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FIELD ARTILLERY

VOLUME 6

BALLISTICS AND AMMUNITION

(BILINGUAL)

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FOREWORD

1. B-GL-306-006/FP-001, Field Artillery, Volume 6, Ballistics and Ammunition, is issued on the authority of the Chief of the Defence Staff.

2. This manual is effective upon receipt and supersedes B-GL-306-006/FP-001, Field Artillery, Volume 6, Ballistics and Ammunition, Interim 1 dated 15 February 1985.

3. Suggestions for amendments should be forwarded through normal channels to Mobile Command Headquarters (FMC HQ), Attention: SSO Arty.

RECORD OF CHANGES

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CHAPTER 1

INTRODUCTION TO BALLISTICS

SECTION 1

GENERAL

INTRODUCTION

1. This manual is only an introduction to the vast and complicated subject of ballistics. It does not deal in advanced theory but does contain material for the benefit of those who wish to pursue this fundamental aspect of gunnery beyond the barest essentials. In this manual, ballistics is discussed in three separate phases:

a. **Internal Ballistics**. This concerns the events that take place from charge ignition to the moment when the projectile leaves the muzzle.

b. **External Ballistics**. This deals with the motion of the projectile from the moment of leaving the muzzle to the moment of impact or burst.

c. **Terminal Ballistics**. This deals with the motion of the projectile and parts or fragments thereof, from the moment of impact or burst.

2. For a short period of time after the projectile leaves the muzzle, the projectile is acted upon by the pressure of the emerging gas. This is known as the transitional phase of ballistics (sometimes referred to as **intermediate ballistics**). Its effect must be taken into account during the design and construction of the equipment when such factors as the functioning of the weapon, the steadiness and stability of the gun and the use of a muzzle brake are considered. Its effect must also be considered in the selection of the point or points of measurement from which to deduce muzzle velocity (MV). The point(s) selected is usually a few metres forward of the muzzle where the effects are known to be negligible and where it can be assumed that the projectile has been subjected to the usual retardation due to air resistance during its flight from the muzzle to the point of measurement. The effects of the transitional phase of ballistics are assumed to have no significant influence on the gunnery problem and are, therefore, not considered in its solution.

APPLICATION

3. Gunnery is the practical application of the science of ballistics to the engagement of targets. It is applicable to the engagement of targets and to the reduction of data obtained by shooting to a form suitable for the eventual re-engagement of targets. While the appropriate data can be arrived at by use of a proforma through a rather **mechanical** process, a knowledge of ballistics and ammunition characteristics will allow an understanding of the process being followed.

SECTION 2

DEFINITIONS

GENERAL

1. The terms defined in this section are in the main, extracts from STANAG 4119, Adoption of a Standard Cannon Artillery Firing Table Format. They are based on the concept of a curved earth and are generalized so that they may be used for any artillery weapon. To simplify the description of the elements of the trajectory of a projectile, the following assumptions are made:

   a. The trajectory is a two-dimensional curve lying in a vertical plane.

   b. The terms **projectile** and **target** are considered as points.

   c. The term **weapon** refers to the trunnions and the term **origin** refers to the muzzle.

2. The definitions listed are classified into three groups as follows:

   a. intrinsic elements are those that are characteristic of a trajectory by its very nature;

   b. initial elements are those that are characteristic of an artillery projectile at the point of origin; and

   c. terminal elements are those that are characteristic of an artillery projectile at the point of impact or point of burst.

3. Definitions relating to the equipment are also covered.

INTRINSIC ELEMENTS

4. **The Trajectory**. The trajectory is the path traced by the centre of gravity (CG) of the projectile in its flight through the air from the muzzle to the point of impact or burst.

5. **Origin**. The location of the CG of the projectile when it leaves the muzzle of the gun is designated the origin of the trajectory. The line of departure cannot be predetermined if the magnitude and the direction of jump is not known. Therefore, the term **origin**, which will be used for the remaining definitions relating to the elements of the trajectory, will be designated by the centre of the muzzle where the gun has been laid.

6. **Ascending Branch**. The ascending branch is that portion of the trajectory traced while the projectile is rising from the origin.

7. **Descending Branch**. The descending branch is that portion of the trajectory traced while the projectile is falling.

8. **Vertex**. The vertex is the highest point of the trajectory. It is the point at which the vertical component of velocity is zero. It is also known as the **summit**.

9. **Maximum Ordinate**. The maximum ordinate is the difference in altitude between the origin and the vertex.

10. **Level Point or Point of Graze**. The level point or point of graze is the point of intersection between the trajectory and the weapon level surface.

11. **Level Surface**. The level surface is the surface of a sphere (earth) tangential to the horizontal plane through a given reference point with a radius equal to the mean radius of the earth plus the altitude of the reference point. Except for very long range weapons, the level surface and the horizontal plane are taken as being the same.

12. **Horizontal Plane**. The horizontal plane is a plane tangent to the level surface through a given reference point, at right angles to the vertical.

13. **Target**. The target is a specified point at which fire is directed.

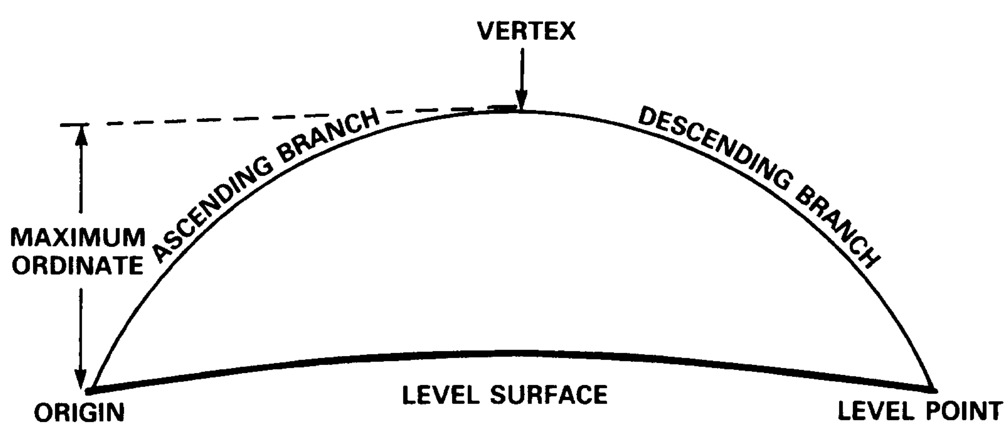


Figure 1-2-1 Intrinsic Elements of the Trajectory

14. **Time of Flight**. The time of flight (TOF) is the time taken by a projectile to travel between the origin and a specified point on the trajectory. When the point is not specified it refers to the point of graze or level point.

15. **Remaining Velocity**. The remaining velocity is the velocity of the projectile at any specified point on the trajectory. When the point is not specified it refers to the point of graze or level point.

16. **Drift**. Drift is that part of projectile deflection due to axial spin.

INITIAL ELEMENTS

17. **Line of Elevation**. The line of elevation is an extention of the line formed by the axes of the bore where the gun is laid.

18. **Line of Departure**. The line of departure is a line tangent to the trajectory at the commencement of free flight. It is deduced from elements measured at convenient points on the trajectory.

19. **Line of Sight**. The line of sight (LOS) is the straight line passing through the weapon or instrument and the target.

