for using artillery against columns of foot soldiers or horse cavalry. For more than 100 years, Galileo's method was used to determine muzzle velocity, until a means was invented to measure velocity directly.

In 1740, in England, Benjamin Robins invented the ballistic pendulum, shown in Figure 2, and made it possible to measure velocity directly. The ballistic pendulum was a simple pendulum with a large, heavy wooden bob. To make a velocity measurement, the bullet was weighed and the bob was weighed.

Then the pendulum was positioned with the bob hanging motionless and the bullet was fired into it. By measuring the height of the pendulum swing resulting from the bullet striking the bob, the velocity of the bullet could be determined. Robins made a series of measurements with 75-caliber, 12-gauge musket balls, including measurements of velocity near the muzzle and at several ranges from the muzzle. Robins reported muzzle velocities ranging from a little over 1,400 to a little under 1,700 feet per second (fps). These numbers were astounding, so much so that they were widely disbelieved. When Galileo's method was used for the musket, the derived muzzle velocities were hundreds of feet per second less than the ones measured by Robins. However, even more astounding were the measurements of decreasing velocity from the muzzle to the target. In order to account for Robins' measured numbers, it was necessary to have an air drag force about 85 times stronger than the gravitational force. This was totally unbelievable, especially since it had been assumed for so many years that air drag was a much smaller force than gravity. Robins was subjected to wide criticism; however, he was proved right. From that time on, ballistics scientists appreciated the importance of aerodynamic forces on bullets, and the ballistic pendulum was used for many years to measure the effects of these forces. Robin's invention was a major milestone in the history of ballistics.

The ballistic pendulum was based upon laws of mechanics formulated by Sir Isaac Newton, who died about 15 years before Robins published his measurements. Newton ranks as probably the greatest scientist of all time. His work established physical laws and mathematical techniques which are the basis for several branches of science, ballistics included. Newton formulated the universal law of gravitation, which shows that gravity varies with altitude above the earth. This law is important in the computation of ballistics for high-altitude rockets. He formulated the fundamental laws of mechanics, which we call Newton's Laws, and these made it possible to understand and analyze the effects of all the forces acting on a bullet in flight.



***Figure 3**: The ballistic pendulum has long been replaced with highly accurate digital chronographs.*

Between the mid-1700s and the late 1800s, ballisticians devoted a great amount of effort — both theoretical and experimental — to the investigation of drag. The theoretical investigations never did arrive at the point where bullet drag could be accurately calculated without measurements. Drag turned out to be a very complicated function of the size, shape, and velocity of the bullet, and of the temperature and density of the air through which it moved. Accurate measurements of drag only became possible in the late 1800s when chronographs, earlier versions of the digital chronograph shown in Figure 3, were invented in Germany and England.

While ballistic study was advancing, firearm design was rapidly changing, and the range and accuracy of artillery and shoulder arms improved considerably. Militaries adopted rifled barrels and elongated bullets for small arms in the early 1800s, and somewhat later for artillery. Percussion ignition also was widely adopted by about 1850, and metallic cartridges and breech-loading arms began to appear in the mid-1800s. The theory of interior ballistics began to grow in the late 1700s, and smokeless powder appeared in the late 1800s. All these advances increased the need for good exterior ballistics, so that both artillery and small arms could obtain accurate long-range firing.

The theoretical drag investigations, which never developed as desired, did point out a major simplification in the experimental treatment of drag. This was the concept of a standard bullet, which was developed about 1850. Bullets had evolved by that time to the familiar shape of a cylinder with a pointed nose and a flat base. Theory indicated that a bullet of such a shape could be adopted as standard. Then, precise drag measurements could be made for that bullet, and the drag deceleration of another bullet of that same shape would then be related to the standard drag deceleration by a constant factor. This was a major step forward, because otherwise the drag characteristic of each bullet would have had to be measured individually. If that had been the case, there would be little ballistics data available today.

This discovery was the birth of the ballistic coefficient. The ballistic coefficient, or C, is the factor that relates the drag deceleration of an actual bullet to the drag deceleration of the standard bullet, as shown below:

$$C = \frac{\text{drag deceleration of the standard bullet}}{\text{drag deceleration of the actual bullet}}$$

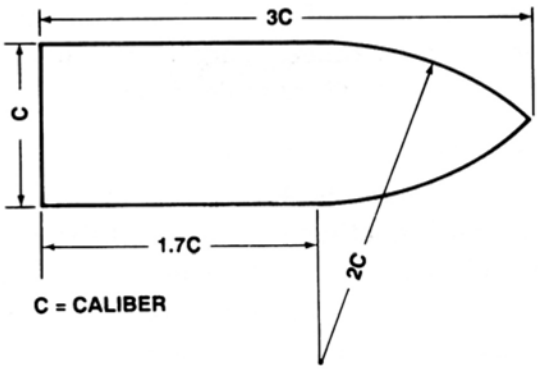


***Figure 4**: Shape and relative dimensions of the Krupp standard bullet.*

Actually, this relationship is only an approximation. But experimentation has shown that the relationship holds well enough, even when the bullet shapes are slightly dissimilar, for accurate ballistic computations.

The ballistic coefficient also led to another major advancement that had to do with computing bullet trajectories. Calculus must be used to compute a bullet trajectory. The numerical computations necessary to calculate just a single trajectory are very lengthy and tedious when done by hand. About 1880, an Italian ballistician named Francesco Siacci discovered a way to simplify this problem. He showed that the ballistics of an actual bullet, fired nearly horizontal, could be computed from the ballistics of the standard bullet by using the ballistic coefficient. By this method, a single trajectory was computed for the standard bullet by the tedious methods of calculus, and then a trajectory for any actual bullet with a known C was computed from the standard trajectory using simple algebra. Siacci's method shortened the computation time, and it has been used widely in ballistics ever since.

Between about 1865 and 1930, many firing tests were conducted worldwide to determine the drag characteristics of standard bullets adopted by different countries. Of particular note were tests made by Krupp in Germany in 1881 and by the Gavre Commission in France from 1873 to 1898, although many other tests were made. The Gavre Commission work was very comprehensive, including extensive firing tests going up to a velocity of 6,000 fps, and a comprehensive survey of data available from tests in other countries. The Commission attempted to correlate all this data, and published a composite drag characteristic for a certain standard bullet configuration.

The Krupp test data became the basis for ballistics tables for small arms right up to the present time. The standard bullet used by Krupp was a flat-base design, three calibers long with a two-caliber head as shown in Figure 4. After the Krupp data was published, a Russian Army Colonel constructed a mathematical model of the standard drag deceleration for this bullet. Colonel James M. Ingalls of the U.S. Army used this analytical model and computed and published his now-famous Ingalls Tables in 1884 (updated in 1917). The Ingalls Tables are the ballistics of a standard, Krupp-shaped bullet. This standard bullet is a good model for computing the ballistics of most sporting bullets. This drag model has even been used for round balls, although three different values of C must be used in each of three velocity ranges to match the round ball drag to the standard bullet drag.

After World War II, the Ballistics Research Laboratories of the Aberdeen Proving Ground undertook another long series of firing tests on military and sporting bullets, and they developed four standard drag models corresponding to four types of bullets. These four types are hollow-point lead bullets; boattail bullets; very sharp-pointed, full-patch bullets; and all others except those in the above categories. It was found that the drag model for the last category, which includes the vast majority of hunting and target bullets in use today, is almost identical to the model developed from the Krupp firing data. These models were published in 1965 by Winchester-Western. They are the most comprehensive for sporting-type bullets.

Once the concept of the standard bullet was adopted, the one remaining problem was how to determine the ballistic coefficient for an actual bullet. One method of determining C is firing tests. This method will be described in more detail later. The basic idea is to measure the ballistic performance of the actual bullet, compare it to the ballistic performance of the standard bullet fired at the same muzzle velocity, and determine the right value of C to make them match. Tests are made at several muzzle velocities to see how well the standard drag model fits the actual bullet.

Another method of determining C by shape comparison was developed and published by Wallace Coxe and Edgar Beugless of the Du Pont Company in the 1930s and has been widely used ever since. The method estimates the ballistic coefficient related to the drag model of the Krupp standard bullet. It consists of comparing the actual bullet point shape to a chart of point shapes for which ballistic characteristics are known. When the closest match is made, the chart provides the form factor for the bullet, from which C can be calculated easily. This is a judgmental method, and therefore not as accurate as the firing-test method. There are many bullets, particularly

for black powder firearms, with shapes that are not included on the charts. Also, it does not provide for the deep lubricant grooves and the bands on cast lead bullets.

