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This paper describes the internal, external, and terminal ballistics of the 30-06 rifle cartridge. With cartridge case capacity of 68-70 grains of water and operating pressures up to 60,000 psi, the 30-06 launches 110-220 grain bullets with muzzle velocities between 3400 fps and 2400 fps, respectively. Low-drag bullets are available which make the 30-06 an effective and capable choice for target and anti-personnel use out to 1000 yards, but longer range applications are challenging due to the sonic transition. With an appropriate bullet choice, the 30-06 penetrates a variety of commonly encountered barriers. It also penetrates soft body armors and can deliver significant wounding effects even when stopped by hard body armor. At shorter ranges, wounding effects in human and deer-sized living targets are impressive and yield rapid incapacitation.					
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# Ballistics of the 30-06 Rifle Cartridge

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**Abstract:** This paper describes the internal, external, and terminal ballistics of the 30-06 rifle cartridge. With cartridge case capacity of 68-70 grains of water and operating pressures up to 60,000 psi, the 30-06 launches 110-220 grain bullets with muzzle velocities between 3400 fps and 2400 fps, respectively. Low-drag bullets are available which make the 30-06 an effective and capable choice for target and anti-personnel use out to 1000 yards, but longer range applications are challenging due to the sonic transition. With an appropriate bullet choice, the 30-06 penetrates a variety of commonly encountered barriers. It also penetrates soft body armors and can deliver significant wounding effects even when stopped by hard body armor. At shorter ranges, wounding effects in human and deer-sized living targets are impressive and yield rapid incapacitation.

**Keywords:** 30-06, bullet, trajectory, muzzle velocity, impact energy, temporary cavity, wound ballistics, hydrostatic shock

## I. Introduction

The 30-06 has a long history as an effective cartridge for military applications and still finds occasional use in law enforcement and self-defense. Introduced in 1906 in the 1903 Springfield bolt-action rifle and later chambered in the semi-automatic M1 Garand rifle, it served as the primary rifle cartridge for the US military for nearly 50 years and continued to find use in US Marine sniper rifles (Winchester Model 70 bolt action) until well into the Vietnam war. The M24 sniper rifle (Remington 700 bolt action) in current service by the US Army was originally specified to use the 30-06 cartridge, but was later changed to the 7.62x51mm and .300 Winchester Magnum cartridges.

The United States Air Force Academy Cadet Honor Guard still carries M1 Garand Rifles chambered in 30-06, (1) and rifles chambered in the cartridge also still see wide use in ROTC drill and training. The Civilian Marksmanship Program (CMP), chartered by the U.S. Congress to promote marksmanship among civilians who might be later called to serve in the U.S. Military, distributes surplus Model 1903 Springfield, Model 1917 Enfield, and M1 Garand rifles chambered in 30-06 and sees a considerable demand for these rifles, as well as 30-06 ammunition. (2)

Bullet Weight (grains)	Hodgdon (3) velocity (fps)	Speer (4) velocity (fps)	Hornady (5) velocity (fps)	Nosler (6) velocity (fps)	Barnes (7) velocity (fps)
110	3505	3356	3500	N/A	3471
125/130	3334	3129	3200	3258	3278
150	3068	2847	3000	3000	3031
165	2938	2803	2900	3002	2980
180	2798	2756	2800	2872	2799
200	2579	2554	N/A	2688	2680
220	2476	N/A	2500	2602	2415

*Table 1: Maximum 30-06 muzzle velocities reported by several reloading manuals for common bullet weights. Hodgdon, Nosler, and Barnes report velocities for 24" barrels. Hornady and Speer report velocities for 22" barrels. The data are all for barrels with a twist rate of 1 turn in 10" which is needed to stabilize the heaviest bullets. The higher muzzle velocities reported by Nosler for 165 grain and heavier bullets use loads employing a slow-burning, double-base powder (Alliant Reloder 22). We have not been able to reproduce these high velocities. Available commercial and peak hand loaded muzzle velocities are also shown in Figure 2.*

The ballistics of the 30-06 make it popular target cartridge and an effective hunting round for

## Ballistics of the 30-06 Rifle Cartridge

everything from groundhogs to deer to elk to bear. (4) With 150-180 grain bullets it typically offers 100 fps more velocity than the .308 Winchester and 200-250 fps less than the .300 Winchester Magnum. In the M1 Garand, the 30-06 is regarded as effective to 440 yards for military use, and the challenge of hitting game animals at longer ranges makes this a sensible maximum hunting range in the hands of most hunters. With care and skill it can be employed at longer ranges in special purpose long-range rifles. Gunnery Sgt. Carlos Hathcock had numerous kills at longer ranges using a Winchester Model 70 chambered in 30-06 while serving in Vietnam. (8) With quality expanding bullets that transfer energy effectively, it provides devastating terminal performance on small to medium sized game including good penetration, large wound channels, and remote wounding effects known as hydrostatic shock. Wide availability of ammunition and rifles, combined with excellent ballistics and terminal performance, make the 30-06 rifle cartridge among the most popular in the world. (9) (10)

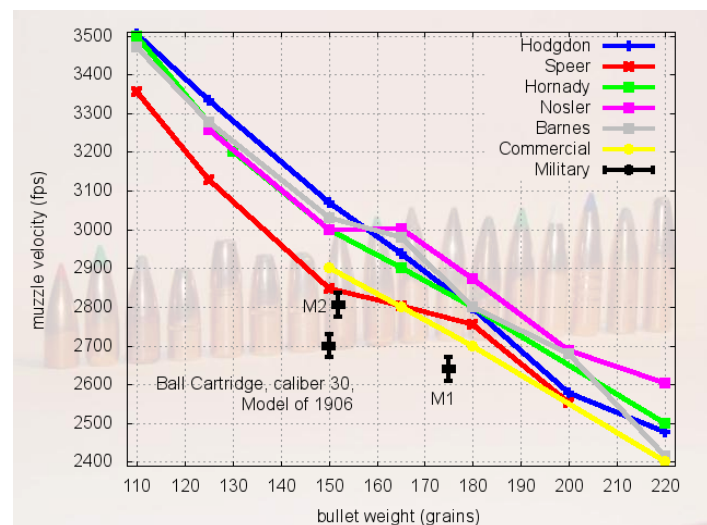


Figure 2: Maximum muzzle velocities reported by several reloading manuals together with typical velocities reported for commercially available loads in common bullet weights. Some well-known military loads are also shown. Background shows assortment of .308" bullets from 110 grains (left) up through 220 grains (right).

### II. Internal Ballistics

The 30-06 cartridge case has an internal capacity of 68-69 grains of water. Early military loads propelled a 150 grain bullet at 2700 fps ("Ball Cartridge, caliber 30, Model of 1906"). In 1926, a 172 grain boat tail

bullet was loaded to 2700 fps ("Ball, caliber 30, M1"). Velocity was later reduced to 2640 fps because of difficulties maintaining the pressure specifications at the higher velocity with available powders. A new 152 grain load was introduced in 1940 ("Cartridge Ball, caliber 30, M2") which was widely used in World War II because of good functioning in the M1 Garand rifle. (11)

The maximum pressure allowed by Sporting Arms and Ammunition Manufacturer's Institute (SAAMI) specifications is 60,000 psi or 50,000 cup. With modern powders, many commercial loads are available that provide 2900 fps for 150 grain bullets, 2800 fps for 165 grain bullets, and 2700 fps for 180 grain bullets (in a 24 inch barrel). 125 grain bullets can be pushed to 3150 fps. 220 grain loads typically achieve 2400 fps. Lighter, lower velocity loads are also available to provide reduced recoil.

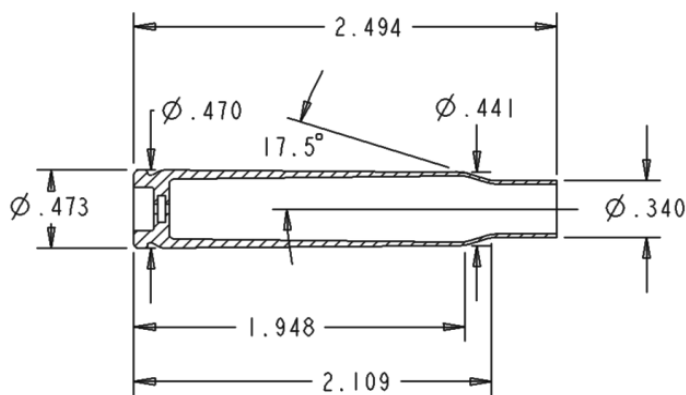


Figure 3: Drawing showing the dimensions of the 30-06 brass cartridge case (all dimensions in inches). (12)

Hand loading the 30-06 provides a broader variety of bullet weights and sometimes slightly higher muzzle velocities. Table 1 shows peak muzzle velocities listed by several reloading manuals for various bullet weights. Most 30-06 loads use large rifle or large magnum rifle primers. Both ball (spherical) and cylindrical (extruded) powders are commonly used, as well as single-base (nitrocellulose only) and double-base (nitrocellulose and nitroglycerine) powders. Powders with a wide range of powder burn rates are commonly employed, including powders with burn rates as fast as Reloder 7 and IMR 4198 and as slow as VihtaVuori N165 and Reloder 22. Hodgdon has also published several low-recoil loads

## Ballistics of the 30-06 Rifle Cartridge

for youth use and target practice using H4198 and 125-135 grain bullets. (13)

According to the Barnes Reloading Manual Number 2, the 30-06 cartridge case capacity of 68.0 grains of water falls between the 7.62x51mm (.308 Winchester) with a capacity of 53.5 grains of water and the .300 Winchester Magnum with a capacity of 90.4 grains of water. (7) Other sources give slightly different case capacities, so case capacities we have measured are shown in Table 2. Case capacity varies slightly by manufacturer and lot number of the brass cartridge case, as well as whether it is determined in new brass or brass that has been fired.

Cartridge	7.62x51mm/ .308 Winchester (grains)	30-06 (grains)	.300 Winchester Magnum (grains)
Barnes Manual	53.5	68	90.4
Remington Brass	56.82	69.86	N/A
Hornady Brass	N/A	70.69	N/A
Federal Brass	55.51	69.17	N/A
Lapua Brass	56.25	70.20	N/A
Nosler Brass	N/A	N/A	94.6

Table 2: Measured internal cartridge case capacities of fired brass compared with measurements reported in Barnes Reloading Manual Number 2.