20. **Jump**. Jump is the vertical component of the acute angle measured from the muzzle axis before firing to the line of departure. Jump is caused by the shock of firing during the interval from the ignition of the propelling charge to the departure of the projectile from the muzzle.

21. **Angle of Elevation**. The angle of elevation (A/E), also known as tangent elevation (TE), is the vertical acute angle measured from the LOS to the line of elevation.

22. **Angle of Sight**. The angle of sight (A/S) is the vertical acute angle measured from the horizontal plane passing through the weapon to the LOS. It is described as **elevation** (or "+" or positive) if the target is above the gun, and as **depression** (or "-" or negative) if the target is below the gun. The A/S compensates for the difference in altitude between the gun and the target.

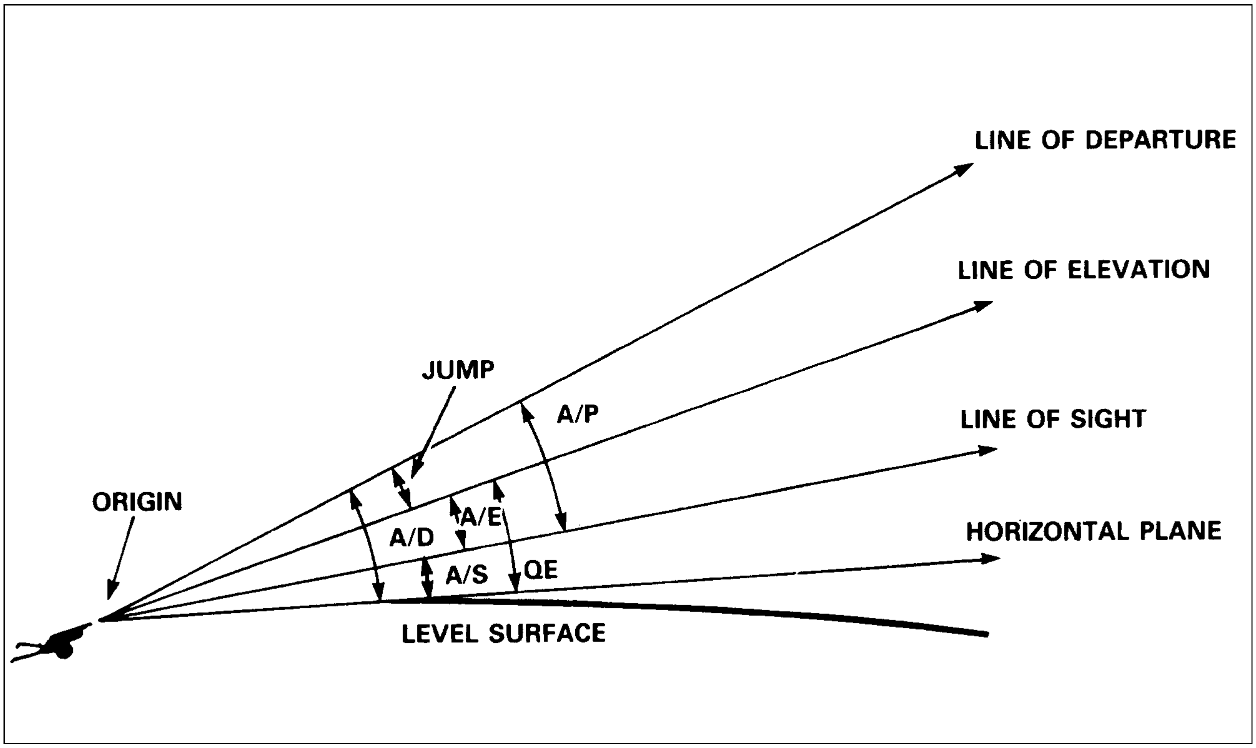


Figure 1-2-2 Initial Elements of the Trajectory

23. **Angle of Departure**. The angle of departure (A/D) is the vertical acute angle measured from the horizontal plane passing through the weapon to the line of departure.

24. **Angle of Projection**. The angle of projection (A/P) is the vertical component of the acute angle measured from the LOS to the line of departure. Generally, elevations listed in the firing tables (FTs) include a correction for jump and are, therefore, angles of projection.

25. **Quadrant Elevation**. The quadrant elevation (QE) is the angle at which the gun is required to be laid under the prevailing conditions to achieve the desired objective. QE is the sum of site plus A/E. It can also be computed by adding A/S to A/E corresponding to range plus complementary range. The two methods of computing QE, one using the complementary angle of sight and the other using complementary range, both compensate for the non-rigidity of the trajectory. Complementary range may be used when the gun data is being determined from the FT; complementary angle of sight is used when site is being determined with graphical site tables.

26. **Firing Table Elevation**. FT elevation is the elevation at which the gun is required to be laid under standard FT conditions to achieve the objective stated in the FTs.

27. **Complementary Angle of Sight**. The complementary angle of sight is an angle that is added to the A/S to compensate for the non-rigidity of the trajectory. The complementary angle of sight for ± 1 mil A/S is listed in Table G of the FTs.

28. **Site**. The term **site** is used to define the sum of A/S plus the complementary angle of sight.

29. **Complementary Range**. Complementary range is the range correction equivalent to the complementary angle of sight. Complementary range is determined from Table B of the FTs.

