3.
Vihtavuori Powders for Small Arms

HISTORY

The history of powders starts from black powder - a mixture of potassium nitrate (saltpeter) sulphur and charcoal. Most history books credit this invention to the Chinese, even prior to the Christian era. In Europe black powder became known in the 13th century. It gained more widespread use as a propellant in guns and also as a blasting explosive during the next century.

Roger Bacon (1214-1294), an Englishman, developed a method of refining saltpeter. He also experimented with different proportions of sulphur and charcoal in order to see which resulted in the most potent explosive properties when mixed with the saltpeter. Bacon knew he had developed a powerful explosive but he could not foresee its use as propellant for guns. This was left to Berthold Schwarz, a German, who is considered to be the inventor of the firearm.

Black powder was used both as propellant and blasting explosive until the turn of this century. It is still being used on a small scale for blasting purposes. A new development in gunpowder took place in the mid-1840s, when Schönbein (of Germany) studied the properties of cotton. Soon afterwards the manufacture of nitrocellulose began, which in due course led to the development of so-called smokeless powder. In 1894 the Frenchman Vieille managed to dissolve nitrocellulose fibers into an ether-alcohol solvent, and thus the first smokeless single base powder was born through gelatinization. The energy producing component was nitrocellulose.

The second important milestone was achieved in the mid-1800s when Sobrero accomplished the manufacture of nitroglycerine. The Swede Alfred Nobel succeeded in gelatinizing nitrocellulose with nitroglycerine in 1888, and thus the first double base powder was born. It was initially called Ballistite. Nitroglycerine is the second energy producing component in addition to nitrocellulose in double base powders.

Although the first smokeless powders were developed over a century ago, they still remain the major propellant in guns today.

Finland has a long tradition in manufacturing gunpowder. Production started in 1926 at Vihtavuori.

TODAY'S POWDERS FOR SMALL ARMS

Small caliber arms mainly use single base gunpowders. The main component in these powders is nitrocellulose, which provides the energy content, while additives are added to control the characteristics. Nitrocellulose is manufactured by treating ordinary cellulose with a mixture of acids. Thus the energy and oxygen content in the powder can be increased. In this way the powder can burn without external oxygen which, of course, is not available in an enclosed cartridge in the chamber of a gun.

With the aid of certain additives the powder's ballistic, chemical and physical properties can be adjusted to a limited extent. The most common additives in small caliber gunpowders are stabilizers, surface treatment and flame reducing agents.

Stabilizer is always added to gunpowder so that the product maintains its physical and chemical properties even after prolonged storage. It is typical for pure nitrocellulose to chemically decompose as time passes. Stabilizer is added to prevent autocatalytic decomposition of the powder. The most common agents in small caliber powders are diphenylamine, centralites and akardites. The typical stabilizer content of gunpowders is 1-3 per cent.

Another additive always used is graphite. This is added on the surface of the powder in order to improve its electrical conductivity. This reduces problems with static electricity, which in turn makes the powder safer, considerably more fluid and easier to handle, especially when using loading machines.

The surface treatment agents employed control the burning characteristics of the powder. The purpose is to slow the initial combustion process. Since these agents are contained solely in the surface layer of each grain, burning accelerates once this layer has been consumed. This results in the desired progressive burning characteristics. Thus the highest possible muzzle velocities can be achieved with the lowest possible maximum pressure. The most common surface treatment agent is centralite, the proportion of which varies from 1 to 4 per cent, depending upon the type of powder.

Figure 3-1 depicts the effect of surface treatment on the ballistic properties of the powder. An increase in the surface treatment percentage results in a greater reduction in pressure than in muzzle velocity. Thus increasing the charge results in a proportionally larger increase in muzzle velocity than in chamber pressure. Of course the internal case volume sets the limit to the choice of powder.

Flame reducing agents are added to gunpowders to reduce or prevent muzzle flash. These agents in general reduce the energy of the powder and increase smoke generation to a degree. As for muzzle flash, gunpowder burning too slowly results in a burst of burning powder, which in turn generates a sizeable muzzle flash. In such cases a faster burning powder should be selected for the purpose. The commonest flame reducing agents are potassium bitartrate and potassium sulphate.

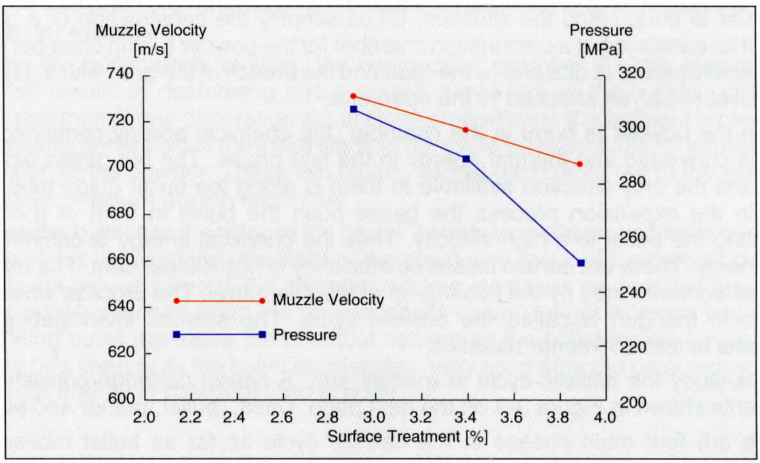


Fig. 3-1. The influence of surface treatment on the ballistic properties of the powder. Test caliber 7.62 x 53R, bullet weight 12 g.

Vihtavuori Oy manufactures numerous small arms powders which are divided into three families: the N100, N300 and N500 series. The N100 series is for rifles. The N300 series is suited to pistol, revolver and shotgun applications. The N500 series was specifically designed for use in rifles firing heavy bullets. Due to the simple chemical composition of Vihtavuori powders and the high quality of Vihtavuori nitrocellulose these powders are truly smokeless and clean burning without barrel contamination, and they are non-corrosive.

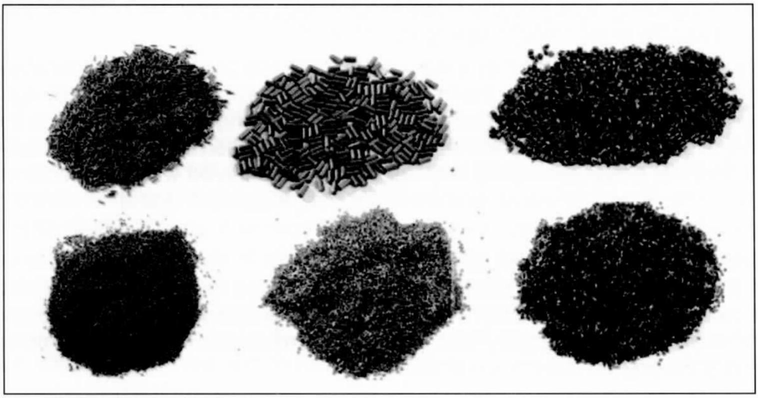


Fig. 3-2. Powders for Small Arms manufactured by Vihtavuori Oy.

FUNCTIONING OF POWDER IN A GUN BALLISTIC CYCLE

When a gun is fired, the shooter normally notices a moderate muzzle blast, a little smoke and the recoil of the gun. But what happens inside the gun? How is it possible to accelerate the bullet to velocities of up to 1000 m/s (3280 fps) and more? And all in a distance of less than 1 meter (3 ft.)?

In order to understand the situation, let us simplify the construction of a gun and imagine it as consisting of a combustion chamber for the powder (= gun chamber), which is hermetically sealed at one end (= the case and the breech of the gun) with a guide tube for the bullet (= barrel) attached to the open end.

When the powder is burnt in the chamber, the chemical energy contained in the powder is converted into thermal energy in the first phase. The hot gases generated expand and the only direction available to them is along the bullet guide tube (= rifle barrel). In the expansion process the gases push the bullet in front of them, thus accelerating the bullet to a high velocity. Thus the chemical energy is converted into kinetic energy. There are certain losses so efficiency is not 100 per cent. The main loss is heat, as demonstrated by the heating-up of the rifle barrel. The process which takes place inside the gun is called the ballistic cycle. The science investigating these phenomena is termed interior ballistics.

Let us study the ballistic cycle in a small arm. A typical cartridge consists of the components shown in Figure 3-3 on the next page: Case, bullet, primer and powder.

There are four main phases in the ballistic cycle as far as bullet movement is concerned:

1) Bullet stationary.
2) Bullet moves forward and leaves the mouth of the case.
3) Bullet moves forward in the barrel and starts to rotate around its own axis.
4) Bullet leaves the muzzle of the gun.

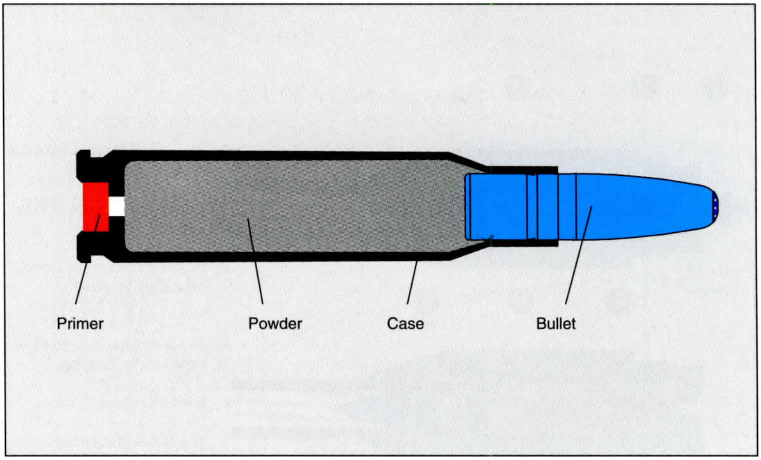


Fig. 3-3. The construction of a small arm cartridge.

Each phase consists of several sub-phases, which are explained below and in Figure 3-4 on the next page.

At the beginning of the ballistic cycle the cartridge has been loaded into the chamber and the breech closed. The gun is now ready to be fired. The ballistic cycle starts when the trigger is squeezed, the sear releasing the striker, the firing pin hitting the primer, which then ignites. It pushes burning, red hot gases and glowing particles inside the case and into the powder. These cause the powder to ignite. Ignition spreads to all surfaces of the powder grains. This causes a chain reaction inside the case. The pressure and temperature increase fairly rapidly. The bullet resists release and the start of movement, so pressure increases to 10...60 MPa (2 to 10 kpsi) before the bullet starts to move along the barrel. The pressure range is wide because of variations in case material and bullet crimping, for example.

When the bullet starts moving, the combustion chamber volume expands. This expansion results in decreasing gas pressure. However, as the burning rate of the powder and thus of gas generation are in close proportion to the ambient pressure, the high pressure generated at the initial stage of the cycle is responsible for expediting the combustion of the powder. These two factors cancel each other out to the extent that progressive pressure growth continues.

When the bullet hits the rifling in the barrel, it starts to rotate around its own axis. The purpose of this is to stabilize the flight of the bullet as a result of the gyroscopic effect. As the bullet moves forward, the chamber volume increases as does the pressure. A stage is quickly reached when the powder gases can no longer increase because the accelerating bullet increases the chamber volume as the bullet moves forward. Peak pressure falls sharply as the bullet accelerates. Very soon after the peak pressure falls, the powder energy in chemical form is gone.

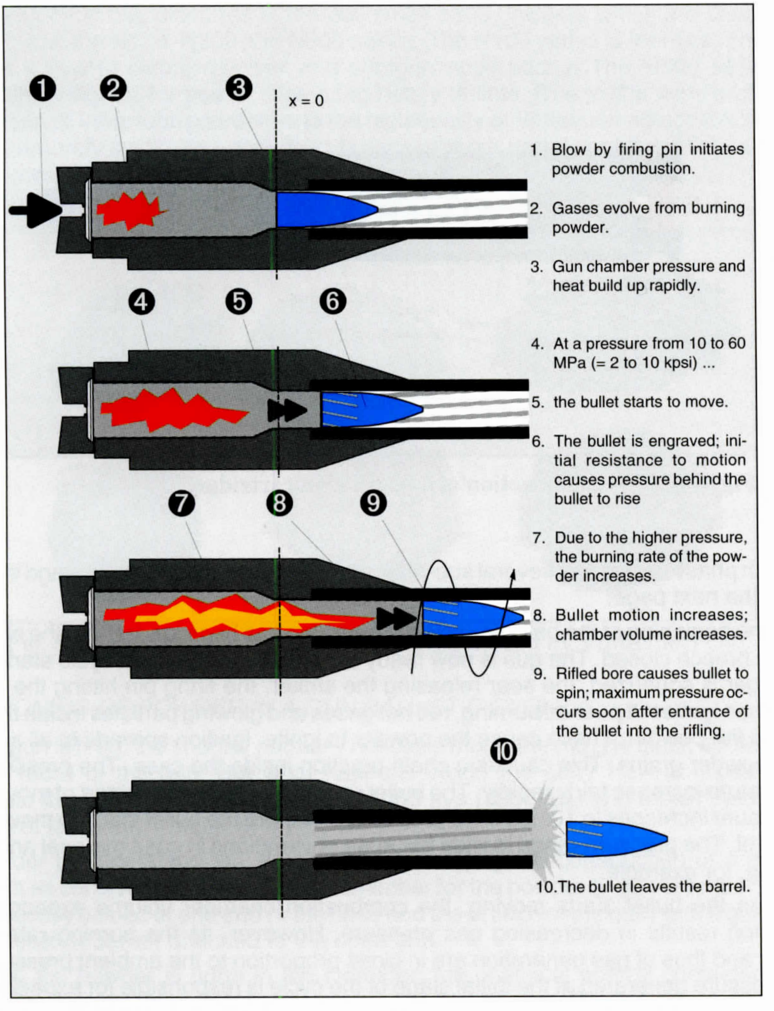


Fig. 3-4. The Ballistic Cycle.