The main ballistic problems have been solved today, in the sense that bullet trajectories can be computed and actual firing test measurements will come very close to the computed values. The problem of drag is still under investigation, although in the last 25 years or so the emphasis has been placed on rocketry. Within this same period, high-speed, electronic, digital computers have developed, and these machines have eliminated the tedium from ballistics computations.

SELF-TEST QUESTIONS

Please check your answers on page 23.

1. ***True or False*. Relatively few guns were actually used before the year 1500.**
2. **What was the name of one of the earliest instruments for measuring the velocity of a moving object?**
3. **Who invented the ballistic pendulum?**
4. **Briefly define ballistic coefficient.**

Exterior Ballistics Performance

After a bullet leaves the bore of a gun, its trajectory is determined by the forces of gravity and air drag. Gravity is considered constant for purposes of calculating trajectories of rifle and handgun projectiles. The small changes in gravity that occur with changes in altitude and location on the Earth cause only negligible changes in trajectories. However, air drag is another matter. Air drag changes significantly with altitude, atmospheric conditions, and wind conditions. These changes have important effects on bullet trajectories. Ballistics tables for small arms, including those in this lesson, are always computed for sea level standard atmospheric conditions. If you happen to live at an elevation of several thousand feet above sea level, your guns will shoot a little flatter than the ballistics tables indicate.

Crosswinds can have a large effect on bullet trajectories, particularly for bullets with a low ballistic coefficient fired at a low muzzle velocity. For example, a 10 mph crosswind can deflect a Minié bullet or a round ball from a black powder rifle many inches off target at ranges of 50-100 yards. Even for jacketed bullets at much higher velocities, crosswind deflections – though not as large – are important. For this reason, crosswind deflections have been calculated for each Lyman bullet in all Lyman manuals, and they are listed in the Ballistics tables along with the other trajectory data.

It also turns out that when a gun is fired either uphill or downhill, it always shoots higher than when it is fired level. When the angle is steep, a gun can shoot high by several inches at a range of 50-100 yards, and the longer the range, the greater the variance.

The effects of altitude and atmosphere, wind, and degree of angle are discussed in this section. These discussions are presented to help shooters understand more about these important effects so that they can shoot more accurately.

EFFECTS OF ALTITUDE AND ATMOSPHERIC CONDITIONS

Drag depends upon the density of the air and the speed of sound; these, in turn, depend upon altitude, temperature, and barometric pressure. For example, at higher altitudes the air is thinner and colder than at lower altitudes. Since the air is thinner, the drag on the projectile is less. Also, since the air is colder, the speed of sound at higher altitudes is lower than at lower altitudes. Consequently, the velocity at which shock waves form around the bullet is lower.

Altitude (ft)	Temperature (°F)	Barometric Pressure mm Hg	inches Hg
Sea Level	59.0	750.0	29.53
1000	55.4	728.3	28.67
2000	51.9	707.1	27.84
3000	48.3	686.3	27.02
4000	44.7	660.1	26.22
5000	41.2	646.2	25.44
6000	37.6	626.9	24.68
7000	34.0	608.0	23.94
8000	30.5	589.4	23.21
9000	26.9	571.4	22.50
10000	23.3	553.8	21.80
11000	19.8	536.6	21.12
12000	16.2	519.8	20.47
13000	12.6	503.4	19.82
14000	9.1	487.4	19.19
15000	5.5	471.8	18.58

***Figure 5**: Standard atmospheric conditions at various altitudes.*

Ballistics tables in reloading manuals are always computed for sea level standard atmospheric conditions. The standard conditions used in this lesson are the ones used by Ballistics Research Laboratories at the Aberdeen Proving Ground in Maryland:

Altitude:	Sea level
Barometric Pressure:	750 mm Mercury = 29.53" Mercury
Temperature:	59° F
Relative Humidity:	78%

The values of air density and velocity of sound corresponding to these conditions are:

Air Density:	0.0751lb/ft3
Speed of Sound:	1120.27 fps

When trajectories are computed for altitudes above sea level, it is customary to calculate them for standard atmospheric conditions at those altitudes. The table in Figure 5 lists the standard temperature and barometric pressure conditions at altitudes up to 15,000 feet.

Projectile	Muzzle Velocity (fps)	Ballistic Coefficient	Altitude (ft)	Drop [inches at Range (yards)]			
				50	100	150	200
Lyman #454613 (265 gr) Minie	1400	.156	Sea Level	−2.38	−10.44	−25.52	−49.00
			5000	−2.34	−10.19	−24.71	−47.12
			10000	−2.31	−9.97	−23.98	−45.40
Lyman #311466 (151 gr)	1650	.250	Sea Level	−1.60	−6.99	−16.80	−31.78
			5000	−1.57	−6.83	−16.33	−30.64
			10000	−1.54	−6.69	−15.92	−29.69
Lyman #301620 (200 gr) Paper-Patched	1650	.370	Sea Level	−1.53	−6.63	−15.75	−29.30
			5000	−1.51	−6.50	−15.41	−28.55
			10000	−1.47	−6.39	−15.09	−27.88
Sierra 180 gr .308 Spitzer Boat Tail	2600	.540	Sea Level	−0.57	−2.51	−5.91	−10.86
			5000	−0.56	−2.47	−5.82	−10.67
			10000	−0.54	−2.42	−5.71	−10.46

***Figure 6**: Effects of altitude above sea level on projectile drop.*

On any given day, the actual atmospheric conditions may be quite different from standard. These differences will affect projectile ballistics. Fortunately, these effects are small enough that they can be ignored. Also, weather conditions are such that departures from standard air temperature and standard air pressure generally have canceling effects. For example, on a warm, balmy day, the barometric pressure also tends to be high. The higher temperature tends to decrease drag slightly, but the higher pressure tends to increase it, so the two effects come very close to offsetting each other.

To illustrate the effects of altitude changes, the table in Figure 6 shows drop data computed at three altitudes and four range values for four different rifle bullets. The first case is the 265-grain, Lyman #454613 Minié bullet fired at 1,400 feet per second. This bullet has a relatively low ballistic coefficient and a relatively low muzzle velocity when fired from a black powder muzzle loader. The next two cases are the .30-caliber, Lyman cast bullets fired at a 1,650 fps muzzle velocity typical for cartridges like the .308 Winchester and .30-06 cartridge. These bullets have ballistic coefficients which are quite good for cast bullets of their weights. However, the #301620 bullet has a ballistic coefficient about 50% greater than the #311466 bullet, so comparing these two cases shows the effect of markedly improving the ballistic coefficient while the caliber and muzzle velocity remain unchanged. The last case is the Sierra .30-caliber, 180-grain, spitzer boat-tail bullet fired at 2,600 fps, which is a typical muzzle velocity for this jacketed bullet in a .308 Winchester or .30-06 cartridge. This case shows how altitude affects the drop of a bullet with a relatively high ballistic coefficient and muzzle velocity.

The table in Figure 6 shows that all the bullets shoot flatter at a higher altitude than sea level. The higher the altitude, the flatter the trajectory. However, this improvement is considerably less for ballistically efficient bullets at high velocities than for less-efficient bullets at lower velocities. In other words, if a gun shoots relatively flat to begin with, changes in altitude will cause relatively small changes in the impact point and vice versa. However, if a shooter sights-in his or her gun at one location and then takes it to another location of much different altitude, it is always a good idea to fire a few rounds to recheck the zero.

WIND EFFECTS

A bullet's reaction to wind depends on both the speed and direction of the wind. In the first place, a headwind or tailwind causes vertical deflection—a change in the drop—of the bullet, while a crosswind causes horizontal deflection. Also, a crosswind causes a much larger deflection than does a headwind or tailwind of the same speed. As we will show a little later, the effects of a headwind or tailwind can be disregarded for almost all shooting situations. Crosswinds, though, are important for hunting as well as target shooting.

Air drag on a projectile depends upon the velocity of the projectile relative to the air through which it travels. When the air moves, the drag on the projectile is different from what it is when the air is still. It is just this drag-force difference that causes the bullet trajectory in a wind to be different from what it is in still air.