Figure 3 compares muzzle velocities commonly available in commercial loads for the 7.62x51mm NATO (.308 Winchester), the 30-06, and the .300 Winchester Magnum in typical bullet weights. As with the 30-06, slightly higher (3-5%) muzzle velocities are often available by hand loading. The availability of a military .300 Winchester Magnum load of a 220 grain bullet at 2850 fps is also notable, but this load exceeds the SAAMI peak pressure (62,000 psi) for this cartridge at 68,100 psi. (14)

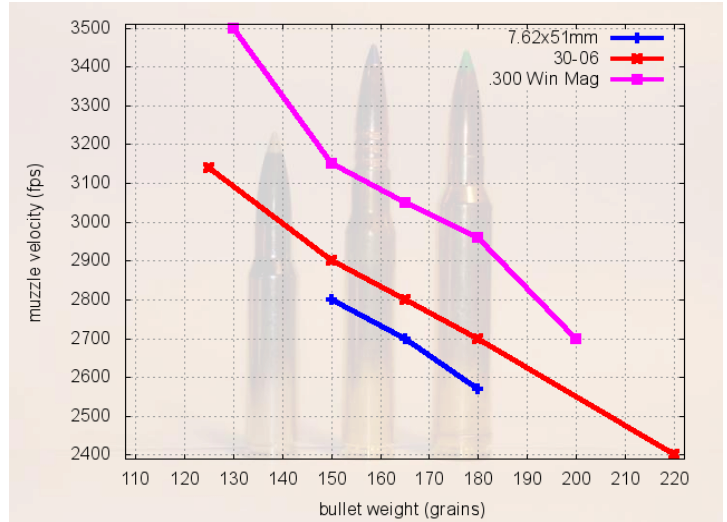


Figure 3: A comparison of available muzzle velocities in 7.62x51mm, 30-06, and .300 Winchester Magnum in commonly available bullet weights. Background shows photograph of .308 Winchester (left), 30-06 (middle), and .300 Win Mag (right) rifle cartridges.

### III. External Ballistics

External ballistics is dominated by a bullet's muzzle velocity and ballistic coefficient, with rifle twist and bullet length also playing a role. This section discusses the issues of twist rates and bullet stability, bullet drop and wind drift, spin drift, and the velocity and kinetic energy retained by a bullet downrange. The broad selection of bullet weights and profiles available for the 30-06 provide a wide range of performance in the area of exterior ballistics.



Figure 4: An assortment of 0.308" diameter bullets available for the 30-06. Left to right: Hornady 110 VMAX, Nosler 125 Ballistic Tip, Hornady 130 SP, Speer 130 FP, Barnes 150 XFP, Speer 150 FP, Hornady 150 RN, Hornady 150 FMJBT, Nosler 150 Ballistic Tip, Nosler 150 E-Tip, Berger 155.5 FBBT, Hornady 165 BTSP, Nosler 165 Ballistic Tip, Nosler 165 Accubond, Barnes 168 TTSX, Speer 200 SP, Nosler 220 Partition SP. Numbers give bullet weight in grains.

# Ballistics of the 30-06 Rifle Cartridge

## 1. Rifling Twist Rates and Bullet Stability

Just as a football must spin in a spiral to fly point forward rather than tumbling end-over-end, a bullet in flight requires a specific rate of spin to prevent tumbling. This spin is imparted by the barrel's rifling, and the rate of spin required for stability depends on a number of complex factors related to air drag and the bullet's moments of inertia about the axes parallel and perpendicular to its symmetry axis. A bullet's stability in flight is analogous to a spinning top. Just as a top that spins too slowly or not at all will fall over due to the force of gravity a bullet that spins too slowly or not at all will tumble end over end due to the force of air drag.

Conservation of angular momentum gives a bullet a certain amount of gyroscopic stability that makes its axis rigid or resistant to being affected by the overturning aerodynamic torque. Just as a bicycle is easier to balance when the wheels are spinning faster, a bullet spinning faster is harder to upset. A bullet's stability,  $S_g$ , is the ratio of the rigidity of the axis of rotation to the magnitude of the overturning aerodynamic torque. (15) More simply stated, stability is the ratio of the tendency to remain point forward to the tendency to tumble in flight. In a perfect world, any stability greater than 1.0 would ensure stable flight. Owing to imperfections in bullet construction, barrel manufacturing, knowledge of atmospheric conditions, and the uncertainty of the formulas, experts recommend selecting a twist rate that provides  $S_g$  greater than or equal to 1.4 to ensure stable flight.

Because a bullet's moments of inertia are not generally known or easily obtainable, a number of formulas have been offered in attempts to reliably estimate bullet stability (or required rifling twist rate) from easily available bullet parameters such as weight, length, and muzzle velocity. The Greenhill formula was widely used for many decades, but the Miller formula for bullet stability has been shown to be more accurate and widely applicable for supersonic flight. (16) (17) The Miller formula for bullet stability is

$$S_g = \frac{30m}{t^2 d^3 l (1+l^2)} \times \left( \frac{V}{2800} \right)^{\frac{1}{3}} \times \frac{(FT + 460)}{(59 + 460)} \frac{29.92}{PT},$$

where  $m$  is the mass of the bullet in grains,  $t$  is the twist of the barrel in calibers per turn,  $d$  is the diameter (caliber) of the bullet in inches,  $l$  is the length of the bullet in calibers,  $V$  is the muzzle velocity of the bullet in feet per second,  $FT$  is the ambient temperature in degrees Fahrenheit, and  $PT$  is the air pressure in inches of mercury. The first factor in this complex equation,  $\frac{30m}{t^2 d^3 l (1+l^2)}$ , is

simply the uncorrected stability, or the stability at a muzzle velocity of 2800 fps and a standard atmosphere of 59 degrees F and 29.92" of mercury. This part of the formula shows that other factors being equal, stability decreases with bullet length, increases with mass, and that a faster twist rate (smaller  $t$ , fewer calibers per turn) increases stability.

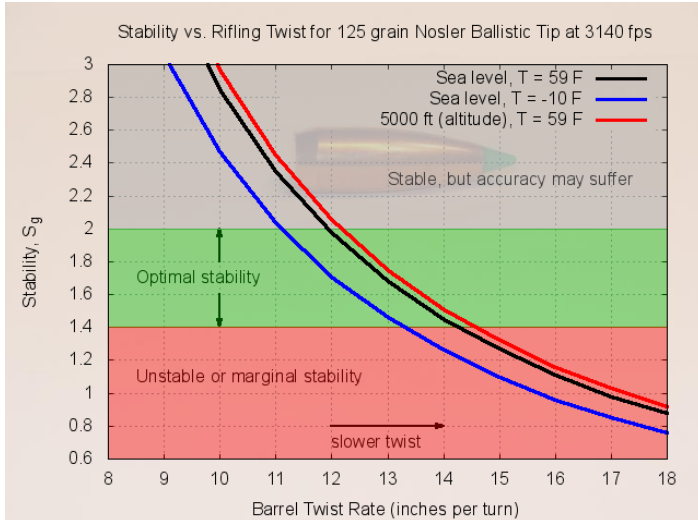
The second factor in the equation,  $\left( \frac{V}{2800} \right)^{\frac{1}{3}}$ , is the velocity correction factor, describing how stability changes for muzzle velocities other than 2800 fps.

The last factor,  $\frac{(FT + 460)}{(59 + 460)} \frac{29.92}{PT}$ , is the

atmospheric correction factor. This factor describes how stability changes with atmospheric density and incorporates effects as temperature deviates from 59 degrees F and pressure 29.92 inches of Hg. The most significant effects here come from the variations in atmospheric pressure with altitude. For example,  $PT = 24.90$ " Hg at 5000 ft, and 20.58" Hg at 10,000 ft. (15)[pp. 533-539].

For any given bullet, muzzle velocity, and atmospheric conditions, stability depends on the rifling twist rate. Longer bullets require higher twist rate than shorter bullets. Since the Miller stability formula is somewhat complicated, the best approach is to use a spreadsheet or to enter all the parameters into an available ballistics program, such as the Litz Point Mass Ballistics Solver (included with the book, Applied Ballistics of Long Range Shooting) or the JBM stability calculator (<http://www.jbmballistics.com/cgi-bin/jbmstab-5.1.cgi>). A spreadsheet is also available for download at <http://accurateshooter.net/Blog/millerformula.xls>. Any of these tools can be used to compute the stability for a given bullet, barrel twist, and other conditions.

## Ballistics of the 30-06 Rifle Cartridge

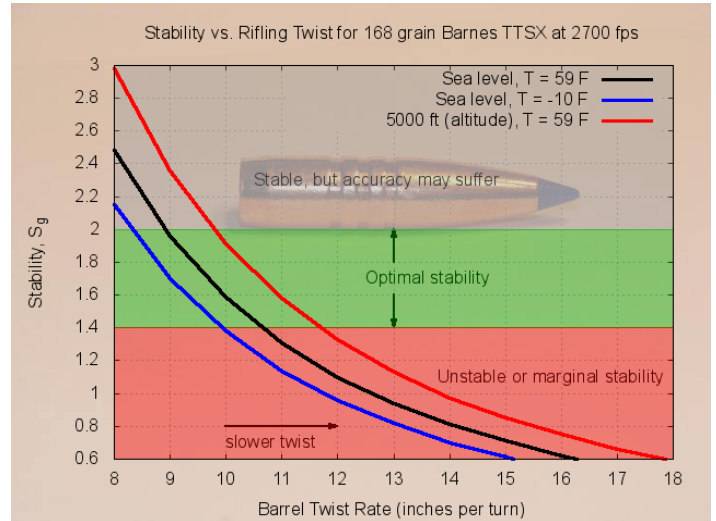


**Figure 5: Bullet stability vs. rifle twist rate for the Nosler 125 grain Ballistic Tip.** Under standard atmospheric conditions (black curve), this bullet is optimally stable at twist rates between 12 and 14 inches per turn. Under relatively dense conditions (blue curve), this bullet is optimally stable between 11 and 13 inches per turn. Under less dense, high altitude conditions (red curve), this bullet can tolerate slightly slower twist rates than standard conditions.

Stability curves are shown as a function of barrel twist rate for three .308 bullets at typical 30-06 velocities in Figures 5, 6, and 7. Figure 5 shows stability curves for the 125 grain Nosler Ballistic Tip at 3140 fps. This is a relatively short and light bullet that is easily stabilized even under the relatively dense atmospheric conditions of -10 F and sea level pressure of 29.92" Hg. Barrels with a twist rate of 1 turn in 10" produce such high stabilities that this bullet may suffer some loss of accuracy. In practice, our work with this bullet shows 1-1.5 MOA accuracy which is fine for groundhogs out to 250 yards and deer a bit further, but longer range varmint hunting or precise target work usually requires a barrel twist better matched to the bullet length.

The 168 grain Barnes tipped TSX (Figure 6) is one of the longest 168 grain bullets in .308 caliber at 1.416" due to its copper construction, sleek aerodynamic profile, boat tail, and plastic tip. The Miller formula probably under-estimates the stability because the plastic tip and hollow nose cavity cause the overall length to result in an over-estimate of the tumbling

moment of inertia.<sup>1</sup> Nonetheless, the Miller formula suggests that this relatively long, light bullet is near the boundary of what can be reliably stabilized in a 30-06 with a 1 turn in 10" twist rate under a broad range of atmospheric conditions.