At the muzzle the barrel pressure is typically 10...30 % of its maximum value. This is highly dependent upon the gun and type of cartridge, though. When the bullet exits the muzzle, the velocity increases slightly due to residual muzzle thrust. After this thrust, the flight of the bullet is determined solely by the laws of exterior ballistics.

Figure 3-5 on the next page shows the typical behaviour of the pressure and the bullet velocity inside the barrel.

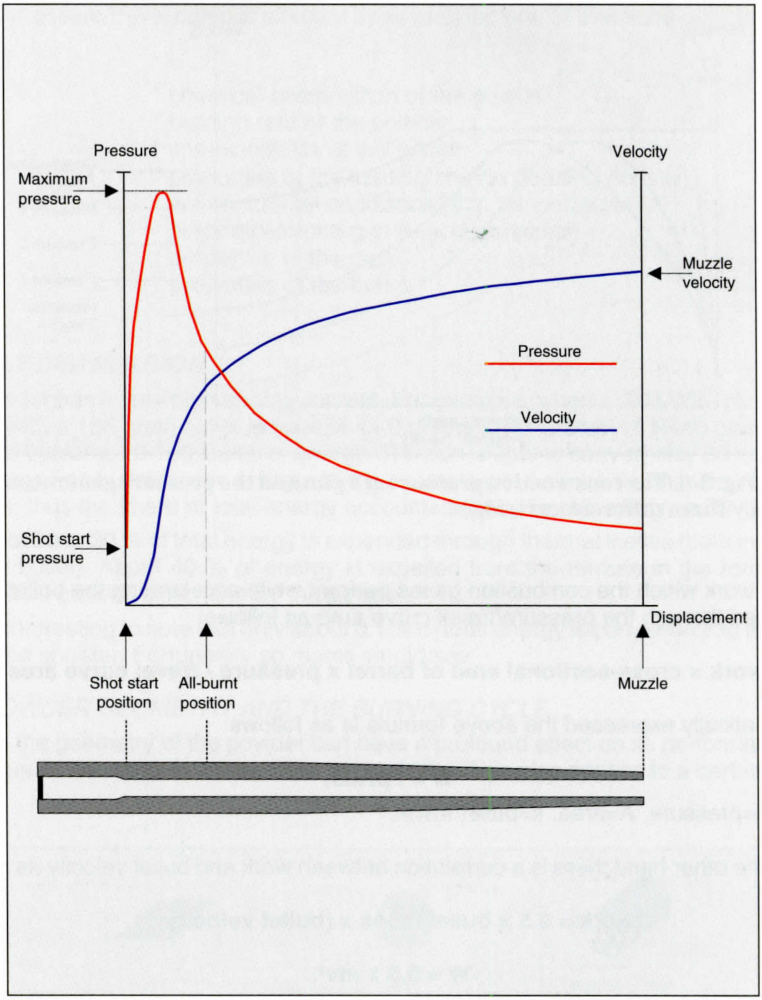


Fig. 3-5. Typical behaviour of pressure and bullet velocity in a firearm.

CORRELATION BETWEEN PRESSURE AND VELOCITY

Every gun is designed to withstand a certain pressure for that particular firearm, which normally peaks at the chamber and falls towards the end of the muzzle. These design criteria set limits to the cartridges used in the gun.

Figure 3-6 on the next page illustrates the typical construction pressure of a gun. Also illustrated are the pressure curves of three cartridges which differ in terms of powder type and powder charge. The pressure curves are shown as p1, p2 and p3.

Looking at the areas of the three different pressure diagrams p1, p2 and p3 it can be said that all the diagrams cover an equal area although the maximum pressure values differ from each other.

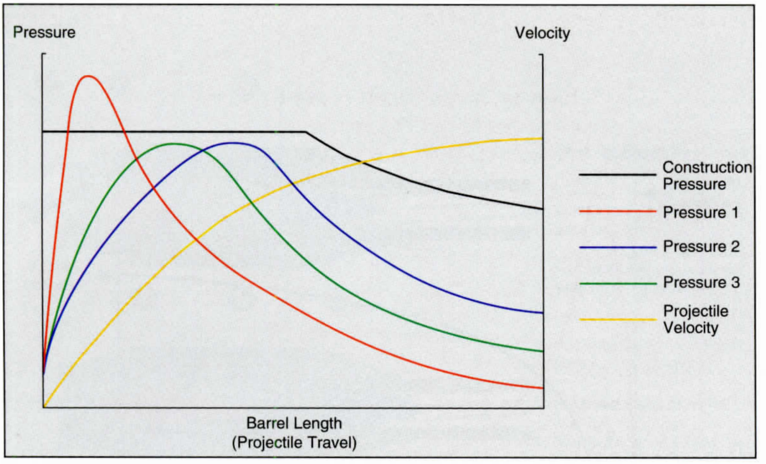


Fig. 3-6. The construction pressure of a gun and the pressure generated by three different cartridges.

The work which the combustion gases perform while accelerating the bullet can be expressed through the pressure/travel curve area as follows:

work = cross-sectional area of barrel x pressure / travel curve area

Mathematically expressed the above formula is as follows:

$$W = \int pAds,$$

where p=pressure, A=area, s=bullet travel.

On the other hand there is a correlation between work and bullet velocity as follows:

work = 0.5 x bullet mass x (bullet velocity)^{2},

i.e.

$$W = 0.5 \times mv^2,$$

where m=bullet weight divided by the gravitational constant.

Since in our example the pressure/travel curve areas are equal, each cartridge produces the same muzzle velocity. The pressure/travel curve p1 exceeds the maximum construction pressure of the gun. This can result in disastrous harm to the gun and the shooter. During the reloading process it must always be observed that the designed maximum pressure of the weapon is not exceeded.

If there is a desire to increase the bullet velocity the pressure/travel curve area needs to be expanded. If the pressure has already reached its peak, the only possibility left is to make the envelope wider. One way to do this is to replace the powder with another one that burns more progressively. The drawback here is that the residual pressure at the muzzle will increase, as will the muzzle blast.

The pressure/travel curve is affected by several factors, of which the most important are the:

* chemical composition of the powder
* burning rate of the powder
* characteristics of the primer
* properties of the loading charge (loading density)
* environmental conditions (e.g. temperature)
* properties of the gun (e.g. dimensions)
* properties of the case
* properties of the bullet

ENERGY DISTRIBUTION

Gunpowder has a very high energy content. For example, when a .308 Win. cartridge is loaded with a 186 grain bullet in front of 41.8 grains (2.71 grams) of N140 powder, the cartridge contains 10 100 joules of energy. The gun is able to convert only 20 to 35 % of this energy into bullet kinetic energy. In the example cited above the muzzle velocity is 740 m/s; thus the share of total energy accounted for by kinetic energy is 32 %.

About 20 to 30 % of total energy is expended through thermal losses (both in the gun and the bullet). About 40 % of energy is expelled from the muzzle in the form of hot combustion gasses generated by the powder.

It is interesting to note that only about 0.1 % of total energy is converted into the recoil felt by the shooter. Fortunately so, some would say.

GUNPOWDER GEOMETRY AND THE BURNING CYCLE

Altering the geometry of the powder can have a profound effect on its performance in a given gun as concerns both pressure and velocity. This also applies to a certain extent

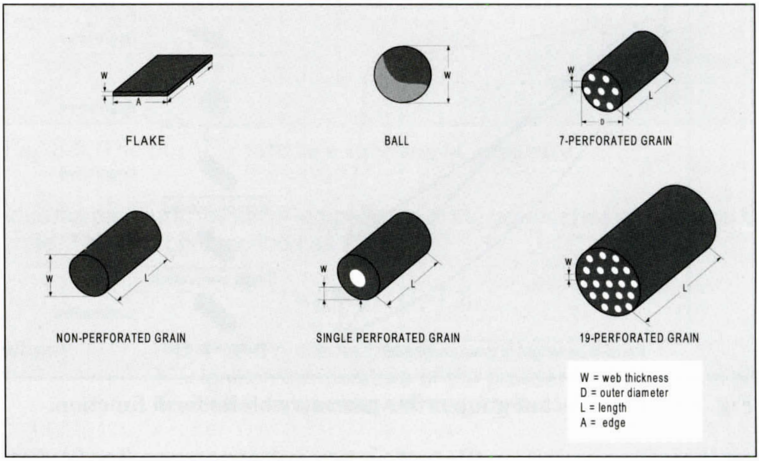


Fig. 3-7. Examples of different powder geometries.

to handguns, which are normally limited to the use of cord or single perforated cylindrical extruded powders or flake powder.

Cylindrical extruded powders can also have multiperforated grains. The most common types are the 7 and 19 perforated varieties.

A multiperforated propellant naturally has a much larger grain diameter than single perforated powder, a factor which limits the former's use in cartridges for small arms.

The web thickness in gunpowder phraseology means the minimum distance within the powder grain that the combustion zones can travel without encountering each other. Thus, in spherical powder, this distance is the diameter of the pellet ("ball"); in flake powder it is the thickness of the flake; and in multi-perforated extruded powders it is the minimum distance between the perforations.

The burning rate of homogeneous gunpowder without surface treatment is related to the momentary area of burning surface at a certain standard pressure. The change in the area of burning surface of the powder during combustion is described by a so-called form function. If this area keeps increasing the form function also increases and its burning behaviour is termed "progressive". If the form function in question is decreasing, in other words the area of burning surface of the powder decreases as combustion progresses, its burning behaviour is said to be degressive. If the flame area remains constant throughout the combustion process, we refer to "neutral" burning behaviour.

A good example of a progressive burning, non-treated powder is multi-perforated cylindrical powder. As each grain ignites simultaneously on all free surfaces the area of burning surface increases until the combustion zones meet and the form function reaches its peak value before turning down.

Flake and ball powders constitute good examples of degressive powders. Long tubular powder, on the other hand, has an area of burning surface which remains

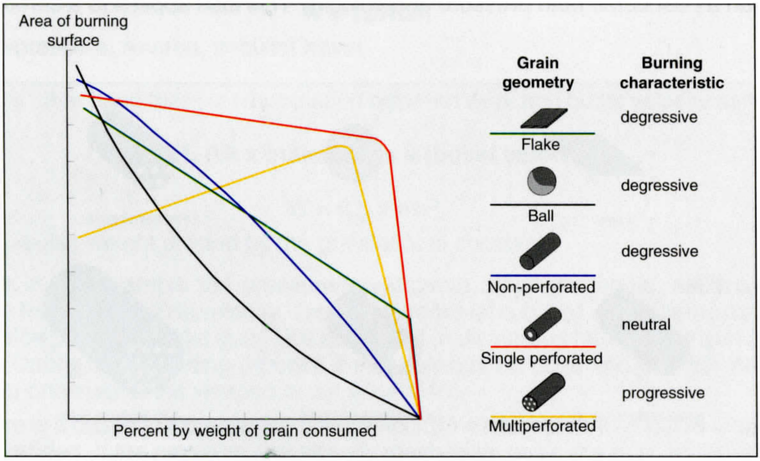


Fig. 3-8. The effect of gunpowder geometry on its form function.

constant and can thus be described as burning neutrally. Figure 3-8. shows the effect of powder geometry on its form function.

When a gun is fired the pressure/velocity ratio is dependent on the rate at which the powder burns, which in turn depends upon the chemical composition of the powder, pressure, temperature and the area of burning surface.

Of the external factors pressure has the greatest effect on the burning rate. As pressure increases so too does the burning rate of the powder. The burning of powder is often described by means of empirical models such as Saint Robert's formula:

$$\mathbf{r = Bp^n, n < 1},$$

where r = linear burning rate
p = pressure
B = empirical constant
n = pressure exponent

In the case of nitrocellulose powders constant 'B' is typically in the range of 0.5...3.0 mm/s/MPa and the value of the pressure exponent close to 1.0.

An example of the correlation between the burning rate and pressure is given in Figure 3-9.

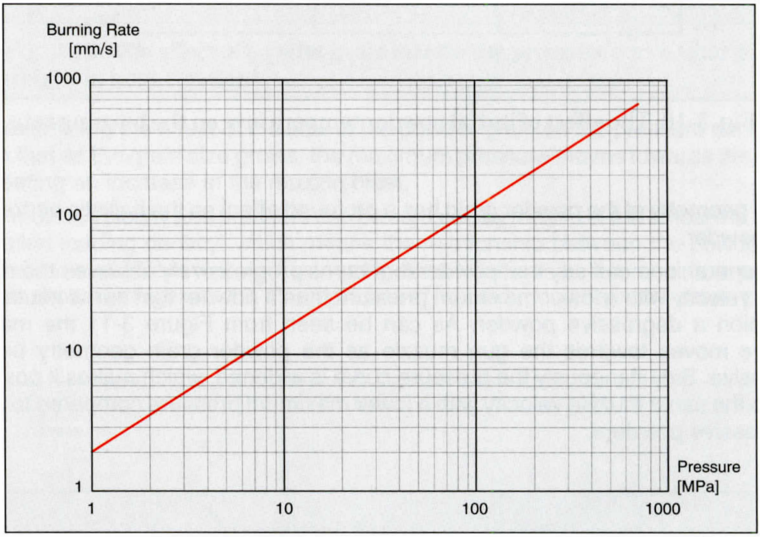


Fig. 3-9. The burning rate as a function of pressure.