Projectile	Muzzle Velocity (fps)	Headwind (HW) or Tailwinds (TW) (mph)	Crosswind (mph)	Range (yds)	Deflection	
					Vertical	Horizontal
Lyman #454613 Minie (265 gr)	1400	20 HW	0	100	−0.14	0
				200	−1.40	0
		20 TW	0	100	+0.13	0
				200	+1.33	0
		0	20	100	0	9.85
				200	0	38.30
		20 HW	20	100	−0.14	10.30
				200	−1.41	40.83
Lyman #311466 (151 gr)	1650	20 HW	0	100	−0.04	0
				200	−0.39	0
		20 TW	0	100	+0.05	0
				200	+0.38	0
		0	20	100	0	5.50
				200	0	22.94
		20 HW	20	100	−0.04	5.61
				200	−0.39	23.61
Sierra .308 Spitzer Boat Tail (180 gr)	2600	20 HW	0	100	−0.01	0
				200	−0.03	0
		20 TW	0	100	0.00	0
				200	+0.02	0
		0	20	100	0	1.32
				200	0	5.47
		20 HW	20	100	−0.01	1.33
				200	−0.03	5.51

***Figure 7**: Wind effects on three projectiles. A negative vertical deflection means the projectile shoots low by the amount shown; a positive vertical deflection means the bullet shoots high by the amount shown.*

This is quite easy to see when the projectile flies in a headwind or tailwind with no crosswind. Suppose that you fire a bullet with a muzzle velocity of 2,500 fps and a tailwind of 10 miles per hour. When the bullet leaves the muzzle, its velocity is 2,500 fps relative to the ground, since you are holding the rifle steady relative to the ground. The wind at your back blows toward your target with a velocity of 14.67 fps (9-10 mph). Then, at the instant the bullet leaves the muzzle, its velocity, relative to the moving air, is 2,485.33 feet per second. If there were no wind blowing, the bullet's velocity relative to the still air would be 2,500 feet per second. Since the relative velocity is lower, the drag is a little lower when the bullet leaves the muzzle. As the bullet rides the tailwind, the drag is lower than it would be if the bullet flew in still air all along the trajectory. With less drag, the bullet reaches the target earlier, has more remaining velocity when it gets there, and suffers less drop, so it will impact a little high.

The table in Figure 7 shows the effects of different winds on three types of bullets. The three bullets chosen span the range from low ballistic coefficients and low muzzle velocities to high ballistic coefficients and high muzzle velocities. The first two entries for each bullet in this table show the trajectory deflections caused by a 20 mph headwind or tailwind only. Three points may be noted from these entries. First, a headwind or tailwind acting alone (no crosswind) causes only a vertical deflection. Second, these vertical deflections are relatively small at reasonable ranges, even for black powder firearms. For hunting situations and most target-shooting situations, a vertical correction would be unnecessary unless the wind was very strong and the range very long. Third, the table shows that a headwind always causes a slightly larger vertical deflection than a tailwind of equal speed. The reason for this has to do with the complicated way that drag depends on the speed of the projectile relative to the air.

When a bullet is fired in a crosswind, it is convenient to think of the crosswind dragging the bullet along with it. However, because of its inertia, the bullet does not follow the crosswind precisely. Actually, the flying bullet resists the wind to a large degree.

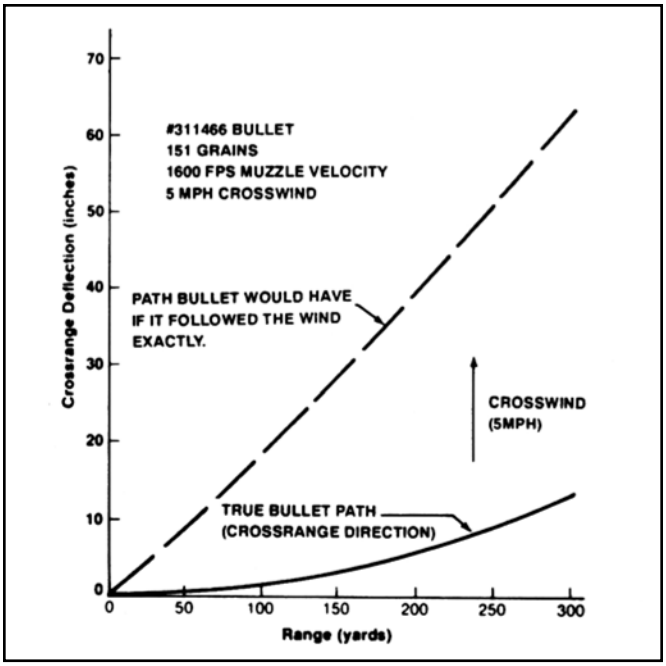


Figure 8: Bullet deflection by a crosswind.

Figure 8 is an example of these effects. The 151 grain, .30-caliber cast bullet is fired straight downrange at a 1,600 fps muzzle velocity in only a 5 mph crosswind. If the bullet precisely followed the wind, it would have the path represented by the dashed line in Figure 8. After traveling 300 yards it would have a cross-range deflection of 62.25 inches. In reality, the bullet follows the true path shown in the figure, and at 300 yards it is actually deflected 12.75 inches. While the 12.75" deflection certainly requires a windage correction, it still is a lot less than the 62.25 inches.

The table in Figure 7 shows the horizontal deflections caused by a 20 mph crosswind on the three example bullets. This is the third entry for each bullet in the table. Comparing the 20 mph crosswind effects with the effects of a 20 mph headwind or tailwind, it can be seen in each case that the horizontal deflection caused by the crosswind is much larger than the vertical deflection caused by a headwind or tailwind of the same speed.

Of course, a shooter seldom encounters a wind that blows only along or across the line of sight to the target, so we are really concerned with winds from any direction. It turns out, though, that a wind from any direction can always be regarded as made up of two component winds, one parallel to the shooter's line of sight and one perpendicular to it. Figure 9 is an example of how this happens. The vector representing the true wind points in the direction in which the wind is blowing, and the length of the vector is scaled to the true wind speed. The crosswind component always has a direction perpendicular to the shooter's line of sight, and the other component (headwind or tailwind) is always parallel to the shooter's line of sight. The two component vectors are just long enough so that when they add together, as shown in Figure 9, they start at the tail of the true wind vector and end at its head. The lengths of these component vectors represent their speeds.

The number table in Figure 9 can help you calculate the two component winds if you know the speed and direction of the true wind. Some well-equipped target ranges have wind meters which display this information. As an example of how to use the number table, suppose that the true wind is 10 mph and that it makes a 30° angle to the line of sight. Looking down the number table to 30°, we see that the headwind component has a speed of 0.866 x 10, or 8.66 mph, and the crosswind component has a speed of 0.500 x 10, or 5.00 miles per hour.

We can clearly expect that when two wind components exist simultaneously, there will be some interaction between them to produce deflections that are at least a little different from those produced by each component acting alone. This interaction arises because the horizontal deflection caused by a crosswind depends on the time of flight. We know that a headwind or tailwind causes a change in the time of flight. Therefore, we must expect that the horizontal deflection acting together with a headwind or tailwind will be different from the deflection caused by the same crosswind acting alone.

This interaction is really quite small. The last entry for each bullet in the table in Figure 7 lists the vertical and horizontal trajectory deflections caused by a 20 mph tailwind acting together with a 20 mph crosswind, which is a true wind of 28.24 mph blowing at a 45° angle to the shooter's line of sight to the target. The comparisons in the table in Figure 7 show that when a crosswind interacts with a headwind or tailwind, there is almost no effect on the vertical deflection which would result from the headwind or tailwind acting alone. The interaction does cause a change in the horizontal deflection, but it is small enough to be disregarded for almost all shooting situations, unless the range is very long and the wind is very strong.

Although the table data in Figure 7 are for a wind blowing at 45° to the line of sight, the conclusions apply to winds blowing in any direction. In general, we can always separate a wind into its two components. Then we can calculate the vertical and horizontal deflections caused by each component independently, forgetting their interaction. Disregarding the interaction will cause an error in the horizontal and vertical deflections, which are small enough to be disregarded in almost all shooting situations. Furthermore, since we are usually interested only in the horizontal deflection, the vertical deflection can also be disregarded for almost all shooting situations.

The Ballistics Tables section of the past several Lyman manuals contains crosswind deflection data for each projectile covered. Since the wind deflections depend very much on muzzle velocity, they are listed for each value of muzzle velocity which appears in the Ballistics Tables.