**Figure 6: Bullet stability vs. rifle twist rate for the Barnes 168 grain tipped TSX.** Under standard atmospheric conditions (black curve), this bullet is optimally stable at twist rates between 9 and 10.5 inches per turn. Under relatively dense conditions (blue curve), this bullet is optimally stable between 8.5 and 10 inches per turn. Under less dense, high altitude conditions (red curve), this bullet can tolerate slightly slower twist rates than standard conditions.

The 220 grain Sierra Math King employs a conventional jacketed lead hollow point construction. Consequently, it is much heavier than the 168 grain TTSX, but only a little longer at 1.489 inches. Due to this, the 220 grain Miller formula predicts higher stability for the 220 grain SMK than for the 168 grain TTSX at given twist rates. Figure 7 shows the bullet stability vs. rifling twist rate for three different atmospheric conditions.

<sup>1</sup> The stability of this bullet even in cold weather and 1 turn in 12" barrels has been verified via private communication with the manufacturer.

# Ballistics of the 30-06 Rifle Cartridge

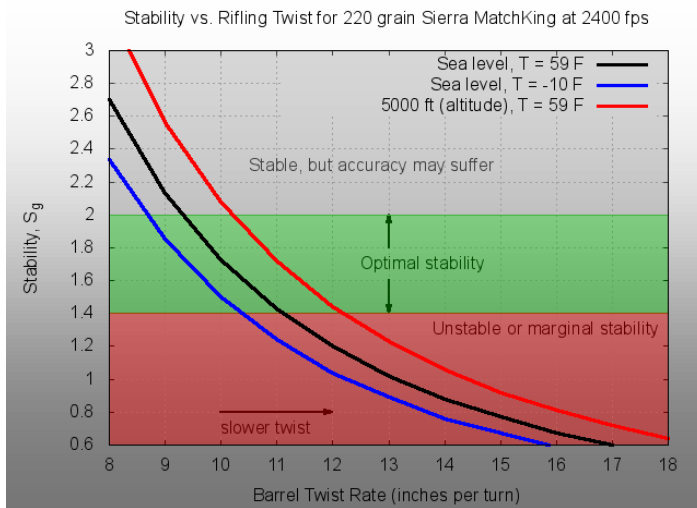


Figure 7: Bullet stability vs. rifle twist rate for the Sierra 220 grain MatchKing. Under standard atmospheric conditions (black curve), this bullet is optimally stable at twist rates between 9.3 and 11 inches per turn. Under relatively dense conditions (blue curve), this bullet is optimally stable between 8.6 and 10.4 inches per turn. Under less dense, high altitude conditions (red curve), this bullet can tolerate slightly slower twist rates than standard conditions.

## 2. Bullet Drop and Wind Drift

Vertical bullet drop due to gravity and horizontal wind drift depend on the muzzle velocity and the aerodynamic drag and can be predicted by ballistic calculators. Short of having a complete table of velocity dependent drag coefficients (usually only available for military bullets) and/or using full 6 degree of freedom ballistics programs which are much slower and require inputs that are not generally available, the best way to accurately compute the bullet drop and wind drift of a given load is to use a 3 degree of freedom point mass ballistics program that allows use of either the G1 or G7 ballistic coefficient. Some available programs are the JBM calculators ([www.jbmballistics.com](http://www.jbmballistics.com)), the Litz Point Mass Ballistics Solver (included with the book, Applied Ballistics for Long Range Shooting (15)), and the Berger Bullets Ballistics Program (downloaded from [www.bergerbullets.com](http://www.bergerbullets.com)). The JBM and Litz point mass solvers also include the ability to compute spin drift (gyroscopic drift).

If gravity is the only vertical force on the bullet, the vertical position of the bullet would be given by

$$y(t) = y_i + v_i \sin(\theta)t - \frac{1}{2}gt^2,$$

where  $y_i$  is the initial height of the bullet leaving the barrel,  $t$  is the time since the bullet left the barrel,  $\theta$  is the angle of the bullet's velocity vector above the horizontal the instant the bullet leaves the barrel, and  $g$  is the acceleration of gravity. This is the equation of vertical motion for an object in free fall and should be familiar to those who have studied introductory physics. It does not apply exactly to a bullet in flight due to four effects, three of which are neglected in point mass ballistics solvers but which can be included in full 6 degree of freedom solutions. A very small vertical force of lift can arise if the bullet nose remains slightly above the bullet's velocity vector. There is also a very small vertical component to the Coriolis force, which is discussed in a later section. The third possible vertical force that is neglected in point mass solvers is vertical wind deflection. In shooting across valleys or other situations where the wind can have a significant vertical component, the wind will produce a vertical component of bullet deflection. The fourth vertical force is the vertical component of the drag force which can be significant (depending on the upward angle) and is included in point mass ballistic solvers and thus included in the analysis of this section.

The most significant differences in bullet drop between 30-06 loads are between aerodynamic bullets with sleek form factors (pointy noses, long ogives, and boat tails) and high drag bullets with flat bases and round noses, flat tips or large hollow points. Bullets with similar profiles often exhibit comparable drop out to 400 yards because the higher muzzle velocity of the lighter bullets tends to compensate for the near-proportional decrease in ballistic coefficient such that the advantages of higher-BC heavier bullets becomes noticeable beyond 400 yards.

## Ballistics of the 30-06 Rifle Cartridge

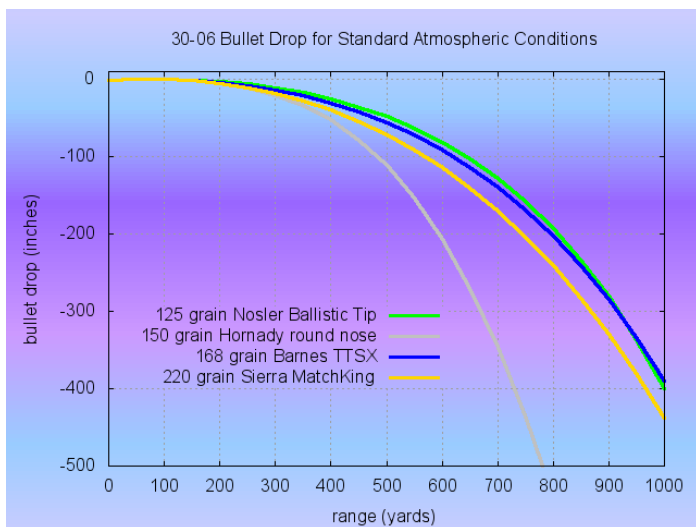


Figure 8: Bullet drop of four bullets at typical 30-06 muzzle velocities: 125 grain Nosler ballistic tip at 3140 fps (green), 150 grain Hornady round nose at 2900 fps (grey), 168 grain Barnes TTSX at 2800 fps (blue), 220 grain Sierra MatchKing at 2400 fps (gold). The round nose bullet drops much more because its low ballistic coefficient slows it down quickly. Trajectories computed in standard atmospheric conditions: sea level, 59 F, 29.92 in Hg, 0% humidity.

For decades, specifications of bullets for sporting purposes have been dominated by the G1 ballistic coefficient which was originally developed for a flat base projectile. A perfect description of drag requires specification of a drag coefficient at every velocity. Reasonable approximations can be made by relating specific types of bullets to a general curve which describes the velocity dependence and then to a ballistic coefficient (BC) which scales the entire curve up or down to approximate the velocity dependent drag. Few bullets match the velocity dependence of the drag curve exactly, but good to excellent results are possible if the appropriate drag curve is used (G7 for boat tail bullets; G1 for flat base bullets) (15)[pp. 13-40] (18) (19) (20) (21) and the ballistic coefficient for the bullet and drag model has been measured by a reliable source.<sup>2</sup> BCs published by bullet

<sup>2</sup> Even reliably measured BCs can differ from 3-5% between different firearms and bullet lots. Some bullet models even show bullet-to-bullet (shot-to-shot) variations this large. To get an idea on how performance with a specific gun or lot of bullets might differ from expectations, one should repeat trajectory calculations with BCs 5% higher and lower than the best

manufacturers often differ considerably from those measured by reliable sources. (22) (23) (15)[ch. 17] (21) (20) For a given drag model, higher BCs mean less drag, less wind resistance, and greater retained velocity. However, G1 and G7 BCs are not directly comparable: A bullet with a G7 BC of 0.2 has about the same drag as a bullet with a G1 BC of 0.4.

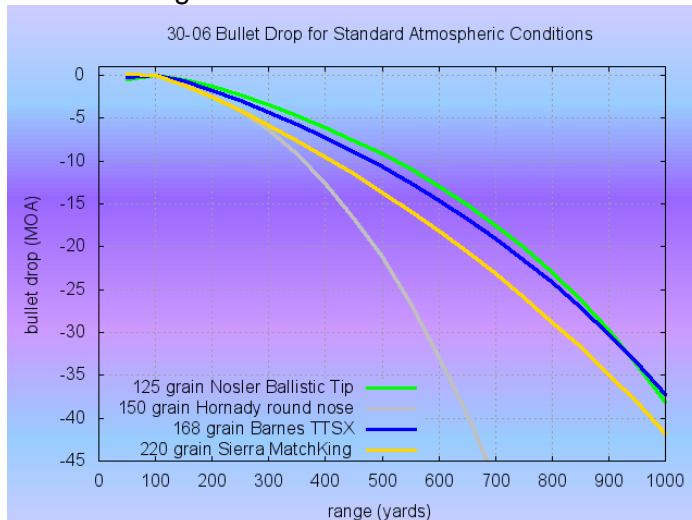


Figure 9: Bullet drop expressed in terms of minute of angle (MOA). A MOA is 1/60 of a degree. This unit is common for expressing bullet drop because many shooters make angular adjustments to their scope to compensate for drop. The graph suggests that a scope needs to be adjusted 12 MOA upward to be properly sighted for the 168 grain TTSX at 500 yards and 37 MOA at 1000 yards.

This article presents wind drift and gravity drop calculations for four bullets: the 125 grain Nosler Ballistic Tip, the 150 grain Hornady Round Nose, the 168 grain Barnes TTSX, and the 220 grain Sierra MatchKing. Bullets with the same BC and muzzle velocity will have the same drop and wind drift. There are numerous ways of comparing bullet drop. One common method is to zero the sights for a range of 100 yards, and express the bullet drop in inches at longer ranges. Valid comparison of different bullets and loads requires the atmospheric pressure, temperature, and relative humidity to also be specified, along with the muzzle velocity and ballistic coefficient.

available BC. Such small variations in BC usually only affect wind drift and drop by an inch or two at 500 yards, but affects become substantial at 1000 yards and beyond.