Besides the pressure, the initial temperature of the powder has an effect on the linear burning rate. This can be described as follows:

$$\mathbf{r = [(Bp^n) / (T_r - T_0)]},$$

where r, B, P and n are as before
T_r = ignition temperature of the powder (= deflagration point)
T_0 = initial temperature of the powder

Figure 3-10 on the next page depicts the effect of the initial temperature of the powder on the linear burning rate.

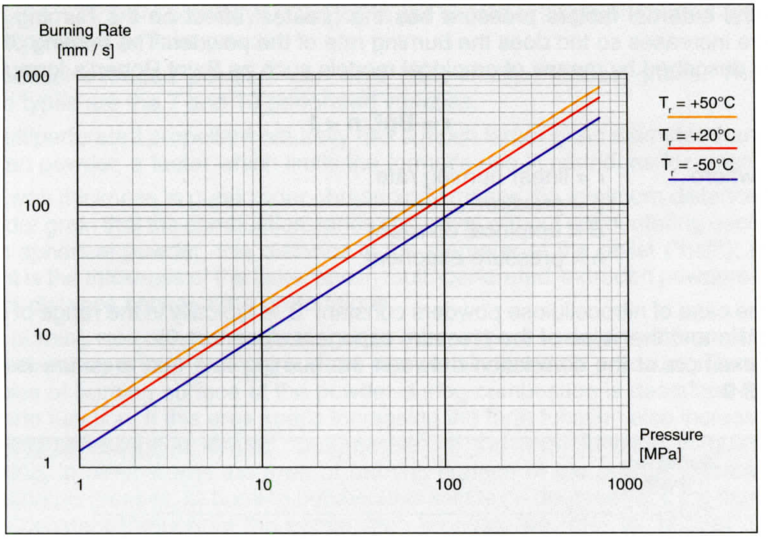


Fig. 3-10. The effect of initial powder temperature on the burning rate.

The geometry of the powder grain has a profound effect on the ballistic performance of the powder.

In general, one can say that powder that burns progressively achieves the required muzzle velocity with a lower maximum pressure than a powder that burns neutrally, not to mention a degressive powder. As can be seen from Figure 3-11 the maximum pressure moves towards the gun muzzle as the powder grain geometry becomes progressive. Simultaneously the pressure curve is widened, which makes it possible to achieve the same muzzle velocity with a lower maximum pressure compared to the use of degressive powders.

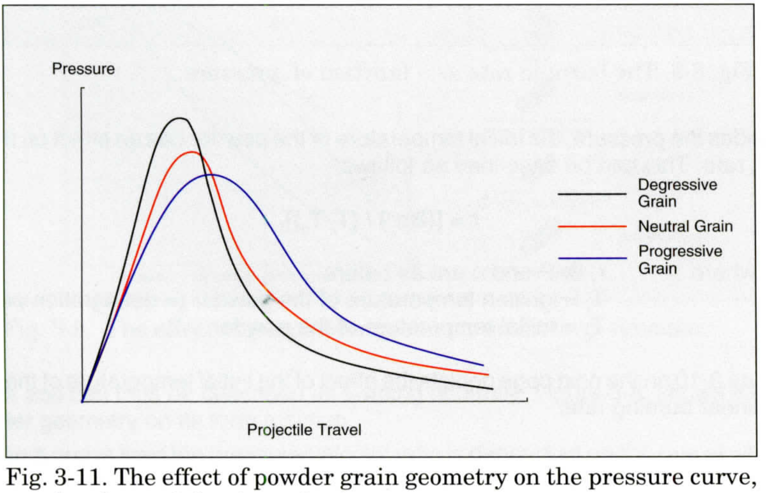


Fig. 3-11. The effect of powder grain geometry on the pressure curve, powder charge is kept constant.

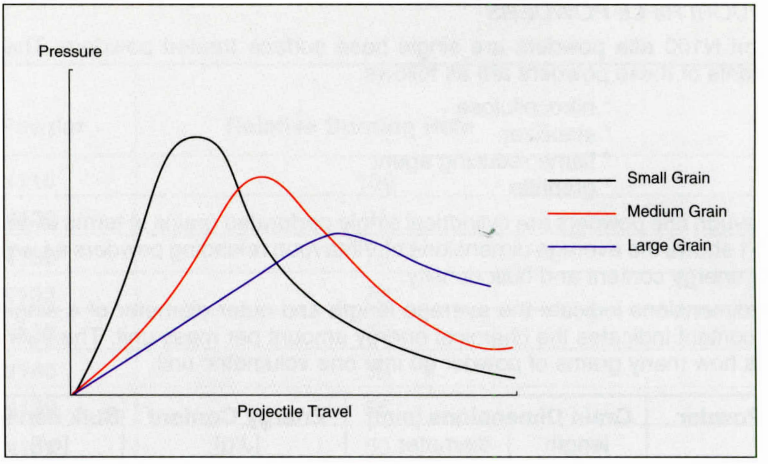


Fig. 3-12. The effect of powder grain size on the pressure curve, charge weight is kept constant.

On examining the effect of the size of the powder grain on the pressure curve it can be seen that as the grain size grows, the maximum pressure moves towards the muzzle thus creating an increase in the muzzle blast.

The muzzle velocity and pressure can be adjusted by means of the amount of powder or so-called loading density, which means the relationship between the powder mass and the volume available to it. As the loading density increases, the maximum pressure grows as shown in Figure 3-13. Peak pressure, however, occurs in the same position.

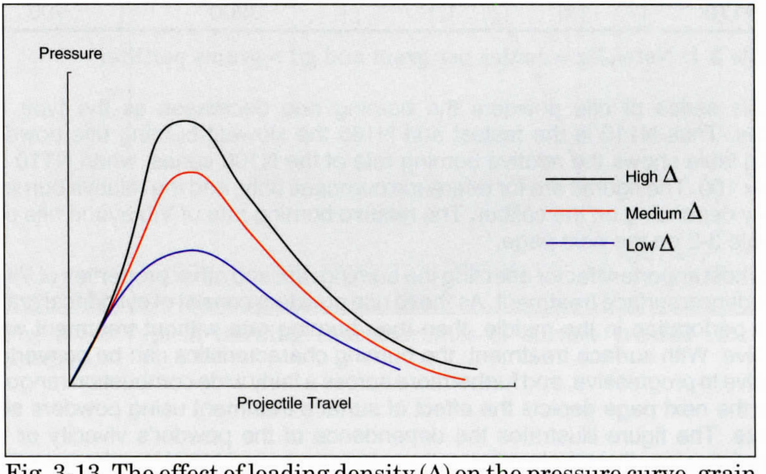


Fig. 3-13. The effect of loading density (Δ) on the pressure curve, grain size and geometry are kept constant.

VIHTAVUORI RIFLE POWDERS

Vihtavuori N100 rifle powders are single base surface treated powders. The typical components of these powders are as follows:

* nitrocellulose
* stabilizer
* flame reducing agent
* graphite

Vihtavuori rifle powders are cylindrical single perforated grains in terms of geometry. Table 3-1 shows the average dimensions of Vihtavuori reloading powders as well as the average energy content and bulk density.

The dimensions indicate the average length and outer diameter of a single grain. Energy content indicates the chemical energy amount per mass unit. The bulk density indicates how many grams of powder go into one volumetric unit.

Powder	**Grain Dimensions** [mm] length	diameter	**Energy Content** [J/g]	**Bulk density** [g/l]
N110	1.1	0.8	3950	800
N120	0.7	0.6	3700	860
N130	1.0	0.7	3800	880
N133	1.0	0.7	3600	880
N135	1.0	0.7	3600	880
N140	1.0	0.9	3700	910
N150	1.3	1.0	3750	910
N160	1.3	1.0	3600	930
N165	1.3	1.0	3500	930
N170	1.6	1.1	3900	900

Table 3-1. Note: J/g = Joules per gram and g/l = grams per liter

In this series of rifle powders the burning rate decreases as the type number increases. Thus N110 is the fastest and N165 the slowest burning rifle powder. The following table shows the relative burning rate of the N100 series, when N110 is given the index 100. The figures are for reference purposes only, and the relative burning rates may vary depending on the caliber. The relative burning rate of Vihtavuori rifle powders is in Table 3-2 on the next page.

The most important factor affecting the burning rate and other properties of Vihtavuori rifle powders is surface treatment. As these rifle powders consist of cylindrical grains with a single perforation in the middle, then their burning rate without treatment would be degressive. With surface treatment, the burning characteristics can be converted from degressive to progressive, and furthermore across a fairly wide combustion range. Figure 3-14 on the next page depicts the effect of surface treatment using powders similar in grain size. The figure illustrates the dependence of the powder's vivacity or burning characteristics on the combustion ratio, which is here shown as the correlation of pressure (at moment in time t) and maximum pressure, in other words when p/pmax = 1, all the powder has been burned. Vivacity can be determined experimentally with a so-called manometric bomb. This is a test device which allows the burning characteristics of a powder to be studied in a hermetically sealed chamber.

Powder	Relative Burning Rate
N110	100
N120	81
N130	75
N133	72
N135	70
N140	58
N150	56
N160	50
N165	47
N170	41

Table 3-2.

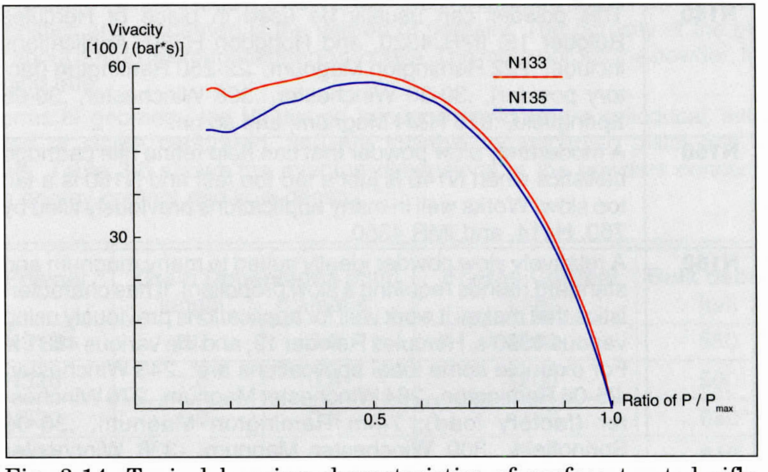


Fig. 3-14. Typical burning characteristics of surface treated rifle powders.

Vihtavuori rifle powders cover a very wide range of use all the way from .17 Rem. to .50 caliber. The most common applications are presented in the following table.

Powder	Applications
N110	A very fast burning propellant that can be used in applications which previously used Hercules 2400, Hodgdon H110, or Winchester 296. Typical applications include: .22 Hornet, .25-20 Winchester, .357 S&W Magnum, .357 Maximum, .44 Magnum, and .45 Winchester Magnum.
N 120	This speed needs higher pressure than N110 in order to optimize burning. Burning rate falls near the various 4227s. It works superbly with comparatively light bullets in .22 caliber cartridges. It is, by nature, a limited application propellant.
N130	Burning rate is between IMR4227 and the discontinued Winchester 680. This is the powder used in factory loaded .22 and 6mm PPC.
N133	This speed is very close to IMR 4198 in quickness. Thus, it is ideal for the .222 Remington, .223 Remington, and .45-70 Government and other applications where a relatively fast burning rifle propellant is needed.
N135	This is a moderate burning propellant. It will fit applications similar to Hercules Reloder 12, IMR-4895 or IMR 4064. Applications range from the .17 Remington to the .458 Winchester.
N140	This powder can usually be used in place of Hercules Reloder 15, IMR 4320, and Hodgdon H380. Applications include: .222 Remington Magnum, .22-250 Remington (factory powder), .30-30 Winchester, .308 Winchester, .30-06 Springfield, .375 H&H Magnum, and so on.
N150	A moderately slow powder that can help refine rifle cartridge ballistics when N140 is just a tad too fast and N160 is a tad too slow. Works well in many applications previously filled by 760, H414, and IMR 4350.
N160	A relatively slow powder ideally suited to many magnum and standard rounds requiring a slow propellant. It has characteristics that makes it work well for applications previously using various 4350's, Hercules Reloder 19, and the various 4831's. For example some ideal applications are: .243 Winchester, .25-06 Remington, .264 Winchester Magnum, .270 Winchester (factory load), 7mm Remington Magnum, .30-06 Springfield, .300 Winchester Magnum, .338 Winchester Magnum, .375 H&H Magnum, etc. This is destined to being one of our most popular powders.
N165	A very slow burning magnum propellant for use with heavy bullets. Applications begin with very heavy bullets in the .30-06, and include the .338 Winchester Magnum.
N170	The slowest Vihtavuori propellant and the one of the slowest canister reloading powder generally available from any manufacturer.

Table 3-3.

POWDERS FOR .50 BMG

For .50 BMG there are two special Vihtavuori powders available, 24N41 and 20N29. They are, like N100 series, single base surface treated powders. Their burning rate is slower and their grain size is larger than that of the N100 series rifle powders. 24N41 is slightly faster burning than 20N29.

Powder	**Grain Dimensions** [mm] length	diameter	**Energy Content** [J/g]	**Bulk density** [g/l]
24N41	2.3	1.3	3700	980
20N29	2.3	1.3	3600	990

Table 3-4. Note: J/g = Joules per gram and g/l = grams per liter

The relative burning rate of the 24N41 is 38 and that of the 20N29 respectively 36.