Angle A (LOS to Wind Vector)	Multiplier for Headwind/ Tailwind Component	Multiplier for Crosswind Component
0 deg	1.000	0.000
5	0.996	0.087
10	0.985	0.174
15	0.966	0.259
20	0.940	0.342
25	0.906	0.423
30	0.866	0.500
35	0.819	0.574
40	0.766	0.643
45	0.707	0.707
50	0.643	0.766
55	0.574	0.819
60	0.500	0.866
65	0.423	0.906
70	0.342	0.940
75	0.259	0.966
80	0.174	0.985
85	0.087	0.996
90	0.000	1.000

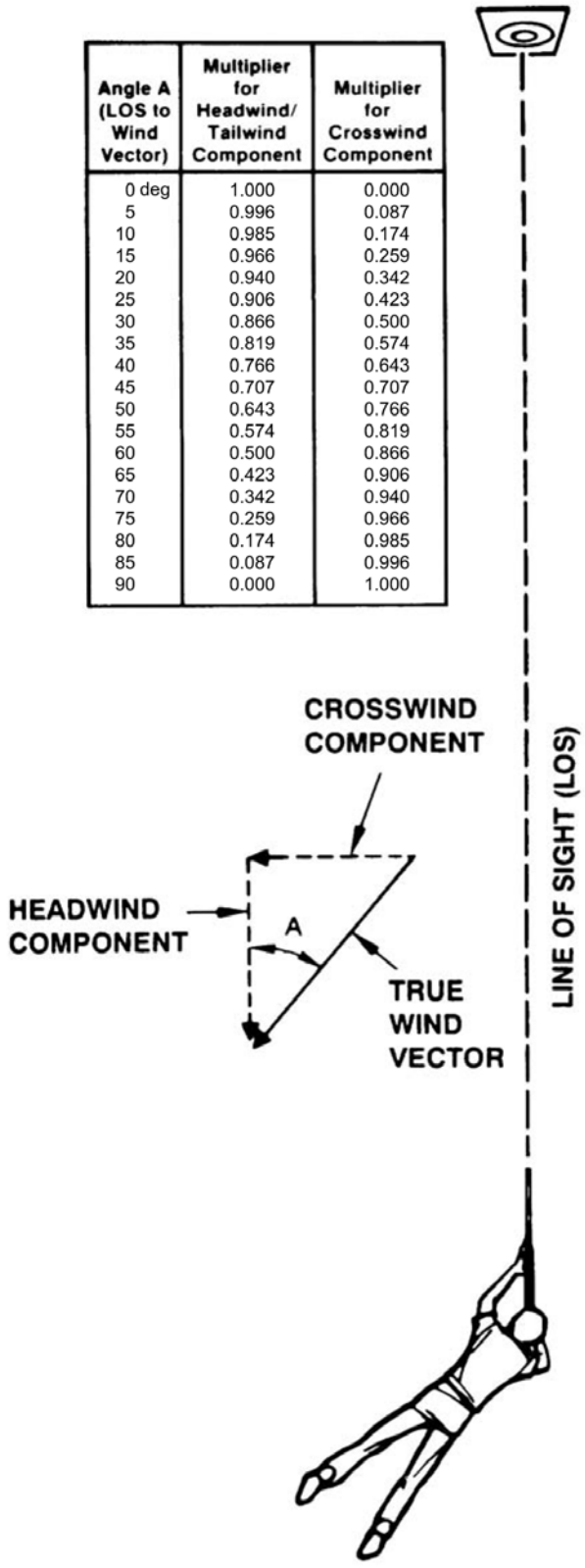


Figure 9: Separating a true wind into two components.

Before closing this section we should also note that it is possible to have vertical wind components as well as headwinds, tailwinds, and crosswinds. Vertical winds are mainly encountered when hunting in mountainous or hilly terrain; they are very seldom important in target shooting. The effect of a vertical wind component is just like the effect of a crosswind component except that it causes a vertical, rather than horizontal, deflection. Hunters should be aware that vertical wind components happen in canyons and close to steep hillsides and that they can cause a bullet to shoot high or low, just as a crosswind will cause it to shoot left or right.

EFFECTS OF UPHILL AND DOWNHILL SHOOTING

Ordinarily, a shooter will sight-in a gun on a range that is nearly level. If the gun is fired at a steep angle, either uphill or downhill, it will shoot high. Figure 10 shows how this happens. It illustrates three cases, sighting-in with level fire, shooting uphill, and shooting downhill.

When sighting-in, the shooter adjusts his or her sights so that the line of sight intersects the bullet trajectory at R, which is the range where he or she wants the rifle zeroed in. The distance between the line of departure (LOD), or bore line, and the line of sight (LOS) at R is the drop, D. We use this symbol to denote the amount of drop at the range where the rifle is zeroed-in.

Note that the angle between the bore line and the line of sight is actually very small. This angle is greatly exaggerated in Figure 10 for purposes of illustration. Even for long-range shooting, it is less than 1°, and it is typically $^1/_{60}$° for hunting rifles.

When the rifle is fired uphill or downhill, the true drop of the projectile measured at any slant range from the muzzle changes very little from the value at the same range under level fire. This is a key point. Drop is always measured in the vertical direction at the target. It is the vertical distance between the line of departure (direction of the rifle bore axis) and the bullet trajectory. Figure 10, on the next page, shows how true bullet drop is measured for level, uphill, and downhill shooting situations.

It seems to be true, in general, that at practical ranges for hunting and target shooting the change in vertical drop with firing elevation angle is negligible even for very steep angles. Despite the fact that drop changes very little with elevation angle, the bullet path height (distance of the bullet above or below the shooter's line of sight) does change a good deal. Consider the situation when the shooter fires the rifle uphill at a steep angle, as shown in Figure 10(B). Since the true bullet drop changes very little at a slant range distance R0 from the shooter, the bullet has a vertical drop essentially equal to d0, as shown in the figure. However, the line of sight at R0 is still located at distance d0 perpendicular to the line of departure. Because of the firing elevation angle, the bullet trajectory no longer intersects the line of sight at the range R0. In fact, the bullet

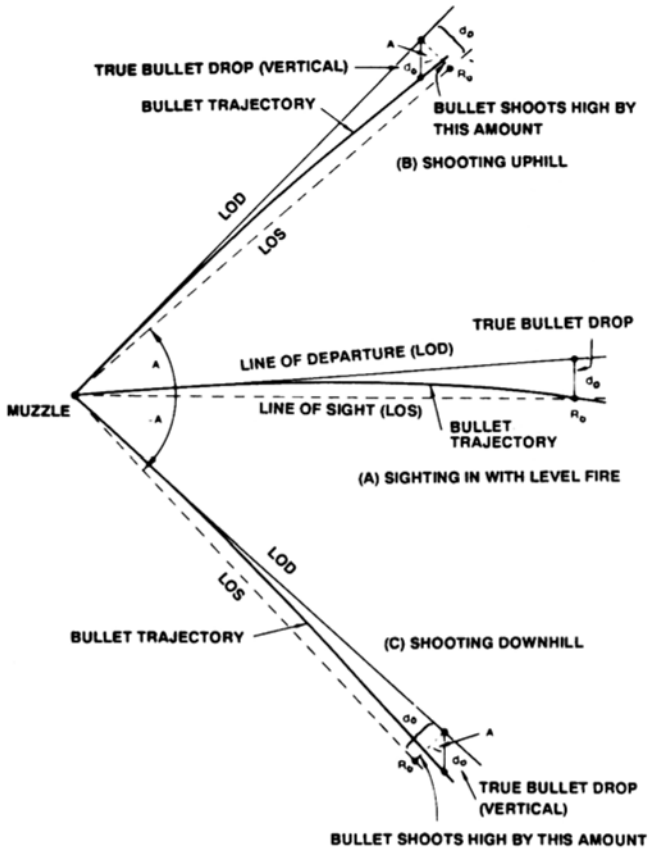


***Figure 10**: Projectile trajectories for (A) level shooting, (B) shooting uphill, and (C) shooting downhill.*

passes well above the line of sight at the point. In other words, the bullet shoots high from the shooter's viewpoint as the rifle is aimed. At steep angles it may shoot high by a considerable amount, as we will show shortly.

Figure 10(C) shows the situation when the shooter fires his or her rifle downhill. Again the vertical drop at the slant range distance R0 changes negligibly from the value d0 for level fire, but the line of sight and line of departure still are separated by the perpendicular distance d0. The bullet again passes above the line of sight, instead of intersecting it, at the range R0. Compared to the case of level fire, the bullet again shoots high from the shooter's viewpoint as the rifle is aimed. Furthermore, if the rifle is fired uphill at some elevation angle, and then fired downhill at the same elevation angle, the two bullets will shoot high by almost exactly the same amount.

It is reasonably easy to calculate how much higher a rifle will shoot for a given elevation angle. To do this, we need to know the bullet drop versus the range for the muzzle velocity used, and we can find this in the Ballistics Tables. The following table shows how much higher the bullet will shoot when aimed either uphill or downhill than it will when fired on a level:

Approximate Elevation Angle	Increase In Bullet Path Height
5°	0.004" D
10°	0.015" D
15°	0.034" D
20°	0.060" D
25°	0.094" D
30°	0.134" D
35°	0.181" D
40°	0.234" D
45°	0.293" D
50°	0.357" D
55°	0.426" D
60°	0.500" D

To use this table, we first look up the drop, D, for each range value of our load in the Ballistics Tables. Then, we calculate the increase in bullet path height for each elevation angle using the multiplying factors in the table. This tells us how much higher the bullet will shoot.