## Ballistics of the 30-06 Rifle Cartridge

Figures 8 and 9 show the bullet drop out to 1000 yards expressed in inches below the line of sight when the scope is zeroed at 100 yards and mounted 1.5 inches above the bore of the rifle. For the 125 NBT, a G7 BC of 0.167 was employed, (15)[ch. 17]. For the 150 grain Hornady Round nose, a G1 BC of 0.163 was employed (22) (Length 0.905") For the 168 grain TTSX, a G7 BC of 0.222 and the 220 grain SMK G7 BCs of 0.222 and 0.310 were used, respectively (15)[ch. 17].

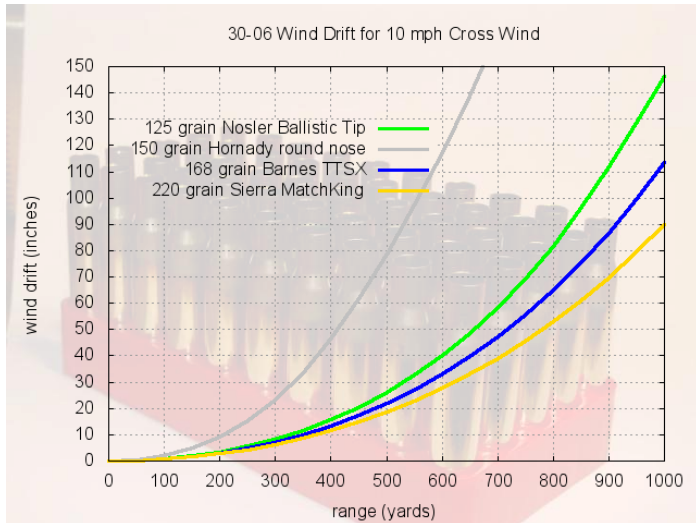


Figure 10: Horizontal wind drift for same four bullets as Figure 8. Wind drift affects low BC bullets such as the round nose much more strongly. The chart shows drift for a 10 mph cross wind. Since wind drift is linearly proportional to the magnitude of the cross wind, a 5 mph cross wind would produce half the drift shown, and a 20 mph cross wind would produce twice the drift. The graph shows that a 168 grain TTSX drifts 21 inches at 500 yards and 113 inches at 1000 yards in a 10 mph cross wind.

Most ballistic calculators compute horizontal wind drift using a procedure equivalent to the formula  $W_d = 17.6 \times V_w \times T_{lag}$ , where  $W_d$  is the horizontal wind deflection (in inches),  $V_w$  is the cross wind velocity (in miles per hour), and  $T_{lag}$  is the lag time, or time delay between the time the bullet would reach that range in a vacuum and the time it actually takes when aerodynamic drag is included (in seconds). (15)[p. 526]. Most ballistic point mass solvers only include horizontal drift perpendicular to the direction in which the bullet is fired. This is reasonable, since even though vertical deflections due to wind drift are possible, they are usually small, and the needed

inputs are usually unavailable. Figures 10 and 11 show the effect of a 10 mph cross wind on bullet trajectory, expressed in inches and MOA, respectively. Only the horizontal component of the wind's velocity vector perpendicular to the bullet's initial direction produces a horizontal displacement. These figures are accurate for a 10 mph coming from the 3 o'clock or 9 o'clock directions (12 o'clock is the direction of bullet travel). However, winds at a 45 degree angle relative to bullet travel (1:30, 4:30, 7:30, and 10:30) need to be 14.1 mph to produce the same deflection as a 10 mph wind from 3:00 or 9:00. Similarly, winds at a 30 degree angle to the bullet path (1:00, 5:00, 7:00, 11:00) need to be 20.0 mph to produce the same deflection as a 10 mph perfectly perpendicular to bullet travel. Head (12:00) or tail (6:00) winds produce no horizontal bullet deflection.

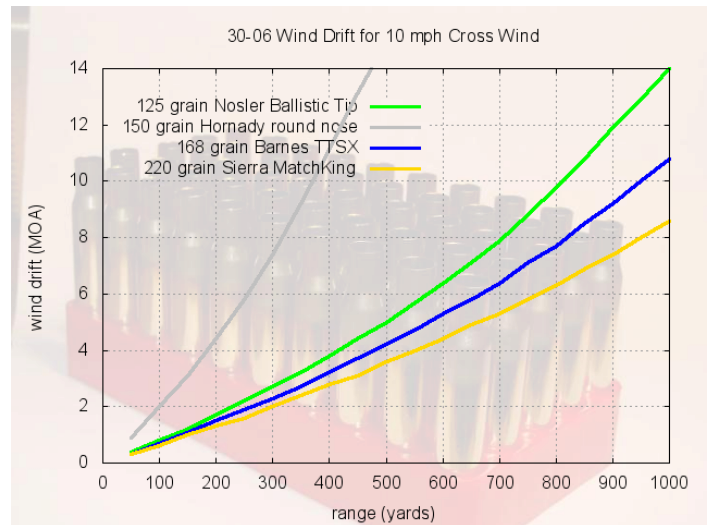


Figure 11: Expressed in MOA, wind drift can be understood in terms of horizontal scope adjustments necessary to compensate for it. With the 168 TTSX and a 10 mph cross wind, a 2, 4, and 8.5 MOA adjustments are needed to compensate for wind drift at 300, 500, and 1000 yards, respectively.

Figure 12 and 13 show drop and wind drift comparisons between the .308 Winchester/7.62x51mm NATO, 30-06, and .300 Winchester Magnum. It is clear that while the 30-06 only has a moderate advantage over the .308 Winchester, the .300 Winchester Magnum has considerably less drop and wind drift than either the 30-06 or the .308 Winchester.

## Ballistics of the 30-06 Rifle Cartridge

Expressed in MOA, drop can be understood in terms of vertical scope adjustments necessary to compensate for it. Since 1 MOA is approximately 1 inch at 100 yards, a convenient rule of thumb to convert from MOA to inches is to simply multiply by the number of 100 yards represented by the range. For example, at 800 yards, the two bullets fired by the .300 Win Mag have both dropped by 20 MOA. The drop in inches is 20 (MOA) times 8 (hundred yards) = 160 inches. The 25 MOA drop of the 30-06 bullet at the same range corresponds to 25 (MOA) times 8 (hundred yards) = 200 inches. A five MOA difference at 800 yards corresponds to 40 inches.

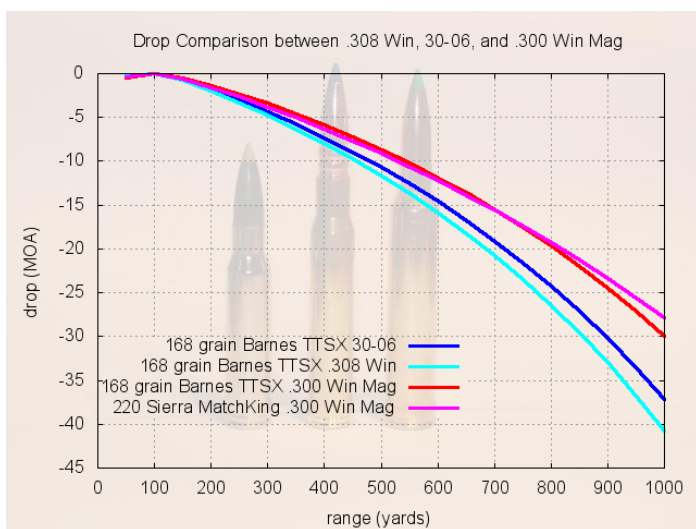


Figure 12: Drop comparison between 168 grain .308 bullet at 2700 fps, the same bullet from a 30-06 and 300 Win Mag at 2800 and 3050 fps, respectively, and the MK248 sniper load using the 220 grain Sierra MatchKing at 2850 fps.

Determining range and correcting for drop is a much simpler task for long range target shooters, hunters, and military snipers than accurately reading and correcting for wind drift. For this reason, loads with minimum wind drift are preferred for work beyond 500 yards. The wind drift comparison in Figure 13 shows why the .300 Winchester Magnum with a heavy match bullet (high BC, low wind drift) is preferred over the .308 Winchester (equivalent external ballistics to the 7.62x51mm NATO with the same bullet) and the 30-06.

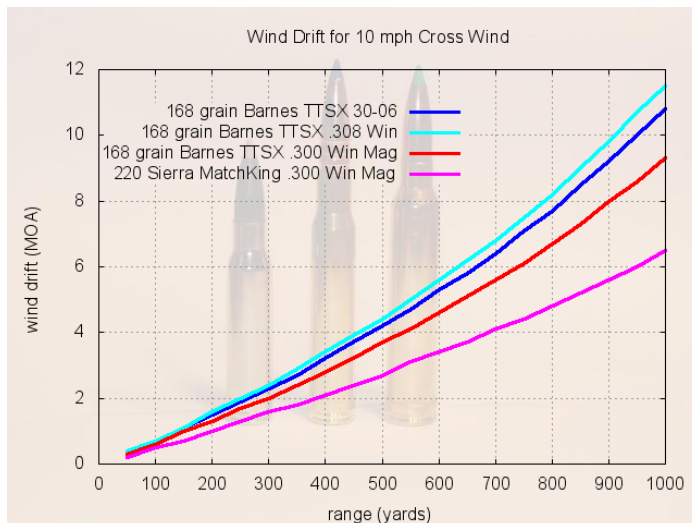


Figure 13: Wind drift comparison between 168 grain .308 bullet at 2700 fps, the same bullet from a 30-06 and 300 Win Mag at 2800 and 3050 fps, respectively, and the MK248 sniper load using the 220 grain Sierra MatchKing at 2850 fps.

### 3. Retained Velocity and Kinetic Energy

The velocity and energy retained by a bullet as it flies downrange can be important considerations and are predicted by the same drag models that predict drop and wind drift. Bullets with higher ballistic coefficient (BC) retain more of their energy and velocity as they travel downrange. Energy and velocity are closely

related via the formula  $E = \frac{1}{2}mv^2$ , where  $E$  is the kinetic energy,  $m$  is the bullet mass, and  $v$  is the bullet velocity.  $E$  is usually expressed in ft-lbs (the English unit of energy).

Target shooters, varmint hunters, big game hunters, and military snipers have different needs in terms of retention of velocity and energy. For target shooting and hunting varmints up to 50 lbs, retained energy is not an important consideration, and the common phenomena of a sudden accuracy loss as the bullet drops below the speed of sound sets the most important requirement as retained velocity above the speed of sound. Under standard atmospheric conditions, the speed of sound is 1116.4 fps, which can be used to compare bullets and loads, but because both the speed of sound and drag depend heavily on atmospheric conditions, specific predictions should incorporate as accurate an

## Ballistics of the 30-06 Rifle Cartridge

estimate of conditions as available for the circumstances.

For self-defense and hunting larger animals retaining sufficient velocity to ensure adequate bullet expansion is an important consideration. Terminal ballistics will be treated in more detail in a later section, but since most bullets designed to expand will expand reliably at impact velocities above 2200 fps,<sup>3</sup> that threshold will be highlighted here. The different schools of thought regarding the importance of impact energy and energy transfer will also be addressed in greater detail in the section on terminal ballistics, here the discussion considers only how much energy the bullet has when impacting at a given range.