VIHTAVUORI HANDGUN POWDERS

Vihtavuori handgun powders are suited to pistol, revolver and shotgun applications. They are single base powders which typically consist of the following components:

- nitrocellulose
- stabilizer
- flame reducing agent
- graphite

With porous series N300 powders the most important factor as far as burning characteristics are concerned is the degree of porosity. The porosity of the powder is brought about during the manufacturing process. The more porous the powder, the faster the burning rate.

In terms of geometry the Vihtavuori handgun powders are cylindrical, either non-perforated or single perforated, and are suitable for reloading pistol and revolver cartridges. Table 3-5 shows the average dimensions of the powders concerned, the average energy content and bulk density.

Powder	**Grain Dimensions** [mm] length	diameter	**Energy Content** [J/g]	**Bulk density** [g/l]
N310	0.7	0.6	4200	550
N320	1.0	0.8	4200	560
N330	1.0	0.8	4150	630
N340	1.0	0.8	4200	640
N350	1.0	0.7	4200	690
3N37	0.6	0.6	4100	740
N105	1.1	0.8	3950	730

Table 3-5. Note: J/g = Joules per gram and g/l = grams per liter

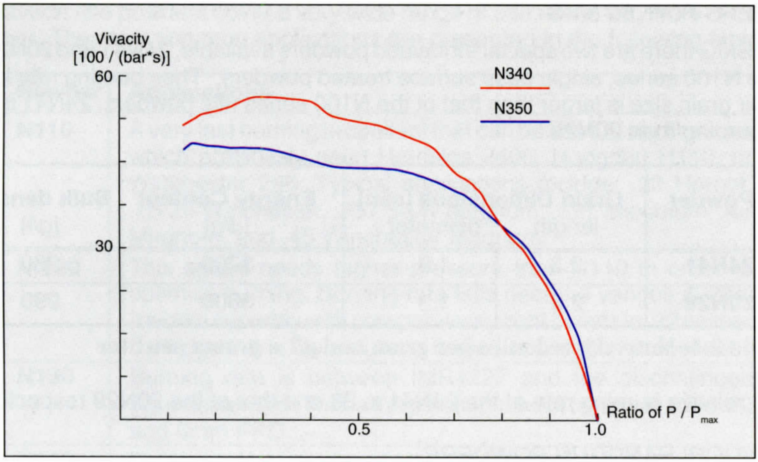


Fig. 3-15. Typical Burning Characteristics of Vihtavuori Series N300 powders.

In the N300 series the burning rate decreases as the type number increases. The fastest burning porous powder is N310, the slowest N350. 3N37, a product of 3N-series, is comparable to N350 in terms of burning rate, while N105 is the slowest burning alternative of Vihtavuori handgun powders. In the following table the relative burning rate of the Vihtavuori handgun powders is shown, where N110 is given the index 100. The numbers are for reference purposes only, and the relative burning rates may vary depending upon the caliber.

Powder	Relative Burning Rate
N310	330
N320	270
N330	205
N340	195
N350	165
3N37	150
N105	111

Table 3-6.

Powders in the N300 series have degressive burning characteristics as surface treatment is not employed. The exceptions are 3N37 and N105, which are given very light treatment. Degressive burning is enhanced by the porosity of the grain, which means a high start-up surface burning area. The typical burning characteristics of the N300 series are shown in Figure 3-15.

Vihtavuori N300 series powders have a very wide range of burning rates. They are thus suited for use in a wide range of calibers. Applications range from .25 Auto to .45 Winchester Magnum. The most common applications are listed in the following table.

Powder	Applications
N310.	Very fast burning and competitive with Bullseye and Accurate No.2. It has applications in a very wide range from the .25 ACP to the 9mm Luger.
N320	A handgun powder of comparatively fast burning rate. Useful in many popular cartridges. Currently available data includes 9mm Luger, .38 Special, .357 Magnum, .44 Magnum, .45 ACP and .45 (Long) Colt. Burning rate generally is perhaps a tad faster than 231 or generally about like Red Dot.
N330.	A handgun powder that has a burning rate similar to Green Dot, No. 5, or PB. Data is currently available for 9mm Luger, .38 Special, .40 S&W, .44 S&W Special and .45 (Long) Colt.
N340	With a burning rate not dissimilar to Winchester 540 or Herco, this powder is a wide application type. Data for the following handgun cartridges is currently available: .30 Luger, 9mm Luger, .38 S&W (Colt New Police), .38 Super Auto, .38 Special, .357 Magnum, .44 Magnum, .45 Auto and .45 (Long) Colt.
N350	This is the slowest burning propellant in the N300 series. Burning speed is about like Blue Dot, "Hi-Skor" 800-X or No. 7. Data is currently available for: 9mm Luger, .38 Super Auto, .38 Special, .357 Magnum, .44 Magnum and .45 Auto.
3N37	This powder is primarily designed for high velocity rimfire cartridges and is not a true N300 series powder. Its burning speed is between N340 and N350, close to "Hi-Skor" 800-X, and it therefore has applications also in handgun cartridges. Data is currently available for: 9mm Luger, .38 Super Auto., .38 Special, .357 Magnum, .357 Maximum, .44 Magnum, .45 Auto and .45 Winchester Magnum. The characteristics of this propellant make it very desirable for competitive handgun shooting.
N105	This special powder has a burning rate between N350 and N110. It is especially developed for handgun cartridges with heavy bullets and/or large case volume. Reloading data is currently available for 9 x 21mm, .38 Super Auto, .357 Magnum, .40 S&W, 10mm Auto, .44 Remington Magnum and .45 Winchester Magnum..

Table 3-7.

This manual does not list data for shotshell reloading, but applicable powders for that purpose include N310, N320, N330, N340 and N350. The new light 24 gram target loads make best use of fast burning N310 and N320. N320 and N330 are suitable for 28 to 32 gram shot loads. The best choice for 34 to 36 gram loads is N340, and type N350 for anything above 36 grams.

HIGH ENERGY N500 SERIES

The ballistic properties of the traditional single base powders can be improved to a certain extent by developing the surface treatment of the powder and improving grain geometry, in other words increasing its progressiveness, by adding energy developing agents (nitramines, nitroglycerol) as well as increasing the compressibility of the powder. Adding nitroglycerine to the traditional single base powder makes possible in addition to geometry and coating a third controlled variable of ballistic properties: energy content. Vihtavuori calls powders which have nitroglycerol added (maximum 25 %) high energy NC-powders, which form the N500 series.

Adding nitroglycerol to the high energy N500 series is done by impregnation. After that the grains are coated with a new type of chemical which results in very progressive burning characteristics.

The composition of a typical high energy powder is as follows:

* nitrocellulose
* nitroglycerol
* coating agent
* stabilizer
* flame reducing agent
* wear reducing agent

Geometrically the powders in the N500 series are equal to the N100 series. Although these new powders have a higher energy content, they do not cause greater wear to the gun. This is because the surface of the powder has been treated with an agent designed to reduce barrel wear.

N500 series powders work well at different temperatures, even better than the traditional N100 and N300 series. Temperature sensitivity naturally depends very much on the weapon and on the cartridge.Vihtavuori High Energy powders are available in three burning rates:

N540 Burning rate like N140. Especially for .308 Winchester.

N550 Burning rate like N150. Especially for .308 Winchester and .30-06 Springfield.

N560 Burning rate like N160. Especially for .270 Winchester and 6.5 x 55 Swedish Mauser.

The manufacturing technique employed permits a very high bulk density, which in turn makes it possible to use a bigger charge in a certain limited loading volume. The following table shows the average grain sizes of the N500 series, energy content and bulk density.

Powder	**Grain Dimensions** [mm] length	diameter	**Energy Content** [J/g]	**Bulk density** [g/l]
N540	1.0	1.0	4050	940
N550	1.0	1.0	3950	940
N560	1.4	1.2	4000	970

Table 3-8. Note: J/g = Joules per gram and g/l = grams per liter

High energy powders are on their best if used in rifle cartridges with a high load density and/or a heavy bullet to the caliber together with a requirement for high muzzle velocity. These powders have been recorded as developing increases in muzzle velocity of 20, 30 and even 50 m/s with no increase in maximum pressure.

The following table on the next page compares the ballistic performance of high energy N550 and N560 to traditional N150 and N160 powders.

Caliber	.308 Win.	.243 Win.
Case	LAPUA	LAPUA
Primer	CCI	CCI
Bullet	LAPUA Mega 12.0 g	LAPUA Mega 5.8 g
Pressure	360 MPa	360 MPa
N150 N550	V_0 763 m/s 2.87 g charge V_0 816 m/s 3.05 g charge	***** *****
N160 N560	***** *****	V_0 960 m/s 2.97 g charge V_0 995 m/s 3.02 g charge

Table 3-9.

In the terms of relative burning rate powders in the high energy N500 series correspond to the N100 series as shown in the following table. The yardstick is N110 powder which has been given the index 100.

Powder	Relative Burning Rate
N540	58
N550	53
N560	42

Table 3-10.

MANUFACTURE OF POWDERS FOR SMALL ARMS

The nitrocellulose used in Vihtavuori powders is always manufactured in-house. High technology is used in the manufacture of both nitrocellulose and powder, which guarantees the top quality of our products. Each type of powder is manufactured on the batch principle. Quality assurance plays a vital role in the manufacture of powders. Quality assurance covers monitoring of raw materials, the semi-finished products and the various stages of the process as well as demonstrating that the end product conforms to requirements. The testing of powder ballistic properties is based on the use of a reference powder. This procedure ensures that variations from one batch to another are as small as possible.

The basic manufacturing process for the N100 and N300 series is as follows. Moist nitrocellulose (approx. 30 % water content) goes through dehydration. This takes place in a hydraulic press by forcing ethanol through the nitrocellulose. The nitrocellulose, moistened with the ethanol, is treated with additives and transferred to a wing mixer. Ether is added as the second solvent. Turning this mass results in a partial solution of the nitrocellulose into a mixture of ether and ethanol. The end result is a plastic raw material for gunpowder.

The raw material is extruded through different nozzles, which give the powder grains their basic shape. The powder cords are then dried to 20...30 % residual solvent content. In the drying process the cords become so strong that they can next be cut to the desired length.

After cutting the grains undergo segregation by size using a sieve. Next they are transferred to vacuum drums which remove most of the solvents, principally ether. At the drying stage the solvents are salvaged by condensing them or by absorbing them into active charcoal.

Surface treatment of the powder grains is carried out also in rotating drums by spraying the powder with a surface treatment agent in solution. Graphite is added in the same manner, which makes the grains polished and electrically conductive. The treated powder is washed with water to remove the solvent in reactors equipped with mechanical mixers. This is also where the first mixing of the powder lot is conducted.

Washing is followed by drying the powder with warm air. The powder lot is mixed again, this time at a drier stage. Residual moisture is regulated to equilibrium level. Before final packing, the powder is again put through sieves.

In the N500 series the energy-giving component nitroglycerol is added to the normal NC- powder by the impregnation method. A nitroglycerol content of up to 25% can be achieved. High energy NC-powder manufacturing can be divided into three phases: (1) Manufacture of traditional, non-surface treated, alcohol-moist NC-powder, (2) addition of nitroglycerol using the impregnation method, followed by surface treatment using special chemicals and washing with water, (3) turning the water-moist powder into the end product by traditional methods.

VIHTAVUORI

Burning Rate Chart

Current canister powders in order of *approximate* burning rate. This list is approximate only and **not** to be used for developing loads.