As an example, and to show how large an effect the firing elevation angle can have on typical projectile trajectories, the table in Figure 11 has been prepared for the example bullets in the preceding discussions. It is evident from the numbers in the table that steep firing angles can cause bullets to shoot quite high at ranges which are useful for hunting. Steep firing angles are likely to be encountered, of course, only by hunters in hilly or mountainous areas. These persons need to be aware of the tendency to shoot high when firing up or down a steep hillside. As the table shows, the amount by which the bullet shoots high is much less for bullets with high ballistic coefficients and high muzzle velocities. Nevertheless, this particular effect is important even for magnum cartridges when the range is long and the firing angle is steep. Consideration of this effect will improve any shooter's accuracy, especially at long ranges.

Projectile	Muzzle Velocity (fps)	Firing Elevation Angle (deg)	Amount by Which Projectile Shoots High at Slant Range (yards)					
			100	200	300	400	500	600
Lyman	1400	±15	0.35	1.67	4.30			
#454613		±30	1.40	6.57	16.93			
(265 gr)		±45	3.06	14.36	37.02			
Minie		±60	5.22	24.50	63.18			
Lyman	1600	±15	0.25	1.14	2.86	5.64		
#311466		±30	1.00	4.49	11.29	22.21		
(151 gr)		±45	2.19	9.81	24.68	48.57		
		±60	3.74	16.74	42.12	82.89		
Sierra	2600	±15	0.09	0.37	0.88	1.65	2.72	4.13
180 gr .308		±30	0.34	1.46	3.47	6.50	10.70	16.28
Spitzer		±45	0.74	3.18	7.58	14.22	23.40	35.61
Boat Tail		±60	1.26	5.43	12.94	24.26	39.93	60.76

Figure 11: Effects of uphill or downhill shooting on three bullets.

Using Ballistics Tables

A brief explanation of terms used in ballistics tables is given in this section. Many shooters are already familiar with these terms. For those who are not, the explanations may be helpful in improving their skills. At the end of this section, two procedures are explained which all shooters may find useful. The first is how to use the tables to determine where your gun will shoot if you choose a different zero range than the one in the tables. The second is the method you can use to maximize point-blank range for your load.

DEFINITION OF TERMS

TRAJECTORY. The trajectory of a projectile is the actual path which that projectile follows after leaving the muzzle of a firearm. Figure 12 illustrates a projectile trajectory. As soon as the projectile leaves the muzzle of the gun, gravity causes it to fall away from its line of departure.

This causes the drop discussed later. The line of departure is an imaginary line extending along the bore in the direction that the bullet travels. Muzzle velocity, air drag, and gravity are the major contributors to shaping the trajectory. If a crosswind blows, the projectile trajectory will also be curved in the direction of the wind.

In order to give some specific examples of the meaning of terms in ballistics tables, let us suppose that we are shooting the Lyman paper-patched, #301618 bullet loaded to a muzzle velocity of 2,400 feet per second. The numerical data from the ballistics table for this bullet at this muzzle velocity will be used to illustrate the following discussion.

VELOCITY. Velocity is the speed of the projectile as it moves along its trajectory. Velocity is measured in feet per second. The projectile moves slower and slower as it flies farther and farther from the muzzle, because air drag slows it down. The velocity of the projectile is listed in the ballistics table at each value of range from the muzzle. For example, our .30-caliber bullet fired at 2,400 fps muzzle velocity has a remaining velocity of 2,265 fps at 50 yards from the muzzle, 2,135 fps at 100 yards, 2,009 fps at 150 yards, and so forth.

ENERGY. A moving bullet has *kinetic energy*, that is, energy of motion. Usually the term kinetic is dropped and we speak simply about *bullet energy*. The notion of energy is closely related to the concept of bullet momentum, although energy is the usual variable listed in ballistics tables.

Physically, momentum is the mass of a bullet multiplied by its velocity. The mass of a bullet is its weight in pounds divided by the acceleration due to gravity. Since bullet weights are given in grains, we first have to convert grains to pounds. The mass calculation is expressed by the following equation:

$$M = \frac{W}{7{,}000 \times 32.174} = W$$

where M is the bullet mass and W is bullet weight in grains. The factor 7,000 converts grains to pounds, and

32.174 fps is the acceleration due to gravity. After mass has been calculated, momentum is found by multiplying mass times velocity:

$$\text{Momentum (lb-sec)} = M \times V$$

where V is bullet velocity in fps, and the units of momentum are pound-seconds (lb-sec).

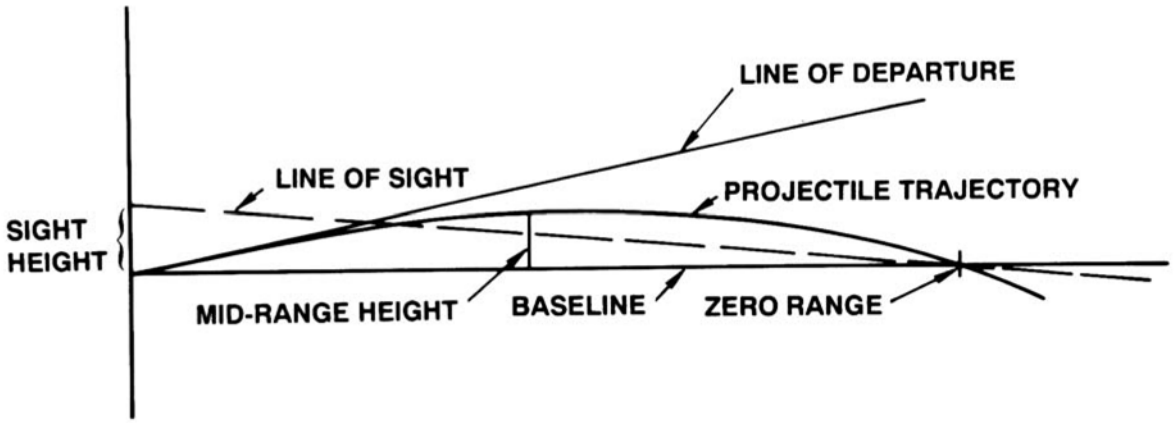


Figure 12: Parts of a trajectory.

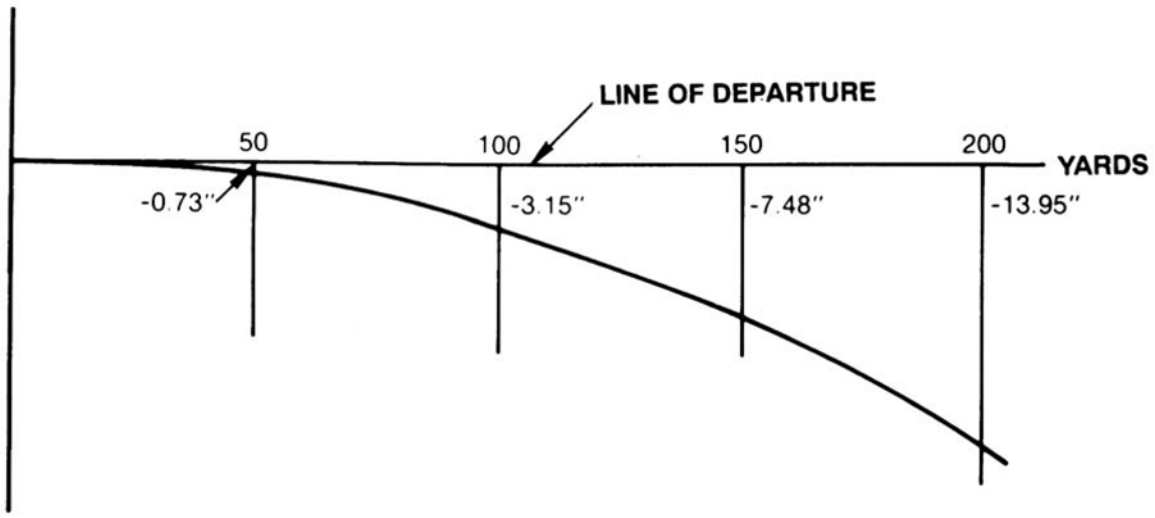


Figure 13: Bullet drop.

Bullet kinetic energy is bullet momentum multiplied by half the velocity:

$$\text{Energy} = \text{Momentum} \times \frac{V}{2}$$

$$\frac{W \times V \times V}{450{,}437} \text{(ft.-lbs.)}$$

where, again, W is bullet weight in grains and V is bullet velocity in fps at any point in flight where energy is to be calculated. There is also a small amount of kinetic energy associated with a bullet's spinning motion. However, this is negligible compared to the kinetic energy associated with its linear velocity, and it is almost never considered. The units of kinetic energy are foot-pounds (ft-lbs).