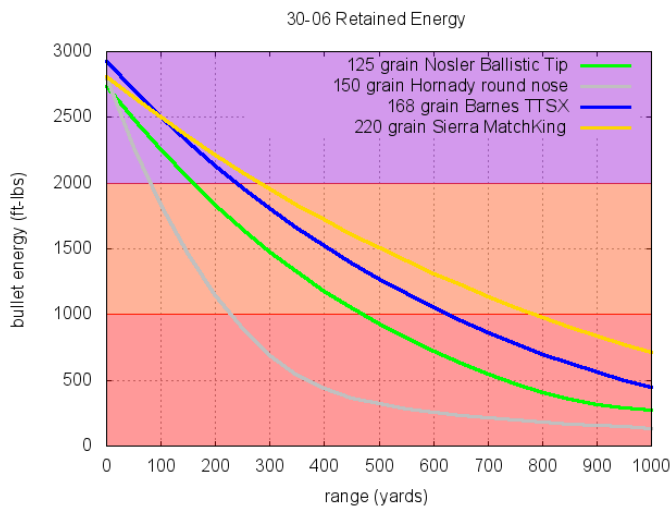


Figure 12: Retained energy vs. range the 30-06 for several bullets fired at typical muzzle velocities under standard atmospheric conditions.

Figure 12 compares the energy of several 30-06 bullets fired at velocities typical of the bullet weight. At the muzzle, all the bullets have 2700-3000 ft-lbs of energy, but the low BC Hornady round nose sheds energy quickly and has approximately 1800 ft-lbs at 100 yards, while the two highest BC bullets retain approximately 2200 ft-lbs at 100 yards. By 400 yards, the round nose bullet has under 500 ft-lbs

<sup>3</sup> Bullet manufacturers often advertise lower expansion thresholds, but one must read the fine print to realize that these low velocity expansion thresholds may only indicate 10% expansion which may not be adequate for the intended purpose.

while the more aerodynamic bullets range from 1200 to 1750 ft-lbs. The highest BC bullet retains the most energy at ranges beyond 100 yards, and its advantage in energy retained grows with distance.

Figure 13 shows the retained velocity of several 30-06 bullets. The 150 grain Hornady round nose drops below 2200 fps inside of 150 yards and becomes subsonic at 400 yards. The 220 grain Sierra MatchKing drops below 2200 fps at about the same range, but owing to its high ballistic coefficient, it remains supersonic beyond 1000 yards. The 168 grain Barnes TTSX drops below 2200 fps at approximately 300 yards, and remains supersonic beyond 950 yards. The 125 grain Nosler Ballistic Tip drops below 2200 fps at about 300 yards and remains supersonic to approximately 850 yards.

Note the pronounced flattening (reduced local slope) of the 150 grain Hornady round nose and 125 grain Nosler ballistic tip bullets once their velocity drops below the speed of sound. This is caused by a significant reduction in the aerodynamic drag forces once the bullet is moving at subsonic speeds. Subsonic bullets lose velocity much more slowly than supersonic bullets.

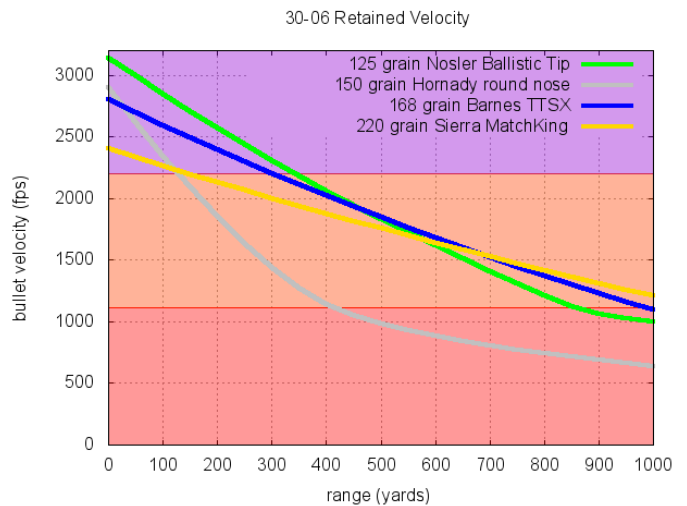


Figure 13: Retained velocity vs. range the 30-06 for several bullets fired at typical muzzle velocities under standard atmospheric conditions.

# Ballistics of the 30-06 Rifle Cartridge

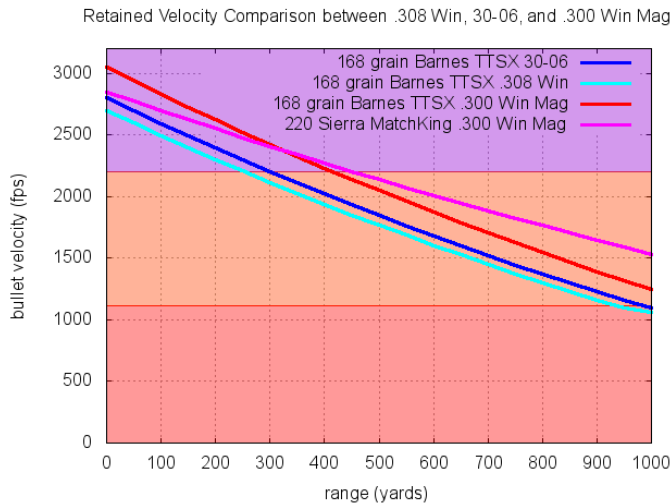


Figure 14: Retained velocity comparison between .308 Winchester/7.62x51mm NATO, 30-06, and .300 Winchester Magnum.

With the 168 grain Barnes TTSX, the .308 Winchester/7.62x51mm NATO remains above 2200 fps to 250 yards and remains above the speed of sound out beyond 900 yards. The 30-06 remains above 2200 fps out to 300 yards and remains supersonic out beyond 950 yards. The .300 Winchester Magnum remains above 2200 fps out to 400 yards and remains supersonic out to 1100 yards. The load with the longest supersonic range is the 220 grain Sierra MatchKing loaded to 2850 fps in the .300 Winchester Magnum. Under standard atmospheric conditions, this load is supersonic out to 1400 yards.

## 4. Spin Drift

The gyroscopic spinning of a bullet that is necessary for stability results in the bullet pointing slightly to the right (for right twist barrels) or left (for left twist barrels) of the direction of flight. This misalignment is very small, usually less than one tenth of one degree, but over very long ranges, it can create a measurable deflection, even though it is usually much smaller than wind drift. Bryan Litz's book, Applied Ballistics for Long Range Shooting, has a good description of how the effect arises, and also presents a simple empirical model based on more complex 6 degree of freedom aerodynamic modeling. (15)[Ch. 6] The Litz formula for estimating spin drift is  $S_d = 1.25(S_g + 1.2)t_f^{1.83}$ , where  $S_d$  is the horizontal deflection due to spin drift (in inches),  $S_g$  is the gyroscopic stability as estimated with the Miller twist

rule (unitless), and  $t_f$  is the bullet time of flight (in seconds).

Note the linear dependence on  $S_g$ . This implies that bullets with a higher gyroscopic stability will have a higher spin drift. In other words, as long as the twist rate is adequate to stabilize a given bullet ( $S_g > 1.4$ ), higher twist rates increase the spin drift. Figure 15 shows the effects of this by comparing the spin drift for 1 in 10" (thick lines) and 1 in 12" twist barrels (thin lines).

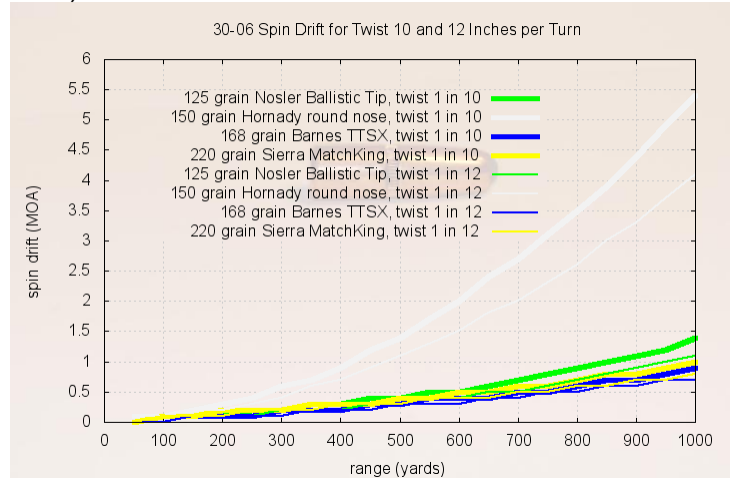


Figure 15: Spin drift of different bullets in 30-06 with differing twist rates.

## 5. Coriolis Effect

The Coriolis effect results from the motion of the earth as the bullet is in flight. It is very small and of little or no consequence for most applications within the practical range of the 30-06. A typical deflection at 1000 yards might be 3" to the right (in the Northern Hemisphere) and about the same distance up (for a shot due east) or down (for a shot due west). At 500 yards, the deflections are less than one inch. Here again, Bryan Litz's book, Applied Ballistics for Long Range Shooting, has a good description of how the effect arises, an excellent discussion in layman's terms while maintaining technical correctness. (15)[Ch. 7] The 1000 yard target shooter would do well to have a semi-quantitative understanding of the scenarios where the effect might matter (changes in horizontal point of impact between Northern and Southern hemispheres and changes in vertical point of impact when switching from shooting eastward to westward.) Wayne van Zwoll is right that within most practical hunting ranges (say 500 yards), hunters can

# Ballistics of the 30-06 Rifle Cartridge

safely ignore the effect and concentrate on all the other aspects of making a clean kill at the given range. (24) The reader with more technical interest should note that the formula given by van Zwoll is for the Coriolis acceleration, and incorrectly gives the rate of the Earth's rotation as degrees per second. In contrast, the formula given by Litz is for the Coriolis deflection (in feet) and correctly gives the rate of the Earth's rotation as radians per second. (15)[p. 102]

Because it is so inconsequential and often ignored, most ballistics programs do not compute the Coriolis deflection. The graphs here were generated by using the JBM ballistics program to provide the necessary inputs (time and drop to a given distance) and then computing the average velocity and resulting deflection with a spreadsheet implementing the Litz formulas for Coriolis deflection. (15)[p. 102-105] Figure 16 shows typical vertical and horizontal for a specified load and conditions. Note that the same shot at the same Southern latitude would deflect left instead of right by the same amount and that the same shot due eastward rather than westward would deflect up<sup>4</sup> instead of down.