1. **R-1**, Norma
2. **N310**, VIHTAVUORI
3. **Bullseye**, Alliant
4. **Solo 1000**, Scot
5. **No 2**, Accurate Arms
6. **Red Dot**, Alliant
7. **Clays**, Hodgdon
8. **N320**, VIHTAVUORI
9. **Royal Scot**, Scot
10. **HP-38**, Hodgdon
11. **231**, Winchester
12. **453,** Scot
13. **Hi-Skor 700-X**, IMR Co.
14. **WST**, Winchester
15. **International**, Hodgdon
16. **Green Dot**, Alliant
17. **N330,** VIHTAVUORI
18. **PB**, IMR Co.
19. **No 5,** Accurate Arms
20. **Pearl Scot**, Scot
21. **WSL**, Winchester
22. **Universal**, Hodgdon
23. **Unique**, Alliant
24. **SR-7625**, IMR Co.
25. **WSF,** Winchester
26. **HS-6**, Hodgdon
27. **N340**, VIHTAVUORI
28. **540**, Winchester
29. **Herco,** Alliant
30. **SR-4756**, IMR Co
31. **Solo 1250**, Scot
32. **3N37,** VIHTAVUORI
33. **Hi-Skor 800-X,** IMR Co.
34. **No. 7**, Accurate Arms
35. **Solo 1500**, Scot
36. **N350,** VIHTAVUORI
37. **HS-7**, Hodgdon
38. **Blue Dot**, Alliant
39. **N105**, VIHTAVUORI
40. **No. 9**, Accurate Arms
41. **2400,** Alliant
42. **N110,** VIHTAVUORI
43. **R-123,** Norma
44. **H110**, Hodgdon
45. **296,** Winchester
46. **SR-4759**, IMR Co.
47. **N120,** VIHTAVUORI
48. **IMR-4427**, IMR Co.
49. **H4227**, Hodgdon
50. **N130**, VIHTAVUORI
51. **1680,** Accurate Arms
52. **N-200,** Norma
53. **N133**, VIHTAVUORI
54. **Brigadier 4197,** Scot
55. **H4198**, Hodgdon
56. **IMR-4198,** IMR Co.
57. **2015**, Accurate Arms
58. **Reloder 7**, Alliant
59. **IMR-3031**, IMR Co.
60. **N-201**, Norma
61. **H322,** Hodgdon
62. **2230,** Accurate Arms
63. **Brigadier 3032,** Scot
64. **748**, Winchester
65. **BL-C(2),** Hodgdon
66. **2460**, Accurate Arms
67. **H335,** Hodgdon
68. **H4895**, Hodgdon
69. **Reloder 12**, Alliant
70. **IMR-4895**, IMR Co.
71. **N135,** VIHTAVUORI
72. **IMR-4064**, IMR Co.
73. **Brigadier 4065,** Scot
74. **2520,** Accurate Arms
75. **IMR-4320**, IMR Co.
76. **N-202,** Norma
77. **N540** VIHTAVUORI
78. **N140**, VIHTAVUORI
79. **2700**, Accurate Arms
80. **Reloder 15**, Alliant
81. **H380**, Hodgdon
82. **760**, Winchester
83. **H414**, Hodgdon
84. **N550**, VIHTAVUORI
85. **N150,** VIHTAVUORI
86. **4350**, Accurate Arms
87. **IMR-4350**, IMR Co.
88. **H4350,** Hodgdon
89. **N-204**, Norma
90. **Brigadier 4351**, Scot
91. **Reloder 19**, Alliant
92. **N160**, VIHTAVUORI
93. **N560**, VIHTAVUORI
94. **IMR-4831**, IMR Co
95. **H4831**, Hodgdon
96. **3100**, Accurate Arms
97. **MRP,** Norma
98. **N165**, VIHTAVUORI
99. **Reloder 22**, Alliant
100. **IMR-7828**, IMR Co.
101. **8700,** Accurate Arms
102. **N170**, VIHTAVUORI
103. **H1000**. Hodgdon
104. **H870**, Hodgdon
105. **24N41**, VIHTAVUORI
106. **50BMG**, Hodgdon
107. **20N29**, VIHTAVUORI

4.
Reloading Components and Cartridge Properties

RELOADING COMPONENTS AND CARTRIDGE PROPERTIES

Rifle and handgun cartridges are usually reloaded for a specific application, for example varmints, big game like bear and moose, running target shooting etc., all of which place different, even conflicting demands on the cartridge. A common requirement for all cartridges, however, is that of good accuracy. Before we begin our discussion of the reloading components and their role in cartridge properties we should keep in mind that the cartridge is only one of the factors resulting in good accuracy. What is more, the term 'good accuracy' means different things to different people. A big game hunter is in most cases happy if his big bore magnum rifle/cartridge combination yields a group of 50 mm/ 3 shots at a range of 100 m. In contrast a benchrest competitor feels unhappy if his five-shot group exceeds 7 mm at the same range. To sum up, when judging the initial accuracy produced by a firearm, one has to remember that accuracy is a combination of many factors and that any one factor that is missing or ill-judged can ruin the otherwise good accuracy of the shooter-firearm-cartridge combination. In addition to the cartridge the following factors at least have an affect on initial accuracy:

1. Barrel quality and rifle twist
2. Quality of the barrel and action bedding
3. Trigger quality
4. Sight quality
5. Conditions at the shooting range

and last but not the least:

6. The shooter himself

Before we can judge the accuracy of the cartridge we should therefore take into account the inaccuracy created by the factors mentioned above. When judging the accuracy of reloaded cartridges it is good to remember that factory-loaded match cartridges give typical groups of less than 1 MOA, i.e. 29.1 mm at a range of 100 m, when shot in a modern factory-made firearm that is in good condition.

Cartridge Case

The case is the body of the cartridge. It acts as a powder store. The bullet and the primer are fitted to this body. The case protects the powder charge and the primer from moisture. It also seals the chamber during firing, preventing the hot powder gases from reaching the shooter. Finally the cartridge case directs the bullet to the rifling centrally and straight.

Case properties affecting cartridge accuracy are:

* case volume uniformity
* case neck concentricity and uniformity
* case head uniformity

and

* flash hole uniformity.

Case Volume Uniformity

Case volume varies from one manufacturer to another, even on a small scale between two lots from the same manufacturer. This is due to the fact that the wall thickness depends on the dimensions of the brass cup from which the case was deep drawn. In addition, the tools used and the manufacturing tolerances applied have an influence on case volume uniformity. The spread of individual case volumes means variation in the loading density and thereby variation in the pressure and muzzle velocity, see Fig. 4-1. This figure shows the pressure and muzzle velocity curves for two different brands of cartridge case. As we can see, the case volume has a remarkable influence on the pressure and velocity properties of a cartridge, especially where a small case volume cartridge is concerned. For reloading, only cases from the same manufacturer should be used, preferably even from the same production lot.

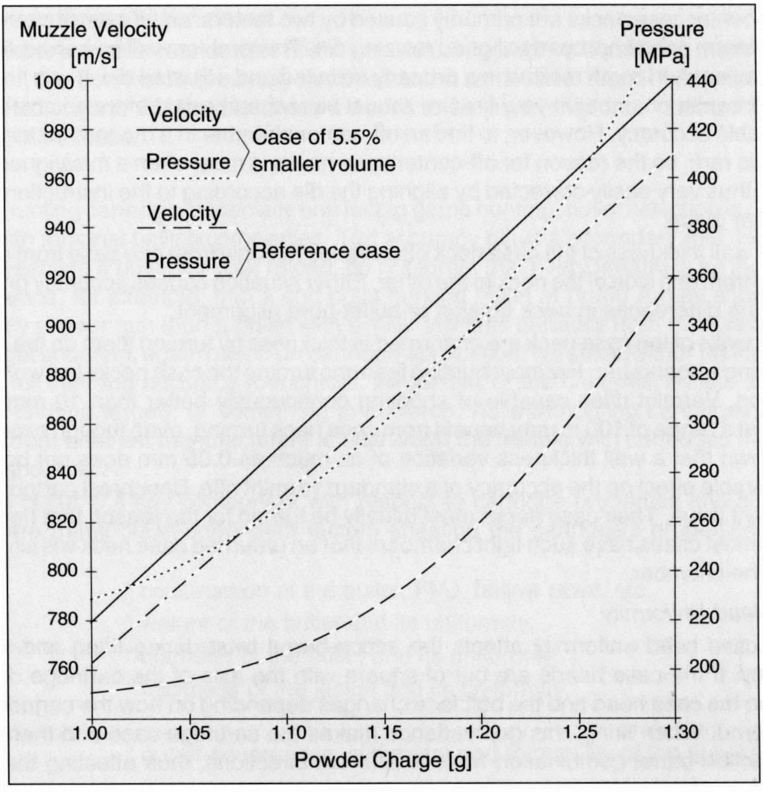


Fig.4-1. The effect of case volume on chamber pressure and muzzle velocity. Test cartridge .222 Rem., test powder N120.

When handloading it is worthwhile selecting the cases by volume, even if they are from the same manufacturer. This coarse selection can be done during charging by monitoring the powder level in the cases. Where the powder level deviates remarkably from the average, the charge should be weighed and, if correct, the cases concerned discarded. The cases can be selected by weighing, too. Clean, trimmed cases are weighed and sorted into groups so that the weight deviation in each group is no more than 0.01 ... 0.03 grams, depending on the case volume. However, if the cases are from one lot, weighing the case is a waste of time when reloading ordinary hunting/ sporting cartridges to be used in standard sporter rifles. When handloading bench-rest or top-accuracy varmint cartridges weighing the cases may be worth the trouble, especially because it is usually a question of handloading only a few cartridges, not hundreds of them as when reloading IPSC handgun cartridges, for instance. To conclude, if your gun is not capable of better than, say, 10 mm 5-shot groups at a range of 100 m repeatedly, weighing the case is a waste of time. However, following the powder level in the case is advisable, particularly when the manufacturing lot is unknown - and use only one brand of cases for each reloading lot!

Case Neck Concentrity and Uniformity

Case neck concentricity affects bullet-bore alignment. If the case neck is off-center, the bullet will enter the rifling with a yaw and the concentricity of the bullet will be destroyed. This will naturally be seen in terms of decreased accuracy.

Off-center case necks are primarily caused by two factors: an off-center chambering of the firearm or an improperly aligned resizing die. This problem will be corrected when the cases are full length resized in a properly installed and adjusted die. If you find signs of an off-center chamber in your firearm it must be rechambered before you can expect reasonable accuracy. However, to find an off-center chamber in a modern factory-made firearm is rare, so the reason for off-center case necks is most often a misaligned sizing die and thus very easily corrected by aligning the die according to the instructions in the die's user guide.

The wall thickness of the case neck often varies not only from one case from another but also from one side of the neck to the other. Either situation causes accuracy problems due to the differences in neck tension or bullet-bore alignment.

The walls of the case neck are uniformed in thickness by turning them on the outside or by using a boring-bar. For most hunting firearms turning the case necks is a worthwhile operation. Varmint rifles capable of shooting continuously better than 10 mm 5-shot groups at a range of 100 m may benefit from case neck turning, even though experience has shown that a wall thickness variation of as much as 0.05 mm does not have any considerable effect on the accuracy of a standard varmint rifle. Benchrest cartridges are a different issue. Their case necks must usually be turned for the reason that benchrest rifles in most cases have such tight chambers that an unturned case neck will simply not fit into the chamber.

Case Head Uniformity

Again, case head uniformity affects the action-barrel twist during firing and thereby accuracy. If the case heads are out of square with the axis of the cartridge, the gap between the case head and the bolt face changes depending on how the cartridge was chambered. When firing, this gap variance makes the cartridge case and thereby the whole action-barrel combination twist in different directions, thus affecting the group size.

With virgin brass, out-of-square case heads are quite rare, but after being fired in a gun with an out-of-square bolt face they become such. If your gun produces horizontal spreading in the groups and the reason is not bad bedding, crosswind etc., you may suspect an out-of square bolt face. This can be tested by shooting, say, 20 cartridges in your gun and noting carefully the position in which every cartridge was chambered, for instance, by chambering every cartridge with the caliber marking showing upwards. Now reload these 20 cases and go back to the range. Shoot the reloaded cartridges by chambering them in exactly the same position as you noted during the previous session. If the groups show rounding, i.e. horizontal spreading has decreased, an out-of-square bolt face and in consequence out-of square case heads may be your problem. During test sessions it has been found that as little as 0.05 mm out-of-squareness in the case heads doubles the vertical spread. However, an out-of-square bolt face is more the exception than the rule among modern factory-made firearms.

Flash Hole Uniformity

Flash hole uniformity or more accurately the lack of it has an influence on the consistency of powder ignition with resultant variation in muzzle velocity. Variation in flash hole diameters may result in uneven ignition. Furthermore, flash holes may have a burr on the inside, left from the manufacturing process. These burrs most probably direct and modify the ignition flame from the primer. Since the burr and its shape in particular are truly random factors, the ignition of the powder is randomized, too and thereby the accuracy of these cartridges is decreased.

There are special reamers for flash hole uniforming. When equalizing the flash hole diameter, the burr inside is usually removed at the same time. Flash hole uniforming is undoubtedly worth the trouble, since it needs to be done only once during the whole lifetime of the case.

Bullet

With a hunting cartridge, especially one for big game hunting, bullet selection is primarily to do with terminal ballistic properties. Top accuracy plays a secondary role. However, when selecting a bullet for your reload, do not forget that every firearm is an individual. This means, for example, that a soft point hunting bullet of brand A may show better accuracy in your gun than a bullet with similar terminal ballistics from manufacturer B. For target shooting, again based on cartridge application, we select either match bullets known for their top accuracy (benchrest, silhouette) or the cheapest bullets available (IPSC, running target), or something in between. As with hunting cartridges, testing bullets from different manufacturers is also worth the trouble with cartridges meant for target shooting.

The bullet is a key component with respect to cartridge properties and accuracy. There are many bullet-dependent factors affecting the cartridge's properties. These include:

* construction of the bullet, FMJ, hollow point, etc.,
* weight of the bullet and its uniformity,
* diameter of the bullet and its uniformity,
* thickness of the jacket and its uniformity,

and

* out-of-squareness, symmetry and formability of the bullet base.

In addition to the bullet itself, bullet seating can make or break the final accuracy of the cartridge. Factors that should be taken into account in the bullet seating include:

* bullet seating technique,
* bullet seating depth,

and in ready-made cartridges

* extraction force of the bullet.

Construction of the Bullet

As was discussed above, the *construction of the bullet* selected is determined mainly by the application.

The cartridges used by varmint hunters are usually reloaded with light, thin-jacketed soft point or hollow point bullets. With these a high muzzle velocity and therefore a flat trajectory can be obtained. Due to their construction varmint bullets usually "explode" on impact thus ensuring a clean kill even if the shot did not hit the bull's eye.

Competitors, both benchrest as well as free rifle shooters, select their bullets from the choice of match grade bullets available in hollow point and full metal jacket designs. Match bullets are manufactured with tight tolerances and thus they are usually of uniform high quality. With match grade bullets the value of the ballistic coefficient is normally high, so the trajectory remains flat and wind drift is minimal even at long range. Exceptions to the above are the bullets used in running target cartridges as well as in cartridges for certain pistol competitions, like IPSC. In these applications high cartridge accuracy is not the main issue and therefore such cartridges are often loaded with the cheapest bullet alternative.