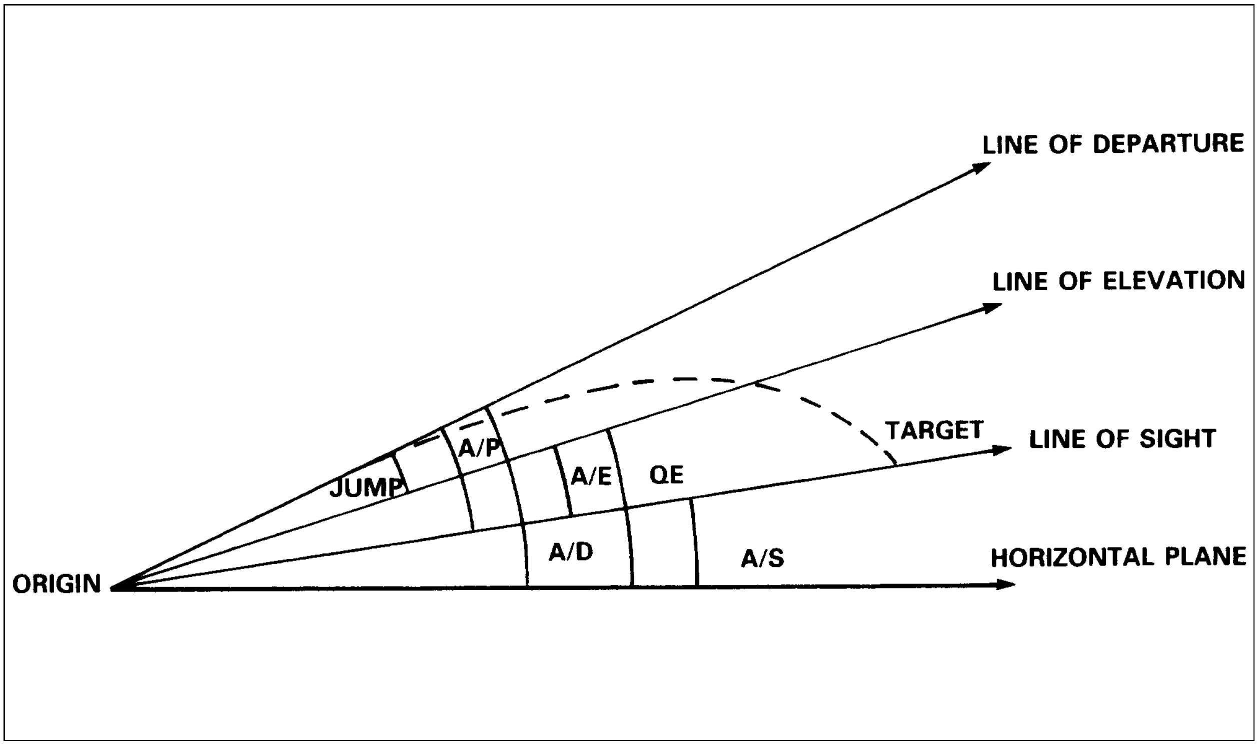


Figure 1-2-3 Plus Angle of Sight

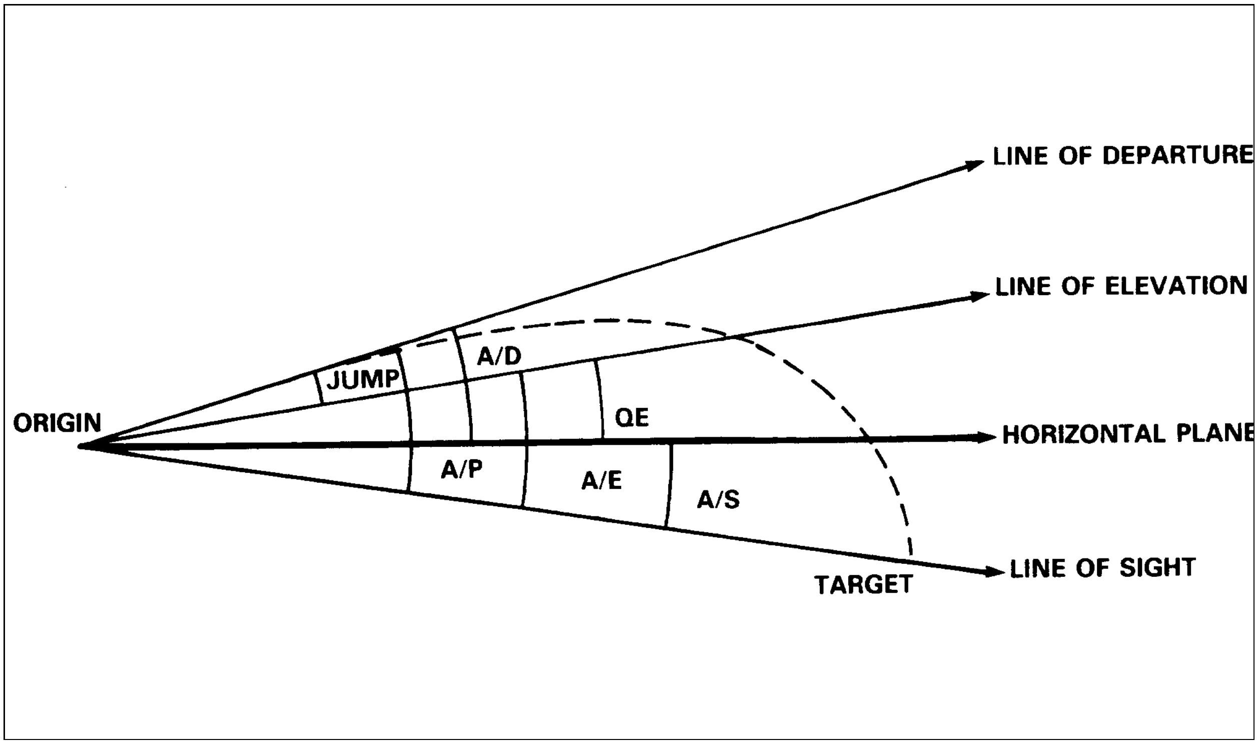


Figure 1-2-4 Minus Angle of Sight

TERMINAL ELEMENTS

30. **Point of Impact**. The point of impact is the point where the projectile first strikes an object.

31. **Point of Burst**. The point of burst is the point at which a projectile actually bursts. It may occur before, at, or beyond the point of impact.

32. **Inclination of the Trajectory**. The inclination of the trajectory is the acute angle measured from the horizontal plane passing through a given point on the trajectory to the oriented tangent to the trajectory at this point.

33. **Angle of Fall**. The angle of fall is the inclination of the trajectory at the level point, the sign being positive.

34. **Line of Impact**. The line of impact is a line tangent to the trajectory at the point of impact or burst.

35. **Angle of Impact**. The angle of impact is the acute angle, at the point of impact, between the line of impact and a plane tangent to the surface struck. This term should not be confused with the term **angle of fall**. They are the same only when the point of impact is at the level point.

36. **Angle of Incidence**. The angle of incidence is the acute angle between the normal to the surface struck and the line of impact.

DEFINITIONS RELATING TO EQUIPMENT

37. **Guns and Howitzers**. There are no sharp distinguishing features between guns and howitzers. Generally, guns produce higher MVs, fire low angle and have fewer charges than howitzers that fire at both high and low angles. Although certain differences may be noted, both have the following properties:

a. They give projectiles specified initial velocity and direction of motion.