The ballistics table for our example #301618 bullet at 2,400 fps muzzle velocity shows that the muzzle energy is 2,046 foot-pounds. At 50 yards it drops to 1,823 ft-lbs and at 100 yards to 1,619 foot-pounds. At longer ranges the energy continues to drop off. This happens because bullet velocity grows progressively smaller.

DROP. When a projectile leaves the muzzle it begins to drop, just as it would if we were to hold it up and then let it go. It drops with just about the same speed when it is fired as it would if we dropped it. There are some aerodynamic forces acting on the projectile when it is fired which keep it from falling quite as fast, and these have been taken into account in calculating ballistics tables.

If you sit on the side of a hill and fire your rifle so that the line of departure is level, then Figure 13 shows how far below the line of departure your bullet will be at each specific range. Drop is usually measured in inches, although at long ranges from the muzzle it can grow to several feet. The minus signs on ballistic table drop values usually signify that the trajectory passes below the line of departure.

When we zero-in a rifle or handgun, we adjust the sights to tilt the barrel up, or elevate the line of departure. When we have just the right amount of tilt, the trajectory is rotated upward to the point where the projectile just crosses the level baseline at the desired zero range. Then, the line of departure is above the baseline by the amount of drop at the zero range.

Figure 14, on next page, shows this situation for our example bullet. When the barrel of the rifle is tilted upward so that the line of departure passes 3.15" above the baseline at 100 yards, then the #301618 bullet at 2,400 fps muzzle velocity will be zeroed-in at 100 yards.

MIDRANGE. When a rifle or handgun is zeroed-in at some particular range, as in Figure 14, the bullet passes above the baseline at ranges shorter than the zero range. The projectile reaches its maximum height above the baseline at a range which is very near the midpoint between the muzzle and the zero range. We call the height of the trajectory at that midpoint the *midrange height* or, more frequently, the *midrange*. The midrange is near the maximum height the projectile reaches in its flight between the muzzle and the zero range.

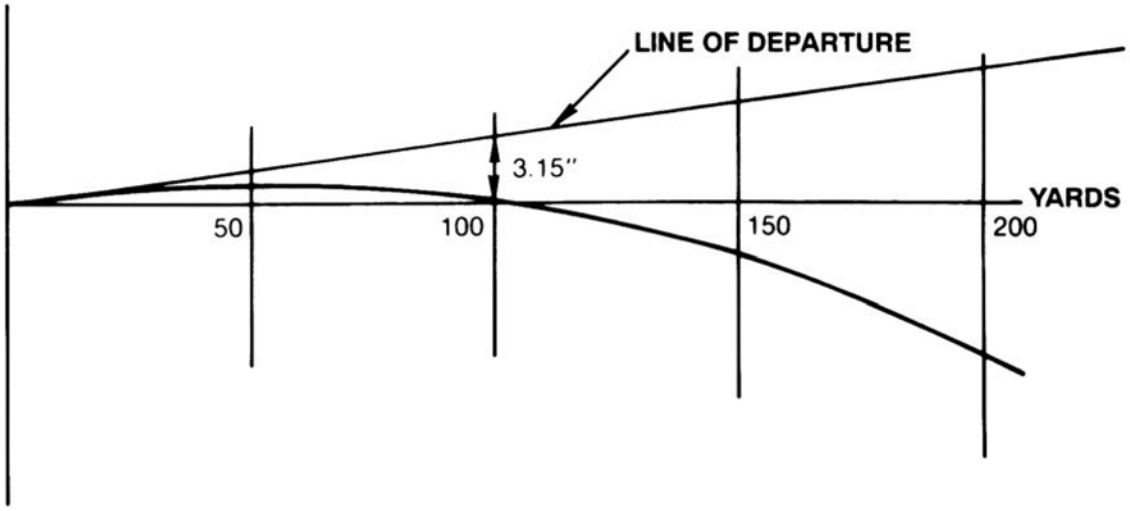


Figure 14: Zeroing-in.

Figure 15 illustrates two midrange values for bullet #301618 at 2,400 fps muzzle velocity. If the rifle is zeroed-in at 100 yards, the midrange is 0.84" and occurs at a distance of 50 yards from the muzzle. If the rifle is zeroed-in at 200 yards, the midrange height is 3.81" at 100 yards.

In ballistics tables, a midrange value is quoted at each range entry. In every case, this is the midrange height of the trajectory if the gun is zeroed-in at the range value at the top of the column. The midrange height always occurs at a distance halfway between the muzzle and the zero range. Midrange height is important for a couple of reasons. It tells a shooter how high the bullet will rise above the line between the muzzle and the target, and it is the trajectory parameter used to get the minimum point-blank-range performance from the rifle, as we'll explain later.

BULLET PATH. The sights on a rifle or handgun are mounted above the bore. This distance between the centerline of the bore and the line of sight is called the sight height. The sight height on a rifle with iron sights is about 0.75 inch. For a rifle with a telescope sight, the *sight height* is about 1.5 inches.

Figure 16, shows the relationship of the line of sight to the baseline and the trajectory. The numerical values given in Figure 16 are for our example #301618 bullet at 2,400 fps muzzle velocity. When the gun is zeroed-in, the line of sight intersects the baseline and the trajectory at the zero range. A shooter's real interest is where the bullet is relative to the line of sight, rather than the baseline. This is called the *bullet path height*, usually shortened to bullet path. As shown in Figure 16, the bullet leaves our rifle 0.75" below the line of sight. So we say that the bullet path is -0.75" at the muzzle. Since we have

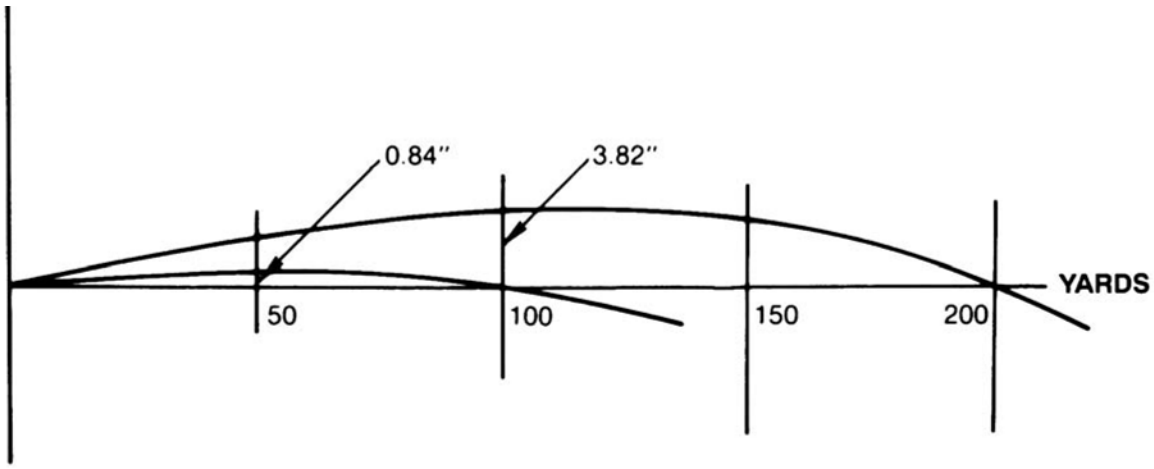


Figure 15: Midrange chart.

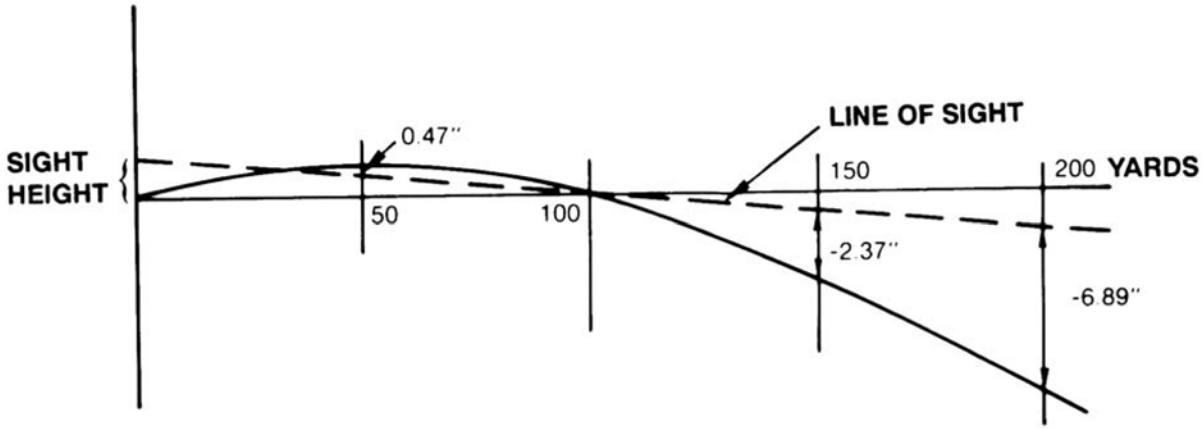


Figure 16: Bullet-path chart.

our rifle zeroed-in at 100 yards, the bullet is above the line of sight by 0.47" at 50 yards, right on target at 100 yards, 2.37"low at 150 yards, and so forth.