Metal silhouette shooting places its own specific requirements on the bullet used. It is not enough to hit the target, the bullet must also knock it over. Selection of a high quality silhouette bullet is therefore usually based on two bullet properties, good accuracy combined with a high level of impact momentum (= bullet mass multiplied by impact velocity). The latter gives an idea of the bullet's ability to knock over the metal silhouette on impact. The optimal silhouette bullet has a high accuracy potential, a good ballistic coefficient to ensure as flat a trajectory and as high an impact velocity as possible, and is also heavy. One additional requirement is mechanical strength so that the impact energy is not wasted on breaking the bullet into pieces but used in knocking the silhouette over.

Game hunters select their bullets according to the game they hunt. Those hunting for small game, forest birds and/or pelts, use full metal jacket bullets. This type of bullet does not enlarge on impact. Therefore damage to the meat and/or pelt is reduced. For big game, like deer, moose and brown bear, semi-jacketed bullets that do enlarge to a certain extent on impact are used. This type of bullet helps to obtain a clean kill even with a somewhat marginal impact. Those hunting dangerous big game, like Cape buffalo, reload their cartridges with solid bullets. A solid bullet will not break up even if shot through thick skin and massive bones at high velocity. This ensures that the bullet reaches the vulnerable internal organ of the animal under all circumstances, even though protected by thick bones.

Bullet Weight

Bullet weight mainly affects the ballistic properties of the bullet. If we compare two bullets of the same construction and caliber, then the heavier is ballistically preferable because its sectional density ($SD = W/d$, where SD = sectional density, W = bullet mass, d = bullet diameter) is higher and the ballistic coefficient ($BC = SD/i$, where i = bullet form factor) therefore better than that of the lighter bullet. So a heavier bullet gives a flatter trajectory than a lighter one, if the muzzle velocities in both cases are equal.

Since the mass of the bullet, including a jacketed bullet, is mainly concentrated in its lead core, the heavier bullet is usually also longer than one of the same caliber and shape. This may cause an accuracy problem because a long bullet needs a faster rifle twist in order to become stabilized than a shorter one. A barrel with a slow rifle twist thus gives better groups with a lighter, shorter bullet than one with a faster rifle twist, the latter being better at shooting cartridges loaded with long, heavy bullets of that caliber.

The lack of uniformity in bullet weights affects accuracy by creating variation in the muzzle velocity as well as in the ballistic coefficient. These are factors that compensate each other, however, and therefore in most cases the influence of variation in bullet weight is negligible. In addition, the weight variation within the same bullet lot is usually so small that it is hard to find with ordinary powder scales.

Diameter of the Bullet

The maximum diameter of a bullet for different calibers is defined by international standards. Furthermore, the same standards define the minimum bore diameter of the firearm. Factory made bullets, match grade ones at least, are usually calibrated as close as possible to that standardized maximum diameter. The groove caliber of the barrel varies according to the firearm but it should always be bigger than the minimum stated in the standards.

From the accuracy point of view the best bullet/bore combination is when the bullet is 0.01 to 0.03 mm larger than the bore. As the bullet diameter increases the pressure starts to climb very rapidly and accuracy will usually decrease. A further increase in bullet diameter may finally cause the bullet to break down in the barrel, the lead core flying out while the jacket remains in the barrel. In this extreme case the next shot may create an expansion into the barrel, if the jacket getting stuck in the bore during the previous shot went unnoticed. If the bullet diameter is smaller than the bore, the muzzle velocity remains low. In that case the bullet also easily yaws in the bore, which breaks down its concentricity. In addition, there is hot powder gas leakage past the bullet thus making the bore corrode more rapidly.

Variation in bullet diameter affects accuracy chiefly due to the variation in muzzle velocity. However, it is good to keep in mind that the variation in bullet diameter within one manufacturing lot, at least with match grade bullets, is so small that it cannot be observed using an ordinary digital vernier caliper. Between manufacturing lots the variation in diameter can be remarkable and it is always advisable therefore to use bullets from a single lot for each particular reloading. Make sure that the bullets you are reloading are meant for the cartridge you are working with. The use of over-sized bullets may be dangerous specially, if they cause the case neck to jam in the chamber neck!

Thickness of the Jacket Wall

The uniformity of the jacket wall thickness is important because, if uneven, the bullet will be unbalanced and tend to veer off its intended line of flight. This is due to the fact that if the jacket is uneven the dimensional center of the bullet deviates from its center of gravity. For as long as the bullet remains in the barrel, it will rotate around its center of form. When it leaves the bore, the center of rotation moves to the center of gravity. If the dimensional center point and the center of gravity do not exactly coincide, the rotational force makes the bullet veer slightly off its intended course at a tangent to the spiral described by its center of gravity as it travelled along the bore. This will decrease accuracy.

Bullet manufacturers have carried out research on the influence of bullet jacket uniformity on accuracy and discovered that less than 0.03 mm error in jacket concentricity can and does have an effect on the bullet's accuracy. Since the jacket is deep drawn from a gilding metal cup, any inconsistencies in it will be transferred to the bullet. Therefore, especially because of the fact that jacket concentricity cannot be tested except by test shooting, if you happen to find a bullet lot of good accuracy potential it is wise to invest some money in buying and stocking up with these bullets for future use, too.

Out-of Squareness, Symmetry, and Formability of the Bullet Base

The out-of-squareness, symmetry, and formability of the bullet base must be under control if we want our bullet to have high accuracy. Bulletmakers have always said that a flat trajectory is due to good nose shape, but high accuracy is related to the well-controlled geometry of the bullet base. It is self-explanatory that an out-of-square, unsymmetrical or reformed bullet base makes the bullet veer off of its intended course thanks to uneven base drag and accuracy is thus lost in the process.

Bullets with out-of-square, unsymmetrical and/or weak bases very seldom pass the manufacturer's quality control. More common is the bullet base deforming during bullet seating, especially when reloading with lead bullets. To avoid that happening the case mouths should be chamfered before seating the bullet. Also, when reloading with lead bullets, do not forget to bell the case mouths so that the bullets are seated freely. If you forget to perform the steps mentioned above there is a potential danger of deforming the base of flat-based, particularly FMJ or soft lead bullets and destroying their otherwise high accuracy potential.

Bullet Seating Technique

The bullet seating technique employed makes or breaks the final accuracy of the load. As already discussed the bullet base must not be deformed during bullet seating. Furthermore, bullet seating should be performed so that minimum run-out of the bullet is achieved. If the bullet is seated to the case neck so that run-out exists, the bullet will be misaligned when entering the rifling and the accuracy potential of the cartridge ruined.

A bench rest competitor who is continuously looking for top accuracy often utilizes a custom made bullet seating die specially manufactured for his rifle. This die is finalized with the same reamer as the chamber of his rifle to ensure that the reloaded cartridges align perfectly with the chamber and bore of his rifle. For an ordinary reloader the accuracy possible to achieve with the bullet seating die included in a standard reloading die set is in most cases enough. You only have to take care that the seating die is installed correctly, carefully following the operating instructions that come with the die set. Among the new tools for bullet seating are so-called straight-line bullet seating dies available today from all the major reloading equipment manufacturers. This type of die is equipped with a guide that holds the case and the bullet in perfect alignment as the bullet is seated. For those looking for top accuracy this type of die may be worth considering.

Bullet Seating Depth

The seating depth of the bullet determines the cartridge overall length, or C.O.L. It has an influence on the volume of the powder space, i.e. the deeper into the case the bullet is seated, the smaller the powder space. Furthermore we can affect bullet-bore alignment as well as the extraction force of the bullet via the bullet seating depth. All the factors mentioned above are important from the point of view of cartridge accuracy. Furthermore C.O.L. has an effect on the functioning of some firearms, usually those of the semi-automatic type. And finally, the correct bullet seating depth is mandatory for safe reloading!

Since all firearms and their chamberings are one-offs, the optimal bullet seating depth for every firearm/bullet combination should be determined by test shooting.

From the accuracy point of view a cartridge with the bullet seated sufficiently far that it touches the lands of the rifling when the bolt is closed is generally best. The freeborn is now eliminated and the bullet is aligned as straight as possible into the rifling. The accuracy potential is thus much better. This is actually true only with firearms that have well squared bolt faces and in which the chamber-bore center axes coincide exactly. This is usually the case in modern factory-made firearms. When the bullet rests on the lands it needs a constant force to start it moving into the rifling. This equalizes to a certain extent the ignition of the powder charge and thereby the muzzle velocity. In addition, the farther out the bullet is seated, the bigger the powder capacity of the case. One drawback is that a bullet seated so as to touch the lands may stick in the rifling when attempting to dechamber the unfired cartridge, your gun being accidentally made temporarily unfireable. It is unwise then to seat the bullets that far out in reloads meant for hunting. In some firearms the freebore is made so long that a cartridge with a bullet seated far enough out to touch the rifling will no longer fit into the magazine, and the bullet selected for reloads is simply too short. In addition, one should always bear in mind that a bullet touching the rifling has a tendency to increase the chamber pressure. So, if you decide to seat your bullets so they touch the rifling, you must develop your reload from the very beginning with a careful eye on pressure.

From the reloading safety point of view the seating depth of the bullet is highly important especially when dealing with small capacity handgun cartridges. The deeper into the case the bullet is seated, the smaller the powder space becomes. This will increase the chamber pressure. Fig. 4-2 contains a graph illustrating chamber pressure and muzzle velocity versus bullet seating depth. The test cartridge was 9mm Parabellum. From the graph you can see that the pressure curve is almost linear and the numeric value of its slope is about 40 MPa/mm! This phenomenon could be the reason behind some unidentified revolver breakages. In cartridges with a larger powder capacity the effect of C.O.L. is not that dramatic, but still exists and must nevertheless be kept in mind especially when reloading long bullets extending far into the cartridge case.

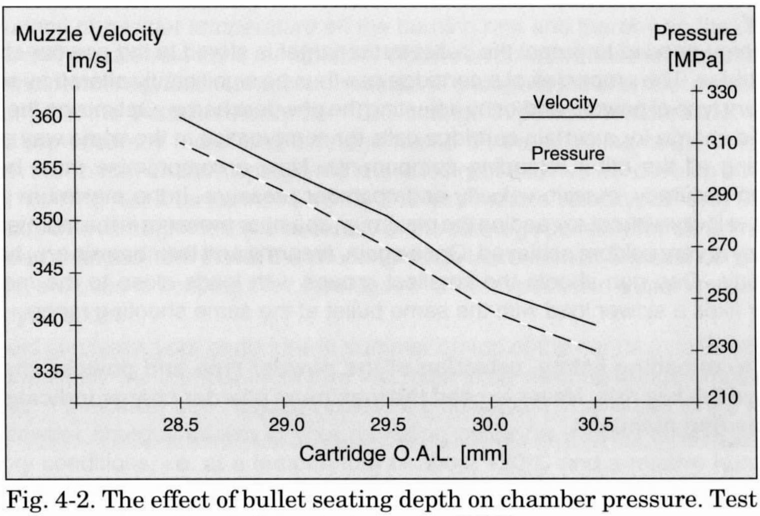


Fig. 4-2. The effect of bullet seating depth on chamber pressure. Test cartridge 9mm Parabellum, test powder 3N37.

From a *functionality point of view* the bullet seating depth is important with autoloaders, big bore hunting rifles as well as guns with a tubular magazine, the latter usually being lever-actions. Autoloaders are designed to function well with cartridges of a certain minimum and maximum C.O.L. Cartridges that are too long or too short may jam. In the cartridges used in repeater guns, guns with a tubular magazine as well as in big bores the bullets are usually crimped firmly to the case mouth to prevent the recoil from pushing the bullet into the cartridge case. In such cases the bullet seating depth is determined by the position of the bullet's crimp groove. Bulletmakers usually select that place so that the O.A.L. of the crimped cartridges allows them to function well in all types of firearms.

Extraction Force of the Bullet

The extraction force of the bullet is the force needed to pull the bullet out of the case mouth. It has an influence on the powder ignition and thereby on muzzle velocity, which from an accuracy point of view should be as constant as possible.

The factors affecting the extraction force are chiefly the variation in case neck hardness and in bullet diameters. By taking care that both the bullets and the cases are from single lots variation in the extraction force can be reduced. If the reload is big, it is quite a time consuming job, however, to select the bullets and the cases. One way of reducing the extraction force is to increase C.O.L. to the extent that the bullet touches the rifling when the bolt is closed. The force needed by the bullet to go into the rifling is many times greater than the extraction force, so variation in the latter no longer plays a significant role in the cartridge's accuracy.

If it is not possible to seat the bullet far enough out to touch the rifling, the influence of the variation in the extraction force can be reduced by crimping the bullets to the case mouths, provided the bullets selected have crimp grooves. An evenly performed heavy crimp increases the extraction force to the extent that the variation in the friction force between the case neck and the bullet becomes negligible. When placing a crimp it is useful to keep in mind that a crimp increases the chamber pressure. For that reason a crimped reload must be developed from the very beginning with careful attention to pressure. It is also good to remember that bullets without a crimp groove are not meant to be crimped. They will most probably become deformed and spoiled if crimped.