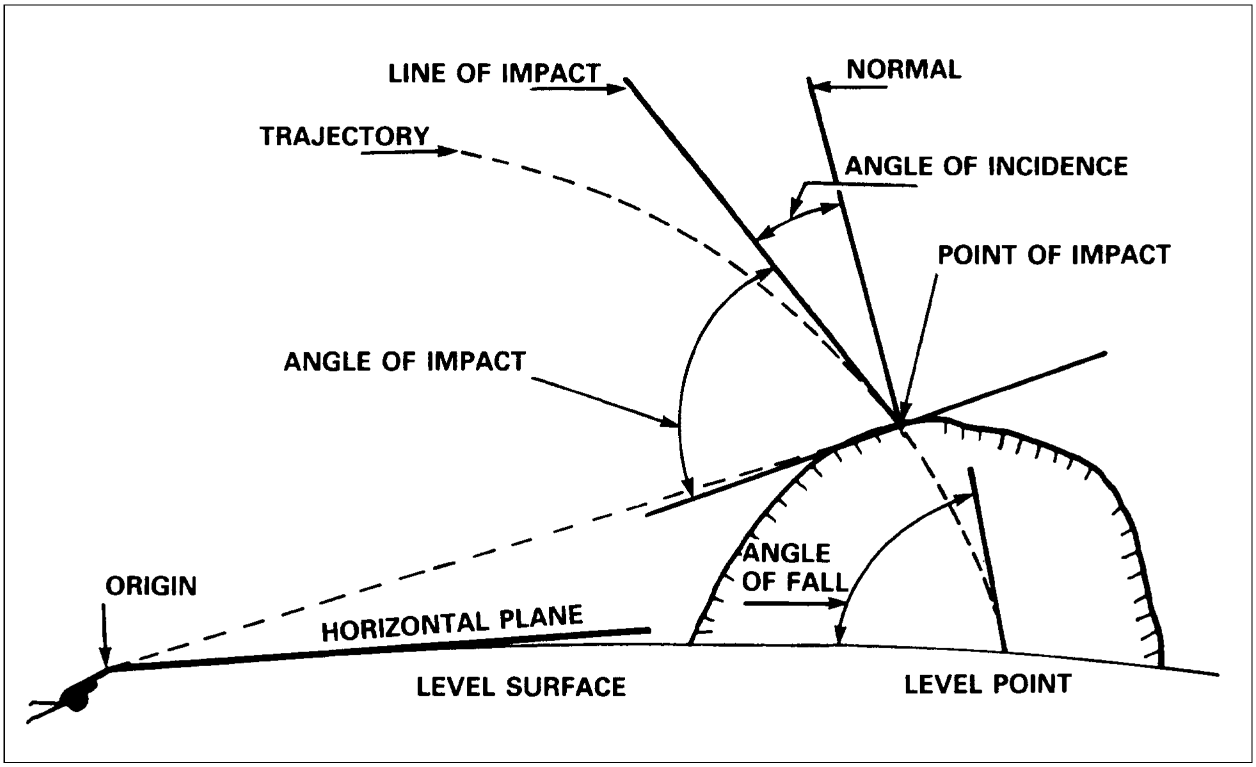


Figure 1-2-5 Terminal Elements

b. There is a rapid burning of a propellant charge in a chamber, that produces gas under pressure which forces the projectile to move along the barrel.

38. **Mortars**. Mortars are usually small, light and easily handled equipments that propel projectiles at high angles of elevation. They are usually loaded through the muzzle whereas guns and howitzers are loaded through the breech. Mortars usually have smooth bores, but can have rifled bores.

39. **Rockets**. Rockets are weapons consisting essentially of a warhead and a tube filled with propellant. Rockets depend for flight on the reaction set up by a jet of rapidly expanding gases released by the propellant.

40. **Recoilless Guns**. Recoilless guns reduce or eliminate recoil forces on the carriage by creating an opposing force that is normally achieved by venting a portion of the propellant gases. Lighter carriages can thus be used.

41. **Rifling**. Rifling is the set of twisted grooves cut along the interior of the bore, leaving raised ribs or **lands** between them.

42. **Calibre**. This is the (standard) diameter of the bore, excluding the depth of the rifling grooves. It is measured from land to land.

43. **Weapon**. The term **weapon** refers to the trunnions, the axis about which the barrel rotates during elevation or depression and which is at right angles to the weapon axis.

44. **Weapon Axis**. The weapon axis is the axis of the bore taken at the breech and it is a straight line. This axis will not go through the **weapon** if the trunnions are offset from the centre line of the bore.

45. **Axis of the Bore**. The axis of the bore is the line passing along the centre of the barrel. This may, owing to drop, be slightly curved. In this manual, the axis of the bore will be assumed to be a straight line from the weapon axis to the muzzle axis.

46. **Muzzle Axis**. The muzzle axis is the axis taken at the bore and it is a straight line.

47. **Droop**. Droop is the vertical angle between the axis at the breech and the muzzle axis. Droop varies with barrel length and/or temperature.

48. **The Breech Clinometer Plate**. This is an accurately machined plane surface on top of the breech ring parallel to the weapon axis. Most angular measurements and adjustments made on the gun are based on this plane.

49. **Muzzle Brake**. Muzzle brakes reduce the recoil forces by deflecting a portion of the propellant gases rearward at the muzzle, thus creating an opposing force. They are used to increase the stability of the carriage on firing.

50. **Muzzle Velocity**. MV is the velocity of the projectile at the muzzle.

CHAPTER 2

INTERNAL BALLISTICS

SECTION 1

INTRODUCTION

GENERAL

1. Internal ballistics is defined as the science that deals with the events that take place in a gun from the moment the propellant charge is ignited until the projectile leaves the muzzle. It deals with the complicated events during burning of the propellant and the movement of the projectile, which in turn depends on the design of the bore and the gas pressure. The task of the events under consideration is to give the projectile the correct MV and the required rate of spin. In spite of numerous and detailed studies on the subject, no exact scientific solution to the problem has yet been found. The internal ballistics in this chapter relate to events as they pertain to the gun only and no attempt has been made to relate these events to the mortar.

2. **The Gun**. A gun is a weapon that ejects its projectile by the action of a burning propelling charge. In a closed chamber a propellant charge burns more vigorously under pressure. The gun provides the chamber in which the charge burns.

3. **Projectile**. A projectile is an elongated object, such as a bullet, that is propelled from a gun by a rapidly burning, low explosive propelling charge. It is fitted with a soft metal rotating (driving) band or bands near its base which is designed:

   a. to engage with the rifling of the barrel causing spin to be imparted to the projectile as it moves along the bore;

   b. to prevent the escape of gases forward past the projectile;

   c. to offer a certain initial resistance to movement that has the effect of allowing an initial pressure rise which contributes to the regularity of burning of the propellant charge and hence regularity in MV;

   d. to assist in centring the projectile in the bore. This is particularly evident when two driving bands are fitted, one well forward of the other; and

   e. for equipments using separate loading ammunition, to hold the projectile in position when rammed, and to prevent slip-back when the gun is elevated.

4. **Propellant Charge**. This is a rapidly burning composition of low explosive that is burned in a gun to propel the projectile. When suitably ignited, the propellant charge has an extremely rapid rate of burning, producing many times its own volume of gases at a high temperature and

pressure. No outside agent, eg oxygen, is necessary for its burning. The rate at which the contained propellant burns increases with, and is approximately proportional to, the pressure developed. The higher the pressure, the faster the rate of burning; the lower the pressure, the slower the rate of burning.

5. The total effect of all interior ballistic factors determines the MV, which is expressed in metre per second (m/s) or feet per second (ft/s).

SUMMARY OF EVENTS

6. When the propellant is ignited, it burns very rapidly, liberating its chemical energy in the form of heat and gas. This causes the gas pressure in the closed space available behind the base of the projectile (the chamber) to rise rapidly.

7. The gases evolved from the surface of each separate piece of propellant continue to build up pressure in the chamber, thereby increasing the rate of burning such that the gases evolve more and more rapidly. Eventually, sufficient pressure is reached to completely overcome driving band engravement resistance and the projectile rapidly accelerates. The point at which the pressure in the chamber overcomes the resistance of the driving band to engravement is called, short-start pressure.

8. As the projectile moves forward, the space behind the base of the projectile increases, reducing somewhat the rate of pressure rise. Maximum pressure is reached when the increase of pressure due to the evolution of the gases is balanced by the decrease of pressure due to the increase of chamber space behind the projectile. In fact, the projectile moves only a short distance before the pressure reaches a value. The pressure then begins to decrease slowly (space is still increasing but gas continues to evolve). However, the projectile velocity continues to rise rapidly.

9. Shortly, a point is reached at which the propellant is entirely consumed and no more gas is evolved. This point is known as the position of all-burnt. The increasing internal volume causes a rapid decrease in pressure while the projectile continues to accelerate but at an ever reducing rate. By the time the projectile reaches the muzzle, the pressure has fallen to a fraction of its former value and acceleration is comparatively small.

10. As the base of the projectile clears the muzzle, hot gases are ejected under tremendously high pressure and high temperature. Close to the muzzle, the outflowing gases have a much higher velocity than the projectile, consequently, they overtake and pass the projectile. In terms of relative velocity, the projectile moves as though moving backward. This is evident by the formation of a shock wave around the base of the projectile during the first few centimetres of flight from the muzzle.