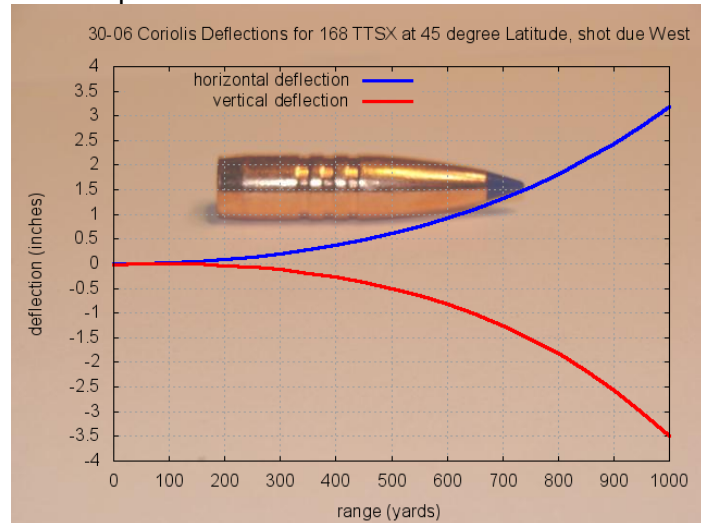


Figure 16: Horizontal and vertical Coriolis deflections for 168 grain TTSX fired due West at 2800 fps under standard conditions at Latitude of 45 degrees North. Horizontal deflection will be to the right in the Northern hemisphere and is independent of azimuth (direction of fire relative to North). Vertical deflection depends on azimuth (cos of the angle relative to North) and will be zero for a shot due

<sup>4</sup> Of course the net deflection is dominated by gravity and is downward, but the Coriolis contribution to the deflection can be upward so that the total deflection is less downward.

North or South and opposite (upward) sign for a shot due East. Both deflections are about 0.5" at 500 yards and 3-4 inches at 1000 yards.

## IV. Terminal Ballistics

### 1. Penetration of Armor and Barriers

Kevlar, Aramid, and soft (flexible) body armors are designed to stop pistol bullets up to velocities below 1500 fps, and are not effective at stopping rifle bullets, except perhaps at long range where they have slowed below this speed. (25) Only NIJ Level III and Level IV body armors, which usually include a hard ceramic plate or other hard barrier, are rated to stop rifle bullets, and only the Level IV armor is rated to stop armor piercing bullets fired from a 30-06. Military body armor plate inserts to stop armor piercing bullets from the 30-06 are the Enhanced Small Arms Protective Insert which adds 5-7 lbs to the underlying Kevlar armor (needed to protect from ceramic fragments) for the front plate alone.

Terminal performance often represents a tradeoff between the ability of a bullet to penetrate barriers reliably and the ability to rapidly transfer energy to tissues during penetration to maximize tissue damage. Unlike the 5.56x45mm NATO and handgun calibers, and much like the 7.62x51mm NATO and .308 Winchester, the 30-06 has the reputation of offering both very good penetration of intermediate barriers and good damage when striking tissues beyond common barriers like car doors, auto glass, etc. (26)[p. 13]

Detailed penetration data are not available for the 30-06 in every conceivable scenario. However, some inferences can be made from the fact that bullets of the same caliber, weight, design, and impact velocity are expected to have the same terminal performance characteristics, regardless of the cartridge from which they were fired. John Henry Patterson reported using his .303 British (very close to FMJ ammunition in the 30-06) to make holes in iron railroad rails. (27) M80 ball ammunition in the 7.62x51mm NATO is reported to penetrate 3.5 mm steel plate out to a range of 620 meters and a U.S. Army M-1 steel helmet up to a range of 800 meters. This round can also penetrate two cinder blocks. (28) Depending on the bullet design, a single shot from a 30-06 has been found to penetrate 1-2" into a large block of Air Force G mix concrete. (29)

# Ballistics of the 30-06 Rifle Cartridge

The U.S. Army developed two loads for the 30-06 designed to penetrate armor. One load is known as “CARTRIDGE, CALIBER .30, ARMOR PIERCING, M2” and has a black tip and a steel core. This cartridge is loaded with 55 grains of WC 852 powder and a 165.7 grain bullet producing 2715 fps a distance of 78 feet from the muzzle. (30)[p. 5-7] The other load is known as “CARTRIDGE, CALIBER .30, ARMOR PIERCING INCENDIARY, M14” and has an aluminum tip, a steel core, and 2 grains of incendiary compound under the bullet jacket in front of the steel core. This cartridge is loaded with 50 grains of WC 852 powder producing 2780 fps a distance of 78 feet from the muzzle. (30)[p. 5-13] Both armor piercing loads are specified to penetrate at least 0.42 inches into 7/8 inch thick homogeneous armor plate at 100 yards.

High hardness armor steel plate is among the materials most resistant to bullet penetration. Test results for 30-06 armor piercing ammunition are available for this armor. The  $V_{50}$  specification is the velocity at which 50% of shots penetrate the armor for a given bullet. At a 30 degree oblique angle the 30-06 M2 armor piercing bullet has  $V_{50} = 2174$  fps for 0.202 inch thick ATI-500 MIL high hardness armor plate;  $V_{50} = 2672$  fps for 0.305 inch thick plate. (31) Consequently, it is likely that near the muzzle, the 30-06 M2 armor piercing bullet will penetrate thinner armors as well as non-armor materials of comparable thickness.

## 2. Wounding Potential

The wounding potential of a bullet is related to the retarding force between the bullet and tissue as the bullet penetrates, which are equal and opposite according to Newton’s third law. In air, the retarding force on a bullet is small, because air is not very dense, the bullet is streamlined, and it has a small cross sectional area. The average retarding force on a bullet can be estimated as the kinetic energy loss divided by the distance over which the energy is lost. For example, if the bullet loses 500 ft-lbs of energy over a distance of 400 feet, the retarding force due to aerodynamic drag over that distance is  $500 \text{ ft-lbs}/400 \text{ ft} = 1.25 \text{ lbs}$ .

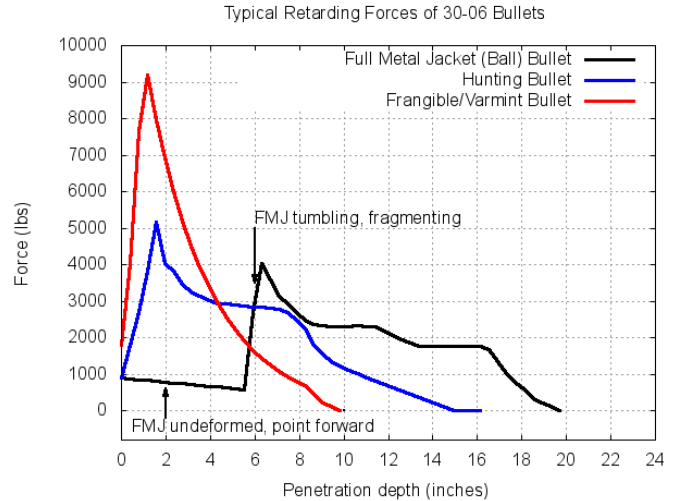


Figure 17: The black curve for the full metal jack bullet was adapted from Bellamy and Zajtchuk. (32)[p. 121]. The retarding force of this bullet is small while it is undeformed and remains point forward in tissue. When the bullet begins to yaw (tumble) in tissue, the increase in cross sectional area of the bullet moving sideways through tissue dramatically increases the retarding forces which leads to deformation and often fragmenting as well. Large retarding forces cause a rapid decrease in velocity, which in turn reduces retarding forces. Typical behavior of expanding bullets is shown in the red and blue curves. The red curve shows the rapid energy loss of a frangible bullet with a shallow total penetration depth of the type often preferred by varmint hunters. The blue curve is typical of a deer hunting bullet. Different bullet designs impacting with the same energy will display different force curve shapes and peaks, but the area under the force curve is always equal to the impact energy.

Several effects in tissue significantly increase the retarding force on the bullet. Tissue is about 1000 times denser than air. Many bullets experience more drag in tissue due to expanding, tumbling, and fragmenting. Bullet penetration requires tissue to be damaged rather than just being pushed aside. Thus while most bullets will travel thousands of yards in air, penetration depths in tissue is measured in inches or feet.

The forces a bullet can exert on tissue are limited by the kinetic energy the bullet has at impact, according to the work-energy theorem. For example, if the force a bullet applied on tissue were constant, a 30-06 bullet impacting with 2500 ft-lbs of energy could exert a force of 2500 lbs over a penetration depth of 1 ft. However, owing to the complex dynamics as the

## Ballistics of the 30-06 Rifle Cartridge

bullet penetrates with some combination of expansion, tumbling, fragmenting, and slowing, the force between a penetrating bullet and tissue are seldom constant, but can be represented by a curve as the instantaneous force changes with the depth the bullet has penetrated, as in Figure 17.

At any point, the instantaneous force between bullet and tissue is equal to the bullet's local rate of energy loss. As an equation,  $F = dE/dx$ , where  $F$  is the force at a given penetration depth  $x$ , and  $E$  is the bullet's kinetic energy. For example, if a bullet loses 100 ft-lbs of energy in the first 0.1 ft of penetration, the force during that 0.1 ft of penetration is  $100 \text{ ft-lbs}/0.1 \text{ ft} = 1000 \text{ lbs}$ . With a given impact energy, different bullet designs can lose their energy with many different force vs. penetration depth profiles, but the area under the curve depends only on the impact energy, and the shape of the force curve depends only on  $dE/dx$ , the bullet's instantaneous local rate of energy loss. As a bullet passes through tissue, it loses energy (thus exerting greater force on the tissue) through drag. Drag is increased by greater frontal area (caused by expansion or tumbling), a blunter profile relative to the travel direction (caused by expansion or tumbling) and by a change in material properties giving more resistance to penetration. Drag is decreased by a decrease in velocity.

Wounding potential in a living target is governed by the force profile of the penetrating bullet in tissue, which is, in turn governed by the impact energy and bullet design characteristics as they relate to tumbling, expansion, fragmentation and penetration. The three wounding mechanisms as they relate to this retarding force profile are often described as 1) permanent cavitation (the remaining hole of destroyed tissue after the bullet has passed), 2) temporary cavitation (the temporary cavity left in the bullet's wake by tissue stretching out of the way from large retarding forces for a few milliseconds until snapping back into place due to elasticity) and 3) remote injury effects beyond the reach of the temporary cavity attributed to propagation of a ballistic pressure wave.