Powder

The energy needed to propel the bullet to the target is stored in the powder charge of the cartridge. The properties of a cartridge can thus be significantly altered by selecting a different type of powder and/or by adjusting the powder charge. Optimizing the powder type and charge for a certain cartridge calls for compromise in the same way as when optimizing all the other reloading components. Now a compromise must be made between accuracy, muzzle velocity and chamber pressure. If the maximum possible muzzle velocity without exceeding the maximum chamber pressure is the main issue, top accuracy is very seldom achieved. Once again, firearms and their barrels are, however, individuals. One gun shoots the smallest groups with loads close to the maximum, another likes a slower load with the same bullet at the same shooting range.

As to reloading safety, selection of the powder type and powder charge plays the key role. Never exceed the maximum powder charge indicated in reloading manuals!

If the goal is high accuracy, it is advisable to start the tests with the powder type that fills the cartridge almost completely with a little bit less than the stated maximum charge. In general, less than maximum loads that nearly fill the case give the most uniform muzzle velocities and thereby best accuracy. You should again remember, however, that firearms are individuals. One firearm may shoot better with loads containing faster burning powder even though the case remains more empty. Optimizing the powder type and load to get top accuracy out of a firearm/cartridge combination is usually quite a time-consuming job.

Where the powder charge is concerned the factors affecting the accuracy potential of a cartridge include:

* variation in the powder charge,
* variation in powder temperature,
* variation in the moisture content of the powder,
* variation between different manufacturing lots,

and

* placement of the powder charge in the case and the effect of an almost empty case.

Powder Charge

It is generally considered that variation in the powder charge plays the main role in the accuracy of a firearm cartridge. Fortunately this is not literally true. In shooting tests it has been discovered that a less than ±1 % variation in the powder charge has no significant influence on accuracy. This means, for instance, that the load in .222 Remington may vary as much as ±0.01 x 1.20 g = ±0.012 g, in .308 Winchester ±0.01 x 3.00 g = ±0.03 g and in .338 LAPUA Magnum ±0.01 x 6.60 g = ±0.066 g without ruining the accuracy! When using Vihtavuori's short-grained extruded powders weighing every load is a waste of time. The powder charges can safely be thrown at an accuracy that is better than that which can be obtained on an ordinary powder scale, i.e. better than ±0.01 g. To achieve such high charging uniformity by throwing you naturally have to develop the proper throwing technique.

Powder Temperature

The influence of *powder temperature* on the burning rate and thereby on the chamber pressure and muzzle velocity is remarkable. Vihtavuori powders have an experimentally defined temperature gradient of approximately 3 % change in the chamber pressure and 1 % change in the muzzle velocity per 10°C change in powder temperature. In other words, a top-accuracy forest bird cartridge tested on the shooting range in mid-July (+20°C in the shade) as developing a muzzle velocity of 930 m/s will develop on a frosty October morning just after sunrise (-10°C) 3 % less muzzle velocity, i.e. only 900 m/s! For certain, even though the initial accuracy of the cartridge possibly remains, the sight-in has been changed from that at the shooting range last summer. Experienced hunters, of course, are used to keeping their cartridges in a warm pocket in winter time until they are ready to shoot.

Should you leave your cartridges in summer on top of the car dash for a while and then immediately try to shoot them they will most likely develop dangerous chamber pressures, if they have been loaded close to the maximum. This is due to the fact that all the powder charges shown in your reloading guide have been developed under laboratory conditions, i.e. at a temperature of about +20°C and a relative humidity of about 55 %. This is good to keep in mind in addition to careful attention to signs of pressure. Accordingly, since all the reloads are meant to be used during the winter hunting season, the influence of low powder temperature can be compensated by increasing the powder charge slightly.

Moisture Content of the Powder

Variation in the moisture content of the powder affects the powder's burning rate and thereby the chamber pressure and muzzle velocity. The moisture content of smokeless canister powders usually lies around 1%. During one test a certain amount of powder was dried by heating it, losing about 0.5 % of its weight. A few cartridges were loaded with the dried powder and then shot through the pressure gun. The chamber pressures and muzzle velocities produced by these special cartridges were compared to those produced by cartridges loaded with the untreated powder. The powder charge and the bullet were naturally the same in both sets of cartridges. When evaluating the test results the chamber pressure increased from 320 MPa to 355 MPa with the dried powder. The muzzle velocity increased accordingly from 770 m/s to 790 m/s.

This gives us good reason to forget the old saying "Keep your powder dry"! Instead, living in this time of smokeless non-corrosive powders we should say something like "Keep your powder in a cool and dry place carefully sealed in its original container".

Variation between different Powder Manufacturing Lots

The volume-weight product of the powder may vary from one lot to another. The coating percentage as well as the moisture content may also differ slightly from lot to lot. All this has an influence on the burning rate and thereby creates variation in the cartridge's pressure and muzzle velocity characteristics. For that reason every powder canister has a label indicating the production lot to which this particular canister belongs. A careful reloader always checks his cartridges for pressure signs if the powder lot changes to a new one.

If you have developed your reload to the maximum you will have to redevelop it by noting carefully the pressure signs every time the powder manufacturing lot changes to another one. The new powder lot will most probably differ slightly from the previous one and that small difference may be enough to produce dangerous chamber pressures.

Placement of the Powder and the Effect of an almost empty Case

There has been lot of talk about the effect which an only partly filled case may have on shooting results. In an only partly filled case the powder evidently burns unevenly. Some involved in investigating mysterious firearm breakages have suggested that uneven ignition/burning of the powder in a partly filled case may have produced a resonating shock pressure wave in the case and that this was the reason for the breakage. Quite a lot of research has been done around this phenomenon, but it has never been possible to demonstrate it in rifle-caliber cartridges under laboratory circumstances. With guns in which it is possible to record the chamber pressure at both ends of the chamber the resonance phenomenon described above has been observed. It is possible that under some circumstances this phenomenon - also known as low charge detonation - may occur also in a rifle/handgun caliber cartridge and the possibility of this should be kept in mind when developing loads.

Even if the risk of low charge detonation were negligible, an *insufficiently filled case* leads to wider variation in muzzle velocity than a load charged with a slower burning powder that fills the case up more, even though there are exceptions as discussed before. This is also why a powder that fills the case up is recommended. **A powder charge that fills the case up less than halfway should not be used for any application!**

The effect of powder placement has also been tested and here are some results:

Test cartridge: .38 Special, test powder: N310, powder charge: 0.25 g.

	Pressure [MPa]	Muzzle velocity [m/s]
Powder on the primer side	129	269
Powder on the bullet side	100	259

In order to achieve uniform shooting results the powder should always be evenly distributed in the cartridge case. This happens automatically when the case is full or almost full of powder.

Primer

The function of the primer is to ignite the powder charge placed in the cartridge case. Primer selection has an influence of its own on the variation in the pressure and muzzle velocity characteristics of a cartridge. During test firing remarkable differences in characteristics between primers and especially between different brands of primers have been noted. Please find on the next page a summary of one primer test session during which both small and large rifle primers from different manufacturers were tested at ambient temperatures of +20°C and -20°C. Pressures and muzzle velocities are both mean values of ten test shots.

As can be seen from the test results, primer selection affects the cartridge's pressure and velocity characteristics to the extent that spending time selecting the optimal powder/primer combination is worth considering especially if you want to makximize the accuracy potential of your cartridge.

In addition to the primer itself, the proper technique of primer seating is essential in order to preserve the ignition characteristics of the primer. The use of a special priming tool is strongly recommended in place of the standard priming arm of your reloading press. A priming tool allows you to feel the primer as it is seated. In this way you know when the primer seats against the bottom of the pocket. Furthermore, special priming tools do not usually produce sufficient force to crush the primer against the primer pocket, a common problem when priming is done with a powerful reloading press.

To achieve top uniformity in primer seating, first seat the primer as usual, relax the pressure on the priming arm, turn the case 180 degrees in the shell holder and apply pressure on the priming arm again. This will ensure the primer is seated evenly against the bottom of the primer pocket, ensuring for its part the even pressure and muzzle velocity characteristics of the reloads. Uniforming the primer pockets with a special tool that cuts the bottom surface of the pocket both flat and parallel to the case head, may furthermore improve the accuracy of the reloads.

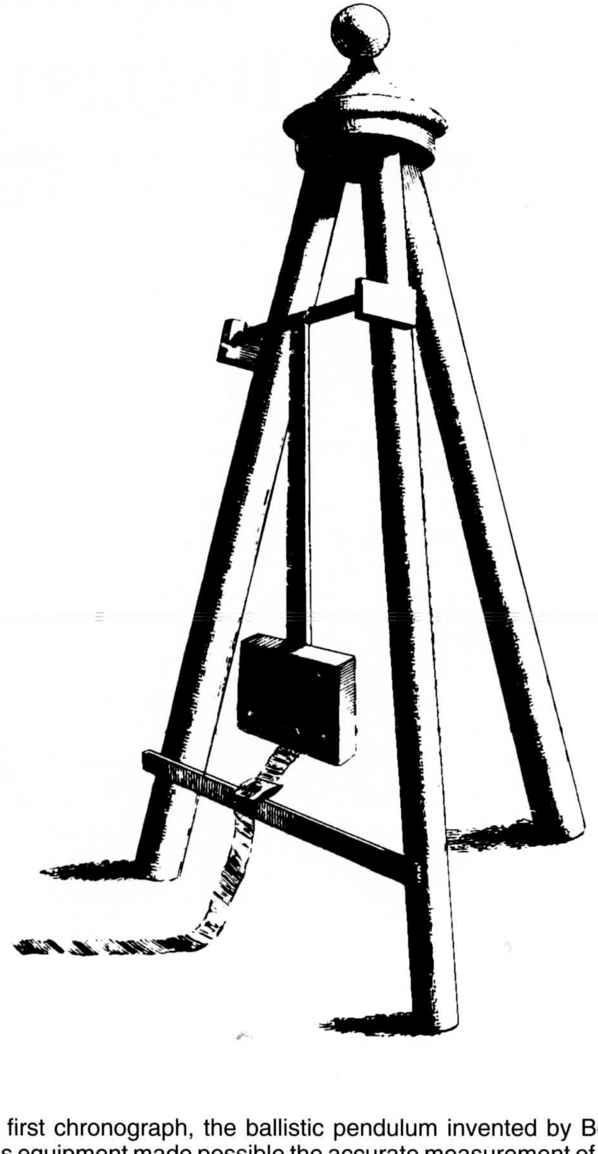
Large rifle primers: Test cartridge .30-06 Springfield, powder N150, charge 3.30 g, bullet 11.7 g SP

Primer	Temperature [°C]	Pressure [MPa],SD		Muzzle velocity [m/s],SD	
A	+20	343	9.2	788	3.9
	-20	316	5.3	774	2.7
B	+20	335	4.7	784	2.1
	-20	317	11.8	773	6.3
C	+20	340	9.5	786	2.3
	-20	325	7.5	777	3.3
D	+20	341	8.4	786	3.1
	-20	319	11.7	776	4.7
E	+20	338	5.8	787	2.4
	-20	319	4.9	772	2.8
F	+20	342	8.0	786	2.1
	-20	328	9.7	776	4.3

Small rifle primers : Test cartridge .222 Remington, powder N120, charge 1.25 g, bullet 3.2 g FMJ

Primer	Temperature [°C]	Pressure [MPa],SD		Muzzle velocity [m/s],SD	
A	+20	283	10.6	921	7.7
	-20	244	6.1	870	5.6
B	+20	283	20.5	912	13.0
	-20	266	22.1	893	13.8
C	+20	279	10.1	912	6.5
	-20	262	18.8	896	12.9
D	+20	263	7.2	903	5.4
	-20	236	3.8	866	4.3
E	+20	271	2.7	905	1.8
	-20	265	20.6	894	15.0

5.
Exterior Ballistics



The very first chronograph, the ballistic pendulum invented by Benjamin Robbins in 1742. This equipment made possible the accurate measurement of projectile velocities.

EXTERIOR BALLISTICS

The term "ballistics" comes through the Latin from the original Greek root word "ballein", meaning to throw. It is defined as the science of the motion of projectiles.

Exterior ballistics is the study of the motion of a projectile from the instant it leaves the gun muzzle to the instant it strikes the target.

When a bullet leaves a gun, it has a kinetic energy which tries to make it move in a straight line with its original velocity. However, gravity pulls it towards the ground, and air resistance tries to hold it back. The result is that it follows a curve called the trajectory.

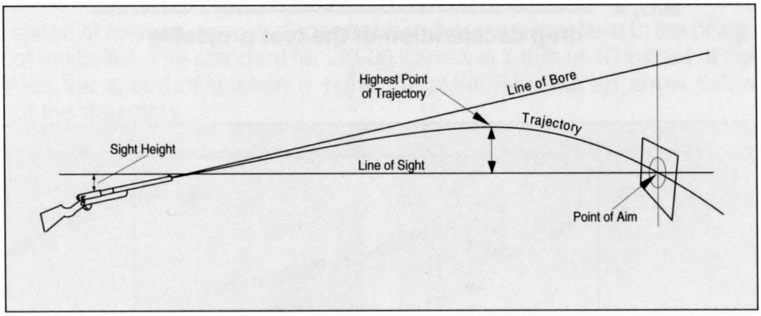


Fig 5-1. The trajectory of a bullet.

Air Resistance

As a bullet flies through the air it is continuously striking against small particles of air. These particles form a resistance which depends on the shape and velocity of the bullet. During its flight the bullet produces shock waves like a boat in water. Figure 5-2 is a shadowgraph of a bullet travelling through air.

The shadowgraph in Fig. 5-2 shows two different shock fronts and a turbulent wake behind the bullet. This turbulent region occurs because as the bullet moves, it pushes the air aside, leaving a void immediately behind it. Air then flows back into this void.