TIME OF FLIGHT. When a projectile leaves the muzzle, it requires a certain amount of time to reach a target. This is called the *time of flight*, and it depends on both distance to the target and muzzle velocity. The farther away the target is, the more time is required to reach it. The higher the muzzle velocity, the shorter the time of flight. Ballistic tables usually list the time of flight to reach each range for each muzzle velocity case. Our example bullet which leaves the muzzle at 2,400 fps requires 0.064 second to reach 50 yards, 0.133 second to reach 100 yards, 0.205 second to reach 150 yards, and so on.

WIND DEFLECTION. Projectiles are very susceptible to crosswinds. For that reason the deflections caused by crosswinds are often listed in ballistics tables for each muzzle velocity level.

A crosswind tends to drag the projectile along with it, so the deflections can be to the right or left. For our example bullet, a 5 mph crosswind will carry the bullet sideways 0.66" at 100 yards and 2.82"at 200 yards. If the crosswind is 30 mph, these deflections grow to 3.98" at 100 yards and 16.91" at 200 yards.

It is evident from the sizes of the wind deflections that strong crosswinds can cause very large misses if windage corrections are not made. This data may help shooters select loads and improve their abilities for windy-day shooting.

POINT-BLANK RANGE

Trajectory flatness really has little significance for target shooting. Target ranges are known exactly, and target guns can be sighted-in well before competition begins. On the other hand, trajectory flatness is very important to the hunter. Game may step out at any range, and in the field, ranges are often hard to estimate. *Point-blank range* is a concept used for many years by hunters. The point-blank range of any gun is the distance to which a hunter can hold right on the game and be able to hit within a vital zone of the animal. As long as the animal is within the point-blank range, the hunter does not have to hold high or low to correct for bullet trajectory. It turns out that the point-blank range of any load can be maximized for a given size animal by simply choosing the right zero range for the gun. When this is done, the hunter gets the best performance from his or her gun. The point-blank range is a very practical measure of how flat the gun can really shoot.

Point-blank range depends on the size of the game animal, because the size of the vital zone varies from one animal to another. On a deer-sized animal, as illustrated in Figure 17, on next page, the vital zone should be centered about the middle of the front shoulder, when the animal is viewed broadside. The top of the zone would be at the top of the shoulder. At the bottom of the vital zone would be the front leg or lung area. The vital zone vertical dimension is then about 10" for medium-game animals. On a varmint-sized animal, the vital zone might be only 3"-4" in height, and on a big-game animal it might extend 15 inches.

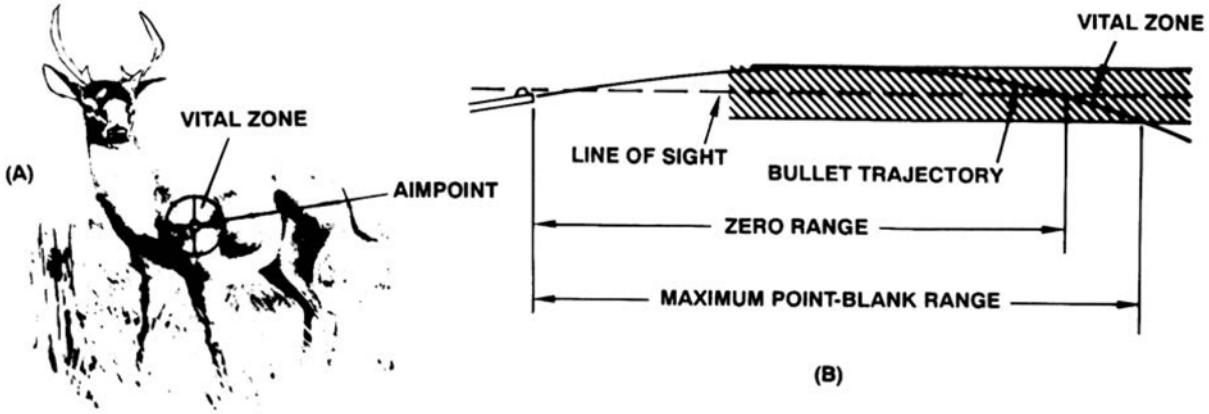


Figure 17: *The point-blank range concept. (A) The vital zone of a deer. (B) Maximizing the point-blank range.*

Figure 17 shows how to get maximum point-blank range. If the hunter aims at the center of the vital zone, the bullet must not rise higher than the top edge anywhere in its trajectory. If the bullet does rise above the line marking the top of the vital zone, the hunter will shoot high if the game steps out at short range. When the bullet crosses the line marking the bottom edge of the vital zone, the crossing point is the point-blank range for the load, as shown in Figure 17. The point-blank range is maximized when the bullet rises just far enough to touch the line marking the top edge of the vital zone, and no higher or lower.

The procedure for maximizing the point-blank range has five steps. Following these steps will determine the right zero range to use and also determine how large the maximum point-blank range is. These five steps are as follows:

1. Estimate the vital zone vertical dimensions for the game you intend to hunt. The following guidelines may help:

Varmints and small game (squirrels, cottontails, jackrabbits, woodchucks, etc.)	3" – 5"
Light game (small deer, javelina, etc.)	6" – 8"
Medium game (white-tailed deer, mule deer, black bear, etc.)	10"
Large game (elk, moose, etc.)	15"

2. Take half the vital zone dimension and then add a correction for the height of the sights on your rifle. If you use iron sights, this correction is 0.4"; if you have a telescope sight, the correction is 0.8 inch. This number is the midrange height your bullet should have to maximize the point-blank range.

3. Turn to the ballistics table for your bullet and muzzle velocity. Look across the midrange values in the table to find the amount you calculated in the preceding step. Usually, you will not find the exact value you want in the table, so you will have to interpolate between a couple of points in the table. The following example will show how to do this. Once you have found the right midrange height, the range value for which this midrange height occurs is the zero range that you want to use.

4. Zero-in your rifle at the range found in the previous step. Usually the zero range that you want to use will not be the one listed in the ballistics tables, and you will need to use a procedure like the one described in the preceding section.

5. When your rifle is zeroed-in, add 40 yards to the zero range you determined in Step 3. This result is the maximum point-blank range for your cartridge load.

As an example of how to use this procedure, suppose that you intend to hunt Eastern white-tailed deer with a telescope-sighted .308 Winchester. You decide to use the Lyman #301618 paper-patched, 160-grain bullet loaded to a muzzle velocity of 2,400 fps, and you want to maximize your point-blank range for this load.

Example calculation:

Cartridge:	.308 Winchester with Lyman #301618 paper-patched, 160-bullet
Muzzle Velocity:	2,400 fps
Sight Height:	1.50" (telescope sight)