11. The effect of the outflowing gases is to give the projectile an additional thrust so that the maximum velocity is not at the muzzle but a short distance in front of it. The gases rapidly lose their velocity and the projectile overtakes the outflowing gases, all within a few centimetres of

the muzzle. This is the transitional phase of ballistics (intermediate ballistics). At this point, the forces normally associated with external ballistics begin to act on the projectile.

VELOCITY AND PRESSURE

12. The summary of events describes in general terms the variation in gas pressure and projectile velocity as the projectile travels along the bore. The variation is shown graphically in Figure 2-1-1. Here, gas pressure and projectile velocity are plotted against the travel of the projectile and the resulting diagrams are known respectively as pressure travel and velocity-travel curves. Evaluation of numerous gas pressure diagrams shows that the gas pressure curves of different guns and types of propellant are very similar in character, Variation in weight of the projectile, propellant size and shape, propellant temperature and many other factors will cause a small change from round to round in the gas pressure curve.

13. Several points are immediately apparent in examining the graph:

a. There is no appreciable movement of the projectile until a chamber pressure of about 28 MPa (2 tons square/inch) is developed indicating that a pressure of about this magnitude is required to engrave the driving band.

b. Maximum pressure of about 240 MPa (17 tons per square inch) is reached when the projectile has moved forward only some 18 cm (7 inches).

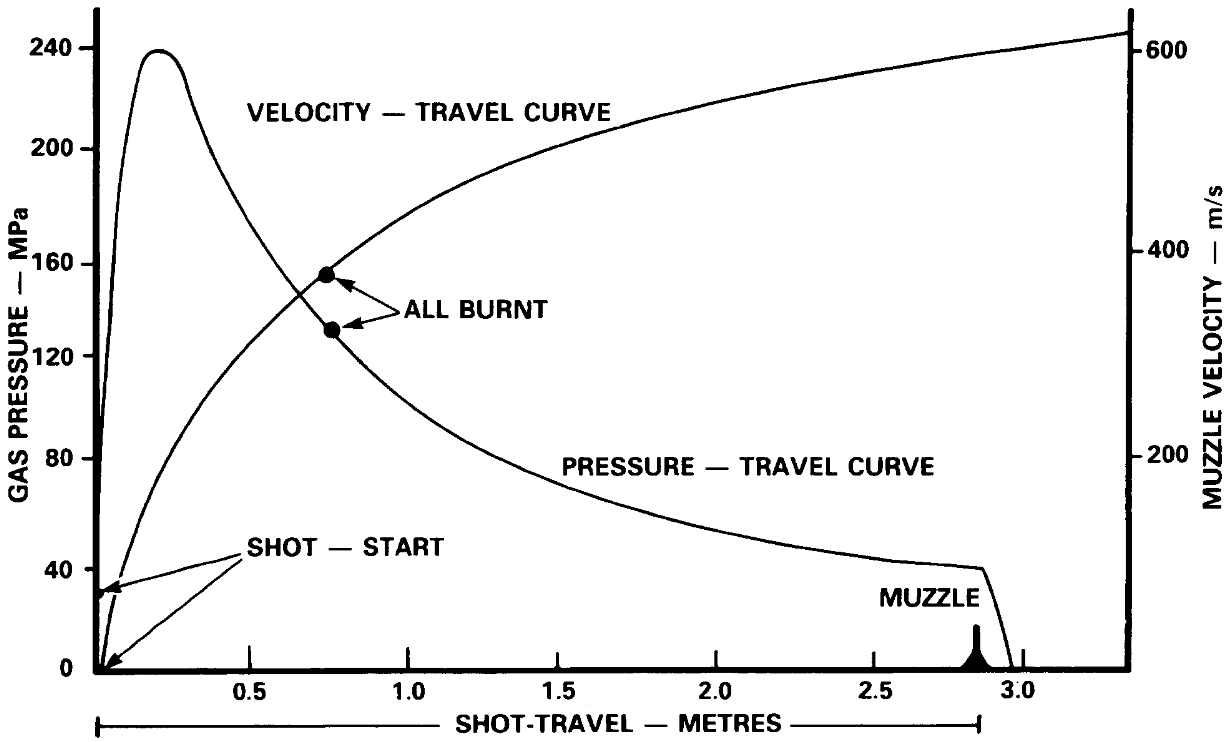
c. The projectile has travelled only 76 cm (30 inches) and is, therefore, well back in the bore when all the propellant is converted into gas (position of all-burnt).

d. The pressure has fallen to roughly 41 MPa (3 tons per square inch) when the projectile finally leaves the muzzle.

14. The velocity-travel curve indicates the following:

a. More than two-thirds of the MV of 620 m/s (2 030 ft/s) is developed while the charge is still burning.

b. Velocity is rising only slowly as the projectile approaches the muzzle.



1 POUND-FORCE PER SQUARE INCH (psi) = 6.894757 KPa
1 TON-FORCE PER SQUARE INCH = 13 789 MPa
1 TON-FORCE (UK) PER SQUARE INCH = 154 443 MPa
1 MPa = 145 P (A PASCAL IS THE PRESSURE (OR STRESS) THAT IS PRODUCED WHEN A FORCE OF ONE NEWTON IS APPLIED TO AN AREA OF 1 m^2.)

Figure 2-1-1 Pressure-Travel and Velocity-Travel Curves

15. By continuing the velocity-travel curve in Figure 2-1-1 to the right, it can be seen that the barrel would have to be lengthened considerably to obtain an appreciable increase in MV. It is, therefore, uneconomical to increase the barrel length beyond a certain amount as the disadvantages of a long barrel would more than offset the extra velocity obtained.

DISTRIBUTION OF ENERGY

16. When gas pressure is plotted against shot-travel, the typical pressure-travel curve, as shown in Figure 2-1-1, is obtained. The area below the pressure-travel curve times the cross-sectional area of the bore corresponds to the work done by the gases (1/2 x mass of projectile x square of MV). The heat energy liberated by the burning of the propellant can only be partly converted to kinetic energy, the remainder is lost in various ways. The total amount of energy liberated on firing is used up as follows:

a. energy of translation of the projectile;

b. energy of rotation of the projectile;

c. energy of recoiling parts;

d. kinetic energy of the gases;

e. loss of heat to the barrel, cartridge case and projectile;

f. energy taken up by engraving the driving band, including frictional losses; and

g. latent heat of gases leaving the muzzle.

17. By the time the projectile leaves the muzzle it has acquired kinetic energy equal to approximately 30 per cent of the total energy liberated on firing. The energy remaining in the gases is wasted in heat and gas effects that serve no useful purpose.

18. The greatest loss in energy occurs because of residual heat energy losses from gases leaving the muzzle, which may represent up to 60 per cent of the total energy liberated. These gases are ejected under tremendous pressure and velocity and, when coupled with the yawing motion of the projectile as it emerges from the muzzle, cause dynamic instability of the projectile. Because of this **transitional effect** it is necessary, when calibrating guns electronically, to measure the velocity of the projectile at some point forward of the muzzle where these effects are considered to be non-existent and then deduce the projectile's MV by extrapolation.