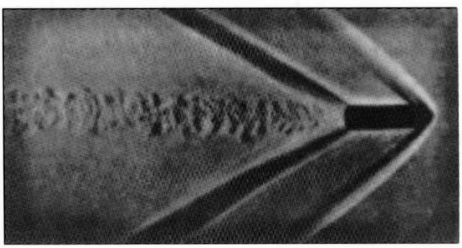


Fig. 5-2.

The angle of the shock wave depends on the velocity of the bullet relative to the shock wave spreading in air.

$$\sin \alpha = [\text{spreading velocity } a] / [\text{bullet velocity } v],$$

where v/a is the so called MACH number.

Air drag of the bullet is most complex subject and Figure 5-3 on the next page shows some factors and their influence.

Ballistic Coefficient (B.C.)

Ballistic coefficient is a measure of the ballistic efficiency of a bullet. This means, that if we compare several different bullets all fired at the same velocity, then the higher the ballistic coefficient of any bullet, the flatter it shoots.

To calculate the trajectory of a bullet, we have to know the air resistance acting on it. In practice, the deceleration of the bullet is calculated by using the bullet's ballistic coefficient (B.C.) This is a dimensionless variable which determines the magnitude of the drag deceleration of the test bullet caused by air resistance.

$$\textbf{B.C.} = \frac{\textbf{drag deceleration of the standard projectile}}{\textbf{drag deceleration of the test projectile}}$$

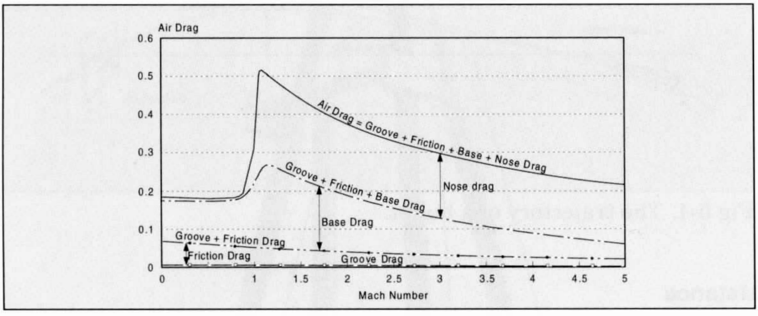


Fig 5-3. This figure shows that base drag is the main factor at low velocities and that nose drag is very big and almost stable at high velocities. The friction and groove drags remain very small at all velocities.

The deceleration characteristics of a standard projectile are usually given in a form known as a drag model. During the past many mathematical drag models have been formulated. Today the best known are the G1 drag function and the Mayevski drag functions, the latter known as the Ingalls Tables.

Nowadays ballistic coefficients are defined by measuring the velocity of a bullet at different distances. The ballistic coefficient has a slightly different value depending upon the velocity of the bullet.

Air resistance depends upon the density of the air, which in turn depends upon altitude, temperature, barometric pressure and relative humidity. Changes in those values will change the ballistic coefficient. Ballistic coefficients in reloading manuals are always calculated for sea level standard atmospheric conditions.

Muzzle Ballistics

Muzzle ballistics concern the very short period of time as the bullet leaves the muzzle. However during this short time many things occur which have a very big influence on the accuracy of the bullet.

Before the bullet comes out of the muzzle, there come different kinds of unburnt particles, smoke and gases, which have a very high velocity. However the velocity of these particles decreases very rapidly and the bullet goes through this smoke.

The smoke is symmetrically around the bullet, but if there are some dents in the base of the bullet or in the muzzle of the barrel, the pressure and the velocity of these particles are bigger on that side. This larger pressure tries to move the base of the bullet off its trajectory. It can thus be seen that the symmetry of the bullet's base and the muzzle of the barrel are very important factors as regards accuracy.

Stability of the Bullet

Stability can be divided into two parts, static and dynamic stability. A bullet is normally statically unstable, but we can make it stable by forcing it to spin around its longitudinal axis.

The speed of rotation, or spin, depends upon the amount of twist in the rifling and the velocity of the bullet. The standard for .30-06 barrels is 1 turn in 10 inches of right-hand twist. When the speed of rotation is right, the bullet flies like an arrow following the tangent of the trajectory.

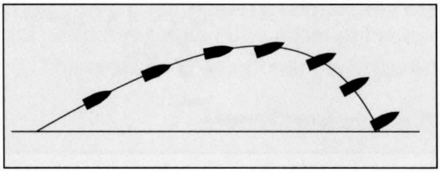


Fig. 5-4. An overstabilized bullet.

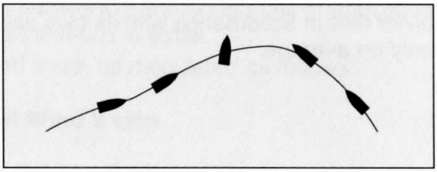


Fig. 5-5. An unstabilized bullet.

Figure 5-4 shows that when the spin rate is too high, the projectile maintains its axis and does not follow the tangent of the trajectory. Furthermore, in Figure 5-5, the spin rate is too low and the bullet loses its stability and begins to tumble. The spin rate of the bullet can be calculated very easily from the twist of the barrel and the velocity of the bullet. If the velocity of the bullet is 2700 fps and the twist 1 turn in 10 inches (0.833 ft), this means that

$$\textbf{during 1 second there are } \frac{\textbf{2 700 ft}}{\textbf{0.833 ft}} = \textbf{3 241 revolutions}$$

The spin stabilized bullet tries to diverge from its trajectory due the influence of gravity, spin and air resistance. The main forces at work are the spin effect, Magnus effect and Poisson effect.

Spin Effect

Spin effect occurs when an object is spinning at a very high rate around its own axis.

When a projectile's spin rate is high enough, spin effect keeps the point in the same direction. When air drag exerts a force on the bullet, it tries to change the direction of the bullet. Thus the bullet travels straight against this force according to the motion of spin.

In Figure 5-6 we can see the case, when a bullet starts to go a little off line. The direction of the drag forces changes. If there are changes of direction all the time, the bullet's point then turns around its own axis. This movement is called *precession*.

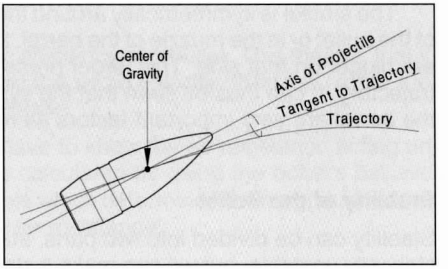


Fig. 5-6. Precession

In Figure 5-7, another movement inside the precession can be found, so called *nutation*. Nutation is accompanied by higher drag due to air resistance because the bullet flies in accordance with its own axis only on average.

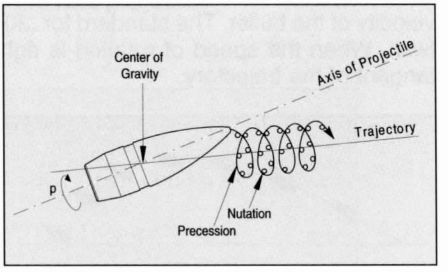


Fig. 5-7. Nutation.

The so called *spin movement* increases very rapidly due to precession and nutation as the range increases. The movement is to the right, when the barrel has a right-hand twist.

Magnus Effect

The so called *Magnus Effect* occurs when a bullet rotates around its own axis and takes some air particles with it. These air particles cause the air density to be higher on the right side of the bullet, when the spin is to the right. The bullet moves to the left because there is less resistance.

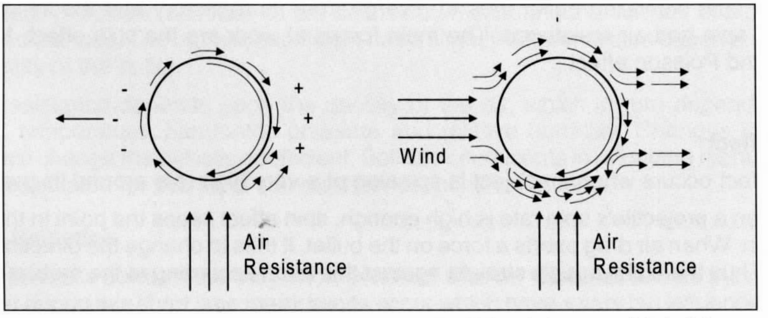


Fig. 5-8. The Magnus Effect can be seen in this picture and it is bigger in a hard side wind.

Poisson Effect

The *Poisson Effect* occurs when the bullet is almost the whole time above the tangent of its trajectory. For this reason the air density is bigger below the bullet. As the bullet spins on this air pillow friction has the effect of moving the bullet to the right when the spin is to the right.

This Poisson Effect is usually very small. The forces due the Magnus Effect are also small when the trajectory is flat. With a big shooting angle, however, it may happen that at the top of the trajectory the magnus effect is bigger than the spin effect and the bullet will move to the left.

Wind Effect

Wind deflection is a factor that the shooter must take account of. It is proportional to the amount of delay in the flight caused by air resistance. Usually crosswind deflection is calculated in reloading manuals for different wind velocities.

Whenever there is a wind blowing from any direction, we must divide it into two components. Normally the component which is parallel to the shooter's line of sight does not need to be taken into account because its influence is small.

The crosswind component is important and it can be calculated as follows:

$$\textbf{Crosswind} = \textbf{Actual Wind} \times \sin\alpha,$$

where α is the angle between the actual wind and the line of sight.

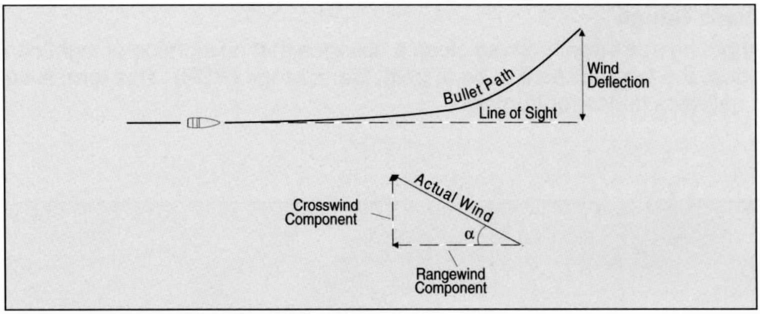


Fig. 5-9. Wind drift.

Shooting Uphill and Downhill

When you are in a hunting situation and forced to shoot either uphill or downhill, it must be remembered that the gun will shoot high. How much you will have to aim down depends on the shooting angle.

If d is the drop at a certain range, the increase in the bullet path height can be calculated according to the following table:

Elevation Angle in degrees	**Increase in Bullet Path Height** d in millimetres or inches
± 10	0.015 x d
± 20	0.060 x d
± 30	0.134 x d
± 40	0.234 x d

Bullet Path

The sights of a firearm are usually fitted to the top of the barrel. In the figure below the bullet path and line of sight can be seen.

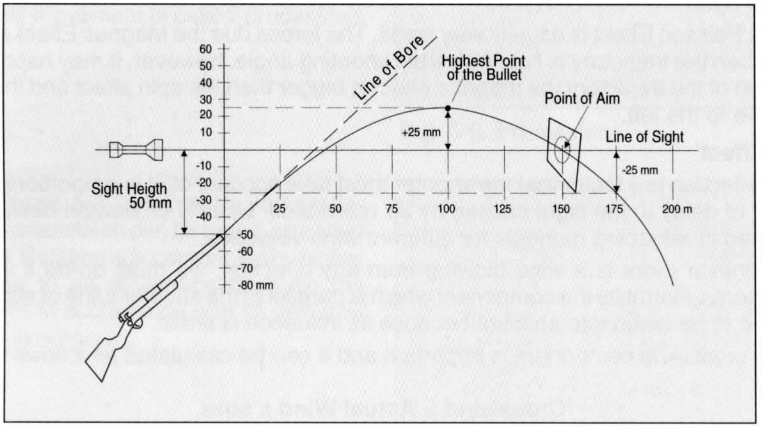


Fig. 5-10. Bullet path.

Point Blank Range

When shooting at a target from so close a distance that no sighting or sight corrections are needed, the target is said to be at point blank range (PBR). This term is very often used in ballistics tables for hunters.

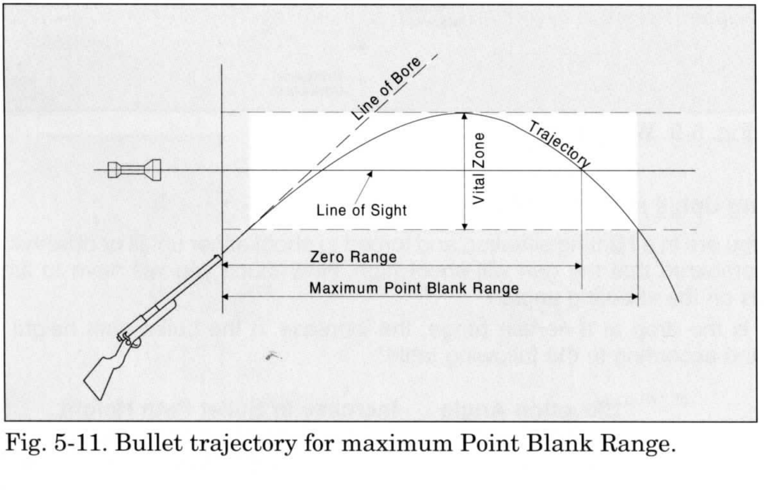


Fig. 5-11. Bullet trajectory for maximum Point Blank Range.