1. The adult Eastern white-tailed deer is a medium-game animal, and the vital zone of the animal is about 10" in height.

2. Half the vital zone height is 5 inches. The sight- height correction for your telescope sight is 0.8 inch. Adding

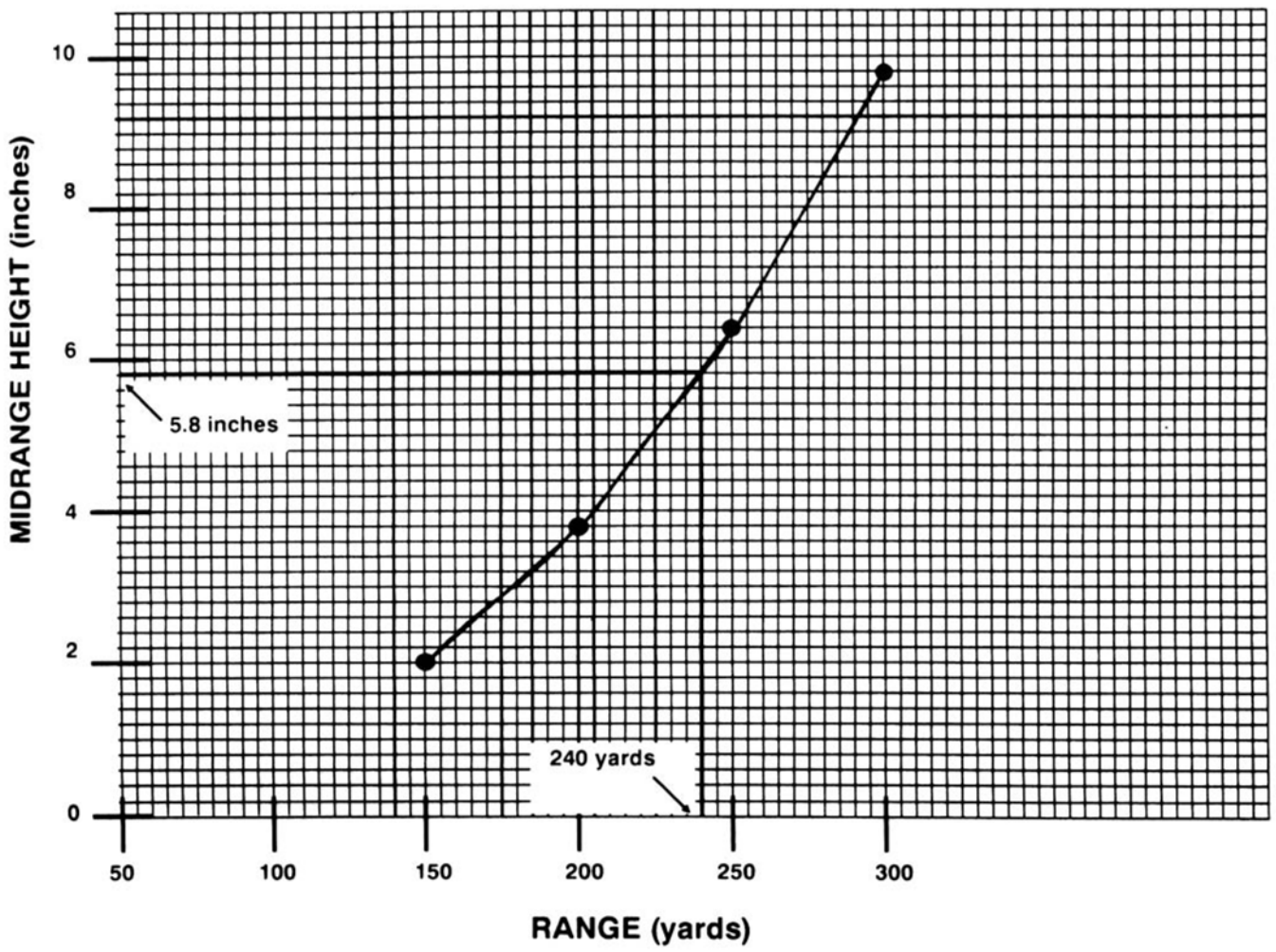


***Figure 18**: Midrange height vs. range graph.*

these two figures gives 5.8" which is the midrange height you need to find in the ballistics table for your bullet and muzzle velocity.

3. The ballistics table for the bullet at 2,400 fps shows that at a range of 200 yards, the midrange height is 3.82" and at 250 yards the midrange height is 6.36 inches. Since the midrange height you need is 5.8", it must occur for a range value between 200 and 250 yards, and we need to use interpolation to find the right value. For this, we can use rectangular graph paper to construct a curve from which we read the answer we are looking for (Figure 18).

   The vertical scale of the graph paper is midrange height, and the horizontal scale is the range. We must select four points — two between 150 and 300 yards, in which the answer must lie, and the other two between 250 and 300 yards. We plot the four midrange heights from the ballistics tables: 2.02" at 150 yards, 3.82" at 300, 6.36" at 250, and 9.79" at 300 yards. Then we draw a smooth curve through the four points. Looking to see where the curve crosses the line representing the 5.8" midrange height, we find the crossing at a range of 240 yards. This is the right zero range to use to maximize point-blank range for white-tailed deer with your load.

4. You must take your rifle out and zero it in for the 240-yard zero range. This is not a very convenient zero range to use if you must use a public shooting range or club because these places normally have targets at 100 and 200 yards. The preceding section gave a procedure for figuring out where your rifle should shoot at a range of 200 yards in order to be zeroed-in at 240 yards, and the result is 3.2" high. You can always use a procedure like the one in the last section to find a way to zero-in your rifle at any range.

5. Now that you have your rifle zeroed-in for 240 yards, adding 40 more yards makes your point-blank range 280 yards, and it is the maximum that your load will produce for medium game. If you see a white-tailed buck at any range up to 280 yards, you can center him in your sights and not worry about holding high or low to correct for bullet trajectory. And 280 yards is quite a respectable point-blank range!

NOTE: Many reloading manuals and other sources of ballistic tables may follow a different format. The information in this lesson should not be considered the only way to use these tables. However, this information should help you to interpret the data in other tables.

SELF-TEST QUESTIONS

Please check your answers on page 23.

5. ***True or False*. If a shooter shoots either uphill or downhill, the shot will normally be high.**
6. **What is the name given to the actual path of a fired bullet?**
7. **What important factors must be taken into consideration when determining point-blank range?**
8. **What is the vital-zone area of large game such as elk, moose, etc.?**

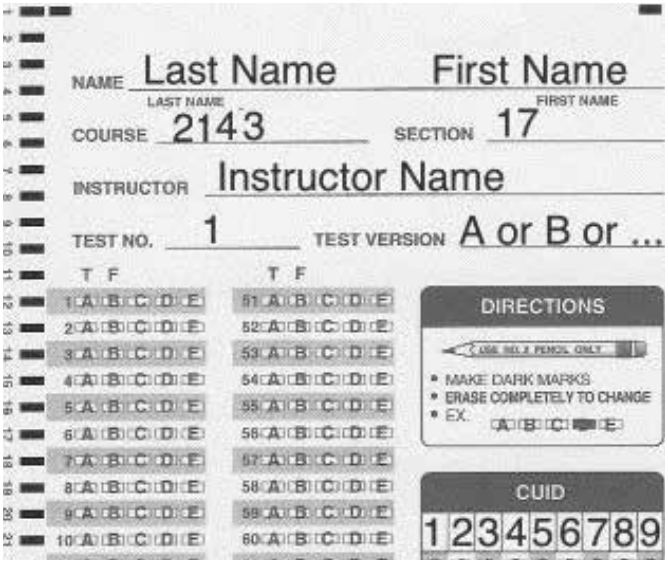
Answers to Self Test Questions

1. True.
2. Ballistic pendulum.
3. Benjamin Robins.
4. The ballistics factor that relates the drag deceleration of an actual bullet to the drag deceleration of the standard bullet.
5. True.
6. Trajectory.
7. The type and size of the target.
8. 15 inches.

Lesson Questions

THIS IS LESSON NUMBER 2199.

Make sure you print your name, student number, and lesson number in the space provided on the Lesson Answer Form. Be sure to fill in the circles beneath your student number and lesson number.



REMINDER: A properly completed Lesson Answer Form allows us to evaluate your answers and send the results and additional study material to you. Do not hold your Lesson Answer Forms to send several at one time. You may run out of study material if you do not send your answers for evaluation promptly.

You may also complete your exam online at www.sdi.edu, click on the *online exams* tab.

1. **Ballistics deals with**
   a. The science of moving projectiles.
   b. Hand-loading centerfire ammunition.
   c. The heat-treatment of metal.
   d. Hand-loading rimfire ammunition.

2. **After a bullet leaves the rifle barrel, what two forces act on the bullet's trajectory?**
   a. Heat and wind pressure.
   b. Wind velocity and ambient temperature.
   c. The breech pressure and gravity.
   d. Gravity and the force due to the air flow around the bullet.

3. **Who invented the ballistic pendulum in the year 1740?**
   a. Tartaglia.
   b. Galileo.
   c. Robins.
   d. da Vinci.

4. **The ballistic pendulum was based upon laws of mechanics formulated by:**
   a. da Vinci.
   b. Galileo.
   c. Sir Isaac Newton.
   d. Robins.

5. **What is the name of the test data, compiled in Germany in 1881 that turned out to be the basis for ballistics tables for small arms right up to the present time?**
   a. Sharpe test data.
   b. Krupp test data.
   c. Sauer test data.
   d. Hunt test data.

6. **What is the altitude used for most ballistics tables?**
   a. 1,000 feet.
   b. 2,000 feet.
   c. Sea level.
   d. 500 feet.

7. **A bullet's reaction to wind depends on what two factors?**
   a. Speed and direction of the wind.
   b. Altitude and ambient temperature.
   c. Altitude and barometric pressure.
   d. Temperature and barometric pressure.

8. **In what type of terrain are vertical winds usually encountered?**
   a. Flat desert areas.
   b. Coastal areas.
   c. Mountainous or hilly areas.
   d. Flat wood lots.

9. When shooting uphill, the gun will shoot

a. Low.

b. High.

c. To the left.

d. To the right.

10. When shooting downhill, the gun will shoot:

a. Low.

b. High.

c. To the left.

d. To the right.