MUZZLE VELOCITY AND WEIGHT OF PROPELLANT CHARGE

19. The demand for longer range guns, hence the highest possible MV, is well known. It is not possible, however, to raise the MV of a projectile indefinitely. Every increase in MV has a double effect in raising the weight of the propelling charge; firstly, to accelerate the projectile to

a higher velocity, and next, to accelerate the additional gases evolved from the larger charge. The proportion of energy required to accelerate the mass of gas rises rapidly with increase in velocity and is finally so large that no energy is left for further raising the velocity of the projectile. Even if the weight of the projectile were nil (theoretical) no further increase in velocity could be expected. This limit for maximum attainable velocity is of the order of 2 500 m/s for the types of propellant generally used for guns. In order to realize this limiting velocity, however, an infinitely long barrel would be required such as to ensure that the entire area under the pressure curve is accounted for - even the seemingly insignificant portion past the point where the barrel would normally terminate.

20. In Figure 2-1-2, the weight of propellant charge and related MVs are shown for the 105 mm and the M109A2/A3 Howitzers. This data can be used to illustrate how rapidly the weight of the propellant charge rises with an increase in MV. For example, to raise the MV of the M109A2/A3 Howitzers from 337 m/s (charge four) to 684 m/s (charge eight), approximately double its value, the weight of the propellant charge is increased fourfold. If the muzzle energy of the projectile alone had to be considered, a lesser increase in propellant weight would be required. The remainder is, however, necessary to accelerate the additional gases evolved from the larger charge.

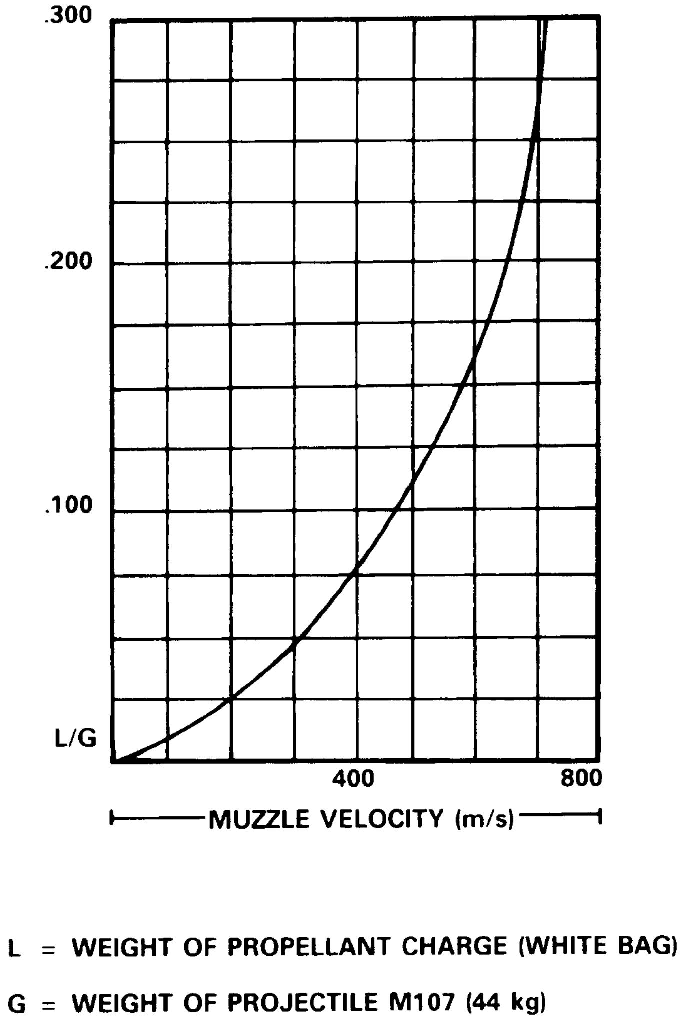


Figure 2-1-2 Ratio of Weight of Propellant to Weight of Projectile Rise with Increased Muzzle Velocity for the M109A2/A3 Howitzer

21. How the ratio of weight of propellant to weight of projectile rises with increasing velocity for the M109A2/A3 Howitzer is illustrated in Figure 2-2-1. An examination of the graph indicates that maximum attainable velocity has been achieved with the M109A2/A3. Even if the weight of the propellant charge were increased further, little, if any increase in MV could be expected because the extra energy generated would be used up in accelerating the additional gases evolved from the larger charge.

SECTION 2

PROPELLANT

GENERAL

1. A propellant is defined as an explosive material whose rate of combustion is low enough and its other properties suitable to permit its use as a propelling charge. Propellant is the single, most important factor that affects the sequence of events in Internal Ballistics. An ideal propellant should:

   a. undergo rapid and regular burning such that the maximum velocity is imparted to the projectile with the lowest temperature and pressure;

   b. be smokeless and flashless;

   c. be neither poisonous nor have an erosive effect on the gun; and

   d. not be affected by varying temperature or atmospheric conditions.

2. These are exacting demands for substances that burn rapidly, producing large quantities of hot gases. These exacting demands cannot all be met, but some degree of adjustment is possible with modern propellants that are capable of being formed to any desired shape or size. This permits a fine adjustment between the surface area and weight of propellant, which leads in turn to a control of the rate of burning and consequently pressures of gases.

3. **Classification**. Propellants are generally classified in accordance with their method of manufacture. The main categories are:

   a. Black gunpowder (or similar) made up from at least two (generally three or more) different components that do not gelatinize, are mostly of inorganic origin and that are brought to the desired form (generally grain) by mixing, grinding and pressing.

   b. Those similar to the first group but distinguished by the fact that the grains are agglutinized together by a binder.

   c. The group comprising all gelatinous propellants on a single base that are always formed by extrusion process with the use of a volatile solvent (note that this group may also include double and triple base propellants if they are manufactured with volatile solvents).

   d. Double and triple base propellants if non-volatile solvents, and possible plasticizers, are used in their manufacture. The gelatinization of the propellant mass is carried out by heated rollers, the shaping by heated extrusion presses.

NOTE

The process of solvent treatment is known as **gelatinization** since the final product is semi-translucent and resembles a solid jelly.

4. **Description**. The following are descriptions of the different propellants:

a. Gunpowder was used as a propellant for centuries but it was far from ideal since its ballistics were irregular, it produced large amounts of smoke and residue and was rendered inert in the presence of water. Near the end of the last century, it was gradually replaced by the modern types of propellants.

b. Nitrocellulose (NC) is the best known example of a gelatinous propellant. During manufacture, the NC mixture is gelatinized by means of volatile solvents (usually alcohol or ether). Stabilizers are added to neutralize traces of acid from the nitration process which in the course of time might cause a breaking down of the NC. The plastic mass thus obtained is shaped by hydraulic extrusion presses into strip, cord or tubular form and cut to the required lengths. Propellants based on only NC are known as single-base propellants.

c. Gelatinization of NC can also be brought about by the use of non-volatile liquid nitric esters such as nitroglycerine (NG). Since this itself is an explosive, it acts as another energy carrier in addition to performing the role of a non-volatile solvent. This process can be brought about by heat. The thermoplastic-like product is then brought to final shape and length according to propellant type by means of calibre rollers, cutting machines and punches or extrusion presses. Propellants containing both NC and NG are known as double-base propellants. In these, the stabilizer is carbamite. Two drawbacks of the earlier types of double-base propellants were -

(1) excessive barrel erosion due to high temperatures of reaction, and

(2) muzzle flash.

d. The addition of nitro guanadine (earlier christened **picrite** for reasons of security), in considerable proportions (over 50 per cent), to double base propellants overcame these deficiencies somewhat. Nitro guanadine is a cool explosive in its own right and is extremely rich in nitrogen. On decomposition, its high nitrogen content serves to blanket and cool the more energetic gases and slow down their reaction, thereby decreasing flash. It also acts as a stabilizer. It is said that barrel life is increased by a factor of two and muzzle flash can be more easily suppressed. One drawback is that with the reduction in temperature, the available energy is reduced, hence, larger charges are necessary. Since **picrite** is added to the double base as a third active component, such a propellant is known as a triple-base propellant.

e. Propellants containing neither NC nor an organic nitrate but consisting generally of a physical mixture of an organic fuel such as ammunition picrite, an inorganic oxidizing agent such as potassium nitrate and an organic binding agent are called composite propellants.

f. The basic characteristics of the M1 propellant in current use with Canadian guns are given in Figure 2-2-1.