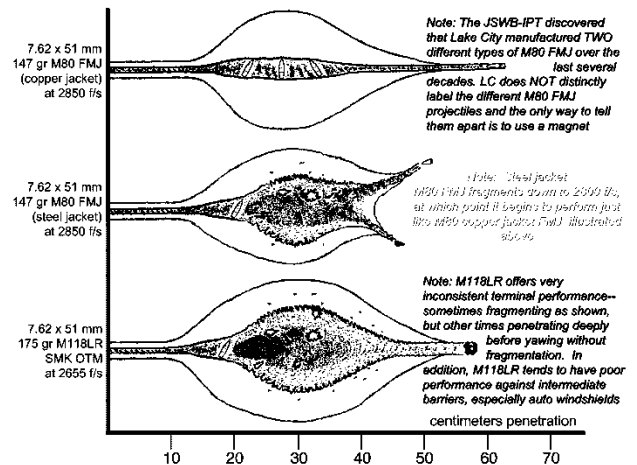


Figure 18: Wound profiles of three .30 caliber bullets. (33)[p.21] The outer curve of each profile shows the extent of temporary cavitation, and the inner shaded area depicts the permanent cavity. FMJ bullets vary widely in performance depending on whether they fragment (top and middle) and at what depth they yaw (tumble) in tissue. Depth of yaw has a sensitive dependence on the angle of attack at impact. An FMJ bullet which yaws early and fragments can create a devastating wound. An FMJ bullet which exits before yawing and fails to directly hit a major artery or central nervous system can create a relatively minor wound.

### 1. Permanent cavitation

In elastic tissues such as lungs and muscle where the tissue tends to spring back into place with little damage from temporary stretch, most tissue damage is caused from the intense field of compressive and shear stress within a few cm of the bullet path. This intense stress field propagates outward from the retarding force between the bullet and tissue, but falls off quickly with distance. Consequently, the permanent cavity tends to be the largest at penetration depths where the retarding force between bullet and tissue is the greatest.

C.E. Peters described the damage due to the localized stress field in the immediate vicinity of the passing bullet as "prompt damage" because of the short time scales involved (microseconds). (34) This damage occurs before tissue is stretched by temporary cavitation and has been observed in careful experiments where the temporary cavity is suppressed by elements in the experimental design.

## Ballistics of the 30-06 Rifle Cartridge

The Textbook of Military Medicine (32) reports that the mass of tissue damaged at a certain penetration depth is well-correlated with the local rate of energy loss of the projectile at that depth. The total tissue destroyed is also well-correlated with projectile energy loss. Experiments show between 0.24 and 0.5 grams of muscle tissue destroyed for each Joule of energy lost by a penetrating .30 caliber projectile. (32)[pp. 137-143]

### 2. Temporary cavitation

The retarding force between bullet and tissue rapidly accelerates tissue radially away from the bullet path. After the bullet has passed, tissue elasticity and fluid pressure move tissue back into the empty volume of the temporary cavity. The cavity formed by the radial expansion of tissue has a maximum diameter near the penetration depth where the retarding force is a maximum. (34)

Fragmentation can contribute significantly to the permanent wound left behind by a penetrating projectile. Bullet fragments create small holes as they penetrate a small distance from the main bullet. As tissue stretches in the bullet wake due to temporary cavitation, these small holes are areas of stress concentration where tears in tissue originate as tissue rapidly stretches. Less elastic tissues such as liver, kidney, and neural tissue can be seriously damaged by temporary stretch, even in the absence of fragmentation. (32)

If the bullet path is sufficiently close to a bone, the bone can be broken by the impact of the temporary cavity. (32) Peripheral nerves can be damaged resulting in a loss of function due to being stretched by a projectile penetrating nearby. (35) Spinal trauma can result if the temporary cavity impacts the spine.

The potential for temporary cavitation to cause wound trauma is related to the location of the bullet path through tissue, the degree of bullet fragmentation (if any) and the size of the temporary cavity, usually expressed in a maximum diameter or volume. Figure 19 shows the average diameter of temporary cavities produced by two military 30-06 projectiles prior to yaw (tumbling) in ballistic gelatin tissue stimulant. It is clear that the maximum

diameter increases as impact velocity increases. Because the retarding force increases when the bullet yaws, temporary cavities are much larger (> 30 cm in diameter) as the bullet yaws.

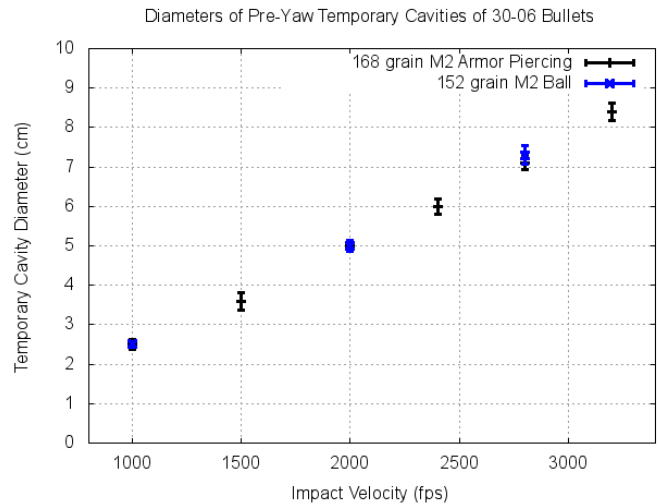


Figure 19: Pre-yaw temporary cavity sizes increase linearly (correlation coefficient  $R > 0.99$ ) as the impact velocity increases. Armor piercing and ball ammunition show very similar pre-yaw and shot to shot behavior. (36)[p. 8]

The book "Wound Ballistics in World War II" describes some of the wounding effects that are caused by temporary cavitation:

*With this realization of forces involved in the production of the missile casualty, some of the otherwise anomalous manifestations in the wound appear much more logical. For instance, fractures occur at some distance from the missile tract without any direct contact between the bone and the missile. Forces may be transmitted through the essentially noncompressible blood and rupture a vein some distance from the missile's path. Nerves may be paralyzed yet fail to show gross evidence of physical damage. In some wounds in muscle, splitting along facial planes will be noted for a considerable distance from the path of the bullet.*

*Fluid filled viscera are often blown asunder by the operation of hydraulic forces. High velocity missiles may pulp the brain substance. In some cases the bones of the skull are separated along suture lines as though an explosion has occurred within the brain case. This is but another manifestation of the forces operating in formation of the temporary cavity, and examination often reveals clean holes of entrance and exit of the missile showing*



# Ballistics of the 30-06 Rifle Cartridge

that the bony rupture occurred after its passage. Similarly, shooting through a can of water, the rupture of the can occurs after the through-and-through passage of the bullet. (37)[pp. 135-136]

In addition to these effects, the temporary cavity creates a region of extravasation of hemorrhagic tissue. Though somewhat smaller than the full extent of the temporary cavity, observation of this zone of extravasation suggests to the military surgeon that there may be blood vessel or nerve damage for a few inches even further from the bullet path. (37)[p. 136]

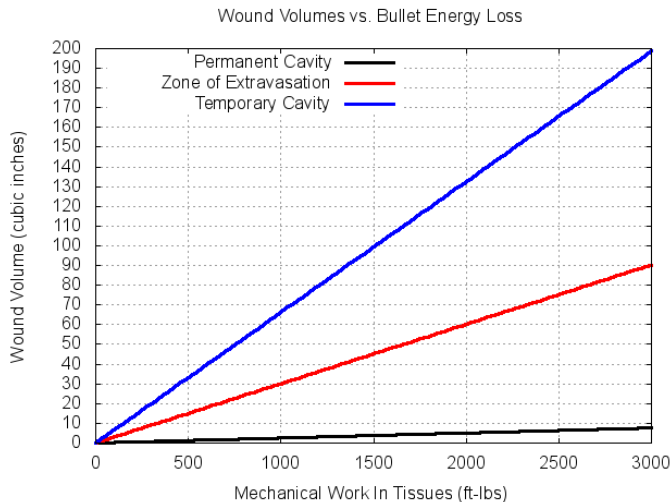


Figure 20: A graph of wound volumes vs. bullet energy loss in tissue, according to "Wound Ballistics in World War II." (37)[pp. 140-141]

The average volumes of the permanent cavity, zone of extravasation, and temporary cavity have found to increase linearly with the mechanical work done by the bullet as it passes through tissue. This mechanical work is equal to the kinetic energy lost by the bullet and directly related to the force between the bullet and tissue as described above. It has been found that the average volume of the permanent cavity is 0.002547 cubic inches for each ft-lb of mechanical work; the average volume of the zone of extravasation is 0.030105 cubic inches for each ft-lb of mechanical work; and the volume of the temporary cavity is 0.066247 cubic inches for each ft-lb of mechanical work done by the bullet passing through tissue. (37)[pp. 140-141]

### 3. Ballistic pressure wave

The stress and shock waves imparted by the retarding forces between bullet and tissue radiate

outward and are transmitted from the impact location throughout the body. Experiments in live animal models have used high-speed pressure transducers to detect these remote ballistic pressure waves in the abdomen, neck, brain, and contralateral thigh of pigs shot in the thigh, (38) (39) and remote wounding effects have been documented in the lungs, (32) spinal cord, (38) (40) and brain both in animal experiments (38) (41) and human case studies. (42)

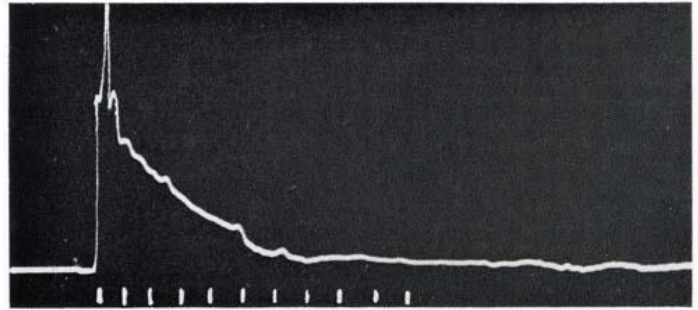


FIGURE 59.—A pressure-time record of a shock wave resulting from impact on the surface of water of a 3/16-inch steel sphere moving 3,000 f.p.s. The crystal gage was 6 inches from the point of impact, at a 45° angle with the missile path. The time marks are 20 microseconds apart. The peak pressure is 600 pounds per square inch. (Experiment No. 41g, July 1945.)

Figure 20: Ballistic pressure wave from projectile impact in water from "Wound Ballistics in World War II, Mechanism of Wounding." (37)[p. 159]

Like other wounding effects that depend on the force of the bullet tissue interaction, the magnitude of the ballistic pressure wave and related effects depends on the local rate of the projectile's energy loss as it passes through tissue. (43) (44) Both remote wounding and rate of incapacitation depend on the peak retarding force between bullet and tissue. (43) A 30-06 bullet with a peak retarding force of 5000 lbs will generate a peak pressure wave of approximately 1600 psi on the surface of a 1" diameter cylinder centered on the wound channel.