5. **Burning of the Propellant Charge**. In general, the propellant charge is made up of a number of geometrically similar pieces of propellant known as **grains**. The total weight of all the grains is called the **charge**. The burning of the propellant can be regarded as the disintegration of its complex molecules into the simpler molecules of the propellant gases when the charge is brought to the temperature of ignition (in the region of 180 degrees C). The outer layer of each grain is initially brought to this temperature by the heat supplied from the igniter. When ignited, each piece of propellant burns over the whole of its surface, and as it burns, the surface of each grain recedes parallel to itself until it is entirely consumed. The gases evolved from the burning propellant are at a very high temperature (1 700 degrees C to 3 000 degrees C) and the heat from the igniter and these gases bring successive layers to the temperature of ignition, inducing flamespread.

6. The law of burning by parallel layers is known as Piobert's Law and is universally accepted by internal ballisticians. Confirmation that such a law is nearly obeyed in practice is obtained by firing charges such that the propellant is not all burnt while the projectile is still in the bore; pieces of burning propellant are thrown from the gun, burning is arrested and the partially burnt pieces are recovered. The shapes of such unburnt grains are found to be preserved almost exactly. In other words, simultaneous ignition over the whole surface of the grains and burning by parallel layers do take place. The picture may be made more clear by taking as an analogy a cake of soap dissolving in water. The soap gradually shrinks but it dissolves approximately by parallel layers and, except for a rounding of the edges, the cake retains its shape.

7. **Rate of Burning**. All discussion of the properties and behaviour of modern propellant in the gun are based on the knowledge that the rate of burning depends on the gas pressure, since an increase in gas pressure causes an increase in the rate of burning on the surface of each grain and conversely, the rate of burning falls with reduced gas pressure. Control of the rate of burning and hence gas pressure is possible by varying the chemical composition of the propellant and by the choice of geometrical shape of the grain and its surface area. The larger the surface area of the grain, the greater is the amount of gas evolved per unit time. In view of the foregoing and to meet the needs of different types of weapons, propellant grains are manufactured in various sizes and shapes. Typical examples of propellant grains are illustrated in Figure 2-2-2.

8. **Ballistic Size/Web Thickness**. The propellant will be completely consumed when the least dimension between two opposite burning surfaces of the propellant grain has been burnt through. This least dimension of the propellant grain is known alternately as the ballistic size or web thickness and its magnitude has a considerable effect on the maximum pressure, position of all-burnt and MV. Web thickness is indicated by "D" in Figure 2-2-2.

WEAPON	PROPELLANT				CALIBRATED VALUES			RATED MAX PRES MPa
	COMP	COMP PER CENT	WEB mm	GRAN	APPROX CHARGE wt kg	VELOCITY m/s	PRESSURE MPa	
105 mm C1&L5	M1	NC — 85.0 DNT — 10.0 *DBT — 5.0	0.381 0.635	Dual SP MP	0.242 0.283 0.355 0.462 0.626 0.875 1.283	195 212 233 262 302 366 465	56 69 75 92 116 160 251	84.1 (12 200 PSI) 269 (39 000 PSI)
155 mm M109A2/A3	M1	Same as Above	0.381 Green Bag 0.8636 White Bag	SP MP	0.885 1.108 1.400 1.806 2.495 1.885 2.413 3.226 4.454 5.982	212 238 277 319 375 293 337 393 476 565	37 52 70 99 153 53 59 85 141 251	258 (37 500 PSI 265 (38 400 PSI
	M6	NC — 87.0 DNT — 10.0 DBT — 3.0	1.420	MP	10.443	684		.

* Dibutylphthalate (DBT) reduces the flame temperature and controls the rate of burning, therby reducing barrel erosion.

Figure 2-2-1 Propellant Characteristics

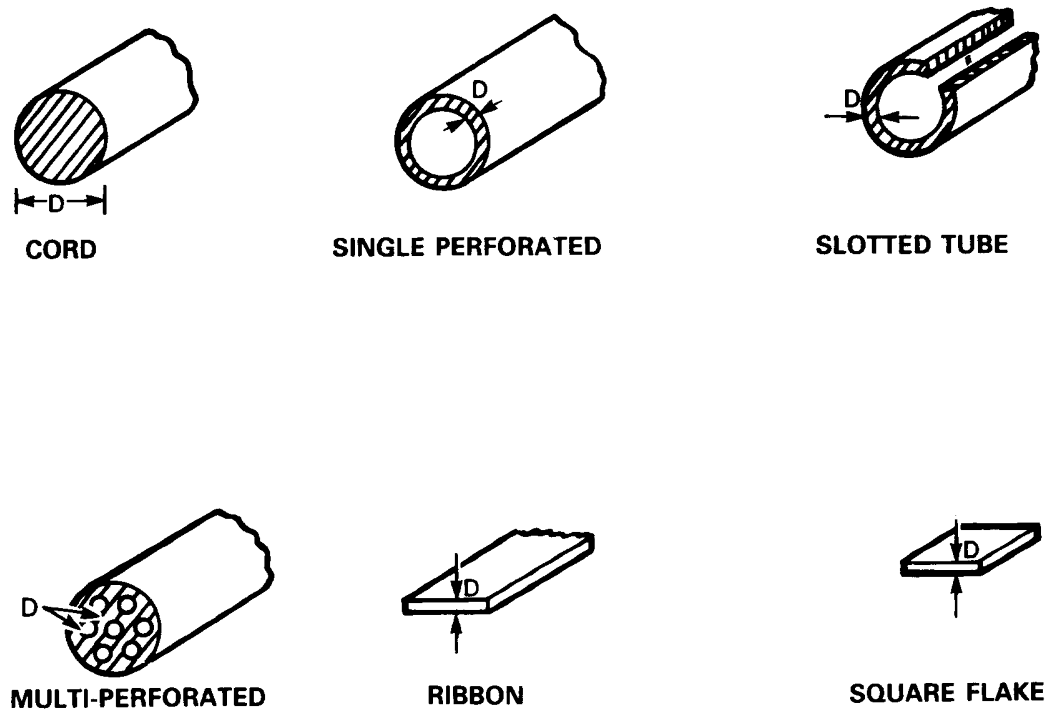


Figure 2-2-2 Sizes and Shapes of Propellant Grain

9. **Shape of Grain**. The shape of the propellant grain has an important effect on the way in which the surface area, from which the gases are evolved, varies during burning. As previously stated, in burning, the surface of each grain recedes parallel to itself, and the amount of gas evolved per unit time will be directly proportional to the amount of surface area available for burning. By altering the geometric configuration of the grain, pressure build-up can be varied and hence the burning characteristics of the grain. There are three possible situations that may occur:

a. As the surface burns, the total area available for burning continually decreases. The gas evolved per unit time thus becomes less and less, hence pressure build-up declines at an ever increasing rate. This is called degressive burning.

b. As the surfaces burn, the total area available remains constant. This is called neutral burning.

c. As the surfaces burn, the total area available for burning continually increases. Amount of gas evolved per unit time increases and pressure build-up is rapid. This is called progressive burning.