### 4. Behind armor trauma

It is not uncommon for soldiers hit with lower energy 30 caliber bullets (AK-47, muzzle energy 1500 ft-lbs, field impact energies often lower due to velocity decay with range) to be stunned but receive no life-threatening injuries if the bullet is stopped by their body armor. (45) Body armor is tested to standards for armor back face deformation, because if the fabric behind the armor deforms too much, serious behind armor injuries are possible. The rapid chest wall acceleration that results from forces imparted by back face deformation causes a large pressure pulse typically 3000-12000 psi in amplitude and on the

# Ballistics of the 30-06 Rifle Cartridge

order of 200 microseconds long in the chest behind armor when a high-velocity rifle bullet is stopped. (46)

To quantify how serious behind armor trauma can be at a given back face deformation, the Swedish Defense Forces studied wounding in pigs resulting from 150 grain 7.62x51mm NATO bullets impacting at 2700 fps in hard armor with resulting back face deformations of 28-40 mm. (47) (48) (49) This research documented EEG suppression, life threatening lung contusions, and other injuries.

D (mm)	W (J)	F <sub>eff</sub> (N)	Mortality rate
40	772	19297	50%
34	524	15411	25%
28	316	11287	0%

Table 3: Mortality rate, mechanical work in tissues (W), and peak effective behind armor force (F<sub>eff</sub>) observed for given back face deformation (D) for 150 grain 30 caliber bullets (M80 ball) impacting at 2700 fps. (47) (48) (49) (50)

The inference from this research is that a soldier or law enforcement officer hit in the chest at close range by a 30-06 bullet stopped by armor with a 44 mm back face deformation runs a significant risk of rapid incapacitation and life-threatening injuries. The Swedish study concluded that the 44 mm standard for back face deformation used by the U.S. and other countries is insufficient to protect from these impact levels. It is also notable that there have been some findings and recalls related to inadequate testing of fielded armors even to the 44 mm standard for back face deformation. (51) The United Kingdom uses a 25 mm standard upper limit for back face deformation when the threat is a high-velocity bullet. (49)

## 5. Incapacitation data

Due to common use of 30 caliber weapons in military conflicts, there is a lot of wounding data available; there is also ample anecdotal evidence regarding the ability of the 30-06 to stop animals and threats of various sizes. However, there is little quantitative data available regarding how quickly living targets are incapacitated by the 30-06. Two studies that contain quantitative data for 30 caliber rifle bullets and allow for some broad inferences are a study by

the South Carolina Department of Natural Resources on incapacitating effects in deer and a study by Evan Marshall and Ed Sanow on incapacitating effects in human attackers.

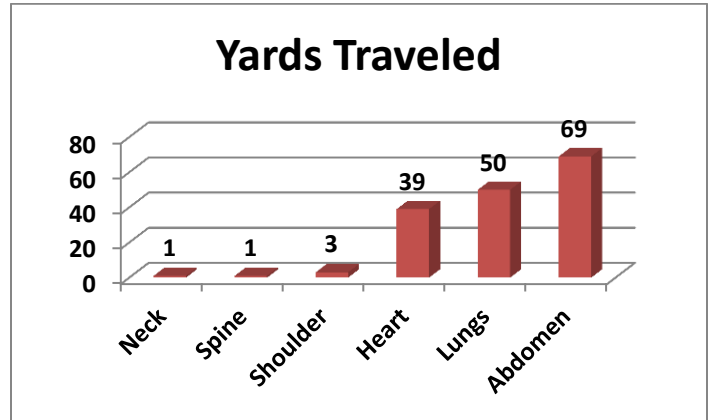


Figure 21: Average yards traveled by whitetail deer after being shot in a given location.

## 1. South Carolina Deer Study

The South Carolina Department of Natural Resources studied the effect of caliber, shot placement and bullet type on the average yards whitetail deer travelled after being shot with reliably expanding hunting bullets in calibers from .243 to .308 inches. (52) The study included over 440 deer harvested, and hunters in the study killed 82% of the deer shot at and the deer were killed at an average range of 127 yards.

Figure 21 shows that the South Carolina study found that shot placement is most important factor in how far deer run after being hit by a hunting bullet from a centerfire rifle. Hits to the neck and spine drop deer immediately, due to disruption of the central nervous system paralyzing the deer and rendering it incapable of running. Similarly, hits to the shoulder usually render the deer incapable of standing due to disruption of necessary bone structure. Deer hit in the shoulder drop very quickly and bleed to death in a few seconds because the bullet and bone fragments shred the underlying lungs, heart, and vascular tissue. Deer hit in the heart bleed to death quickly, but deer run fast, and can cover a bit of ground in the few seconds before they succumb to hypoxia resulting from loss of blood pressure. Deer hit in the lungs and abdomen cover a bit more ground before succumbing to blood loss effects because they bleed out more slowly.

## Ballistics of the 30-06 Rifle Cartridge

The authors of this study recommend the shoulder shot on deer because it quickly incapacitates and has some margin for error with imperfect shot placement.

*Based on the data collected in this study we feel that the best shot placement for deer is the broadside shot directed at the shoulder. Traveling an average of only 3 yards, deer shot in the shoulder traveled significantly less distance than deer shot in the heart, lungs, or abdomen. Also, with such a short distance of travel, deer shot squarely in the shoulder did not generally leave the hunter's sight. In this study, the broadside shoulder shot essentially gave results similar to what most hunters expect from a neck shot. Presumably the broadside shoulder shot works well because it strikes part of the heart and or lungs which itself is a mortal blow. However, a shot through the scapula damages the brachial plexus which is part of the central nervous system thereby rendering the animal immobile. It knocks the animal out and it never regains consciousness. Also, the shoulder is a very large target offering room for error; a high shot hits the spine, a low shot the heart and a shot to the rear hits the lungs. (52)*

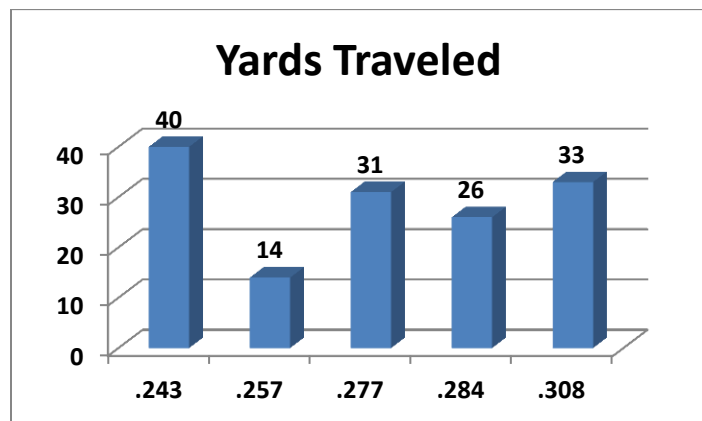


Figure 22: Average yards travelled by deer after being shot with the specified bullet diameter (in inches) in the South Carolina deer study.

Figure 22 shows that the yards travelled by deer does not vary much for calibers between 0.277 and 0.308 inches in diameter. The decrease in travel distance for 0.257" might be due to the high impact velocity of 25 caliber cartridges or it might be a statistical anomaly due to the small number of deer (36) shot with that caliber in the study. The authors conclude that there is little difference between calibers in this study.

Table 4 shows that deer shot with soft, rapidly expanding bullets that lose energy quickly in tissue generating larger retarding forces travel shorter distances (on average), drop in their tracks with greater frequency, and leave better blood trails sign compared with hard, controlled expansion bullets which tend to penetrate deeply, lose energy more slowly in tissue, and resist fragmentation. The hard bullets yielded longer average travel distances, a lower percentage dropped in their tracks, and a higher percentage that leave poor blood trails.

Type	# Deer	Yards traveled	% Dropped	% Poor sign
Soft	360	27	58%	12%
Hard	84	43	49%	21%

Table 4: Results from the South Carolina study on deer shot with soft, rapidly expanding bullets compared with results on deer shot with hard, controlled expansion or heavy for caliber bullets.

### 2. Marshall and Sanow Study

In a study that included analysis of thousands of shootings, Evan Marshall and Edwin Sanow evaluate incapacitation potential of ammunition by classifying shooting events as to whether a single hit to the thorax results in the rapid incapacitation of a violent criminal attacker. (53) Sufficient data were available to give a "one shot stop" (OSS) rating to a wide variety of handgun, shotgun, and rifle loads. Loads in the 9mm handgun varied from a 67% OSS rating for full metal jacket (FMJ) ammunition up to an 91% OSS rating for the best-performing jacketed hollow points. The .45 ACP varied from a 69% OSS rating for FMJ loads up to a 94% OSS rating for the best-performing JHP loads.

Detailed numerical analysis of the OSS data set showed that the OSS rating was highly positively correlated with bullet energy loss in tissue, the size of the temporary cavity, and the size of the permanent cavity; however, the OSS rating was negatively correlated with penetration depths above 12". (53)[Ch. 28] (54) The available data did not include sufficient shootings to determine OSS ratings for 30-06 loads, but the ballistic similarities between the 30-06 and the .308 Winchester allow some inferences. Several .308 Winchester loads with 168 grain match

# Ballistics of the 30-06 Rifle Cartridge

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bullets were reported to have OSS ratings from 97-100%, which were among the most effective ammunition included in the study. Simply put, it is a rare event when a violent attacker continues the attack after a hit to the thorax with a .308 bullet. For comparison, the .223 Remington loads in the study had OSS ratings between 93% (55 grain FMJ) and 100% (the best JHP and match loads), and 00 buckshot 12 gauge loads had OSS ratings from 88% to 94%.

One should be mindful that most of the data for the .308 Winchester loads is from incidents involving police sharpshooters with typical engagement ranges under 100 yards. At longer ranges, the lower impact velocities probably yield less spectacular results. Incapacitation data are not available for the .308 Winchester or 30-06 at longer ranges, but some inferences are possible by considering the data for the 30-30 Winchester which fires 150-170 grain bullets of the same caliber at lower muzzle velocities (2200 fps). The 30-30 Winchester has OSS ratings that vary from 90% to 95% for bullets designed to expand. (55)[p. 337]

### 3. Terminal Ballistics Summary

The 30-06 is the most powerful rifle cartridge that has found wide application in military, hunting, law enforcement, and target shooting applications. At shorter ranges, it displays better barrier penetration and wounding effects than less powerful cartridges at a level of recoil that is manageable for most experienced shooters. It is a reasonable choice for its terminal ballistics against targets the size of humans, deer, black bear, elk, and moose.

In the same way that no one brings a handgun to a gunfight with any degree of enthusiasm, no one brings a 30-06 to hunt dangerous game with enthusiasm. However, dangerous game is occasionally hunted with archery, and there are certainly loads for the 30-06 which are better matched for the task than the “outrageous fortunes” of “slings and arrows.” One might also reasonably wonder what bullet would be a good choice if a lion escapes from the zoo or for protection from bears when camping or packing out meat from a successful hunt. It is not unreasonable to pick the trusty 30 caliber with which one has slain dozens of deer over

a larger caliber with much less familiarity. After killing several lions with his trusty .303 British, Col. John Patterson had one of the famous Tsavo man-eater lions in his sights when a borrowed larger caliber malfunctioned and the opportunity is lost. (27)

### V. Conclusion

The 30-06 is never a mistake. – Townsend Whelen

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