10. The burning characteristics of the propellant grains illustrated in Figure 2-2-2 are as follows:

a. **Cord**. Cord burns degressively since the surface area decreases as burning progresses. The web thickness of cord is the diameter.

b. **Single Perforated or Tube**. This burns nearly neutral as the decrease of the outer surface is matched by the increase of the inner surface. Web thickness is the difference between the outer and inner radii.

c. **Slotted Tube**. It was found that intense heat and pressure inside caused normal tube to split and crack thus altering the burning characteristics. Provision of a slot allows expansion and pressure release and thus more consistent burning characteristics. Aside from the slightly different dimensions, it is similar to a normal tube.

d. **Multi-Perforated or Multi-Tubular**. These are progressive burning propellants. The grain has both an inner and outer web thickness which may be equal or different. When the portion between the holes has burned through, the whole unit breaks up giving degressive burning particles. Sometimes the average web is used. This is simply the average of the inner and outer web.

e. **Strip or Ribbon**. These burn degressively. Square flakes also exhibit the same characteristics. All are used for quick propellants, eg mortars.

11. **Granulation**. As previously stated, propellants can be manufactured in different sizes and shapes. Occasionally, mixtures are used depending on the effect desired. Such mixing necessitates a further classification of the charge:

a. **Single Gran**. This is a charge that has one size/shape of propellant.

b. **Dual Gran**. This is a charge that has two sizes of shapes combined. It is usual for such charges to consist of some bags of one size or shape while the remaining bags of the charge will be of another size/shape combination as opposed to mixing of the different grains together.

12. The factors discussed in this section govern the rate of energy release, the total quantity released and the temperature and pressure developed. The total surface available for burning and the time required for burning are determined by the rate of burning, initial burning surface and any change in area of burning surface as burning progresses. The ballistic effect of the propellant charge is determined and kept within certain limits by controlling the mass rate of burning of the propellant charge through control of physical form. From a ballistic point of view, the best form of powder grain is that which will impart the prescribed velocity to the projectile with the smallest weight of charge without exceeding the maximum allowable pressure.

SECTION 3

THE EFFECTS OF VARIATIONS IN LOADING CONDITIONS

GENERAL

1. In this section, a set of pressure-travel curves for a representative gun is given to illustrate the variations that can be expected when loading conditions are varied, one at a time, eg charge weight, propellant size, etc. The pressure-travel curve for the representative gun is shown by a solid line. The dotted line refers to the same gun when one loading condition is altered - usually by an increase of 10 per cent. In each graph, the maximum pressure and MV for the two sets of loading conditions under discussion are shown in the top right corner. Figure 2-3-1 shows the change that can be expected for a 1 per cent increase in loading conditions.

One Per cent Increase in	Percentage Variation in Muzzle Velocity	Percentage Variation in Maximum Pressure
Projectile weight.		
All shapes of propellant.	− 0.40	+ 0.60
Charge weight.		
(Cord, Multi-tube)	+ 0.60	+ 1.60
(Tube, Slotted Tube)	+ 0.70	+ 1.80
Chamber capacity.		
(Cord, Tube)	− 0.25	− 1.15
(Slotted Tube and Multi-tube)	− 0.25	− 1.00
Shot travel.		
All shapes of propellant	+ 0.20	
Propellant size.		
(Cord Tube)	− 0.15	− 0.85
(Slotted Tube and Multi-tube)	− 0.30	− 1.40

Figure 2-3-1 Approximate Variation Due to Change in Loading Conditions

POSITION OF ALL-BURNT

2. All-burnt represents the final release of all the propellant's energy into a gaseous form. The position of the projectile at the instant of all-burnt is of great importance, particularly in order to ensure round-to-round regularity (consistency) in MV. Because the action of the propellant gases is more regular and consistent after all-burnt, it can be expected that the longer a distance over which these gases are permitted to act on the projectile, the more likely it is that minor variations in energy content up to all-burnt will be corrected. Round-to-round regularity in MV, therefore, can be expected to be greater when the projectile is well back in the bore at the instant of all-burnt.

3. A second consideration is that the temperature of the propellant gases decreases as the gases expand. If all-burnt is well back in the bore, the temperature of the expelled gases will be

lower than if burning continued until the projectile was near the muzzle. This would result in less tendency for muzzle flash.

4. The third consideration is peak pressure in the chamber. If the position of all-burnt is too close to the chamber, peak pressure would exceed the pressure the gun is designed to withstand. Very high pressure also increases barrel wear. Therefore, the ideal position for all-burnt is at a point one-third of the way up the bore.

5. The position of the projectile at the instant of all-burnt is indicated in the following graphs by a dot on the standard curve and by a cross on the dotted curve.

VARIATION IN CHARGE WEIGHT

6. The energy available from a given charge depends on its weight and chemical composition. An increase in charge weight, therefore, clearly entails an increase in pressure and velocity for there is more chemical energy available (see Figure 2-3-1). This also implies that at any point there will be a greater area under the pressure curve. As the pressure with the increased charge is higher, the rate of burning will be faster. The effect of this is that, although the projectile is moving more rapidly when fired with the increased charge, the projectile is further back from the muzzle when the propellant is all-burnt. This situation is illustrated in Figure 2-3-2.

7. Since round-to-round regularity in MV is greater when the projectile is well back in the bore at the instant of all-burnt, consistency in fall-of-shot is likely to be better with a larger charge. This is why it is desirable to use a high charge when engaging a target in close proximity to our own troops. With some howitzers, in which a large number of different charges is used, eg 105 mm C1 Howitzer, it is necessary to use a smaller size of propellant for the lower charges, otherwise, the propellant would not be all-burnt when the projectile left the muzzle.

VARIATION IN PROPELLANT SIZE

8. Variation in propellant size will affect mainly the rate at which energy can be extracted from the charge. For the same charge weight, an increase propellant size has the effect of decreasing the total initial burning surface of propellant exposed to the gases. Consequently, gas is evolved less quickly; pressure build-up is not as rapid resulting in a decrease in MV (see Figure 2-3-3). The area below the pressure-travel curve can be taken as a measure of the muzzle energy of the projectile. If the two curves were continued indefinitely in the shot-travel direction, the areas below the curves would be the same or there would be the same chemical energy available in both cases.

9. With the assumption of no energy loss, all this energy must be converted into mechanical energy of the projectile. This implies that the pressure-space curve for the larger size propellant must eventually cross over the normal curve at some point. Since the difference in areas before and after the cross-over must be the same in an infinitely long barrel, it is apparent that in a normal barrel, the area under the curve corresponding to the larger size propellant will be less than for the standard size propellant hence, a lower MV will be attained. Also, because of the

initial less rapid pressure build-up, a slower rate of burning can be expected and the projectile will be further along in the bore at all-burnt. As a result of this, less round-to-round regularity of MV can be expected. Figure 2-3-1 illustrates the approximate change in MV and maximum pressure for an increase of 1 per cent in propellant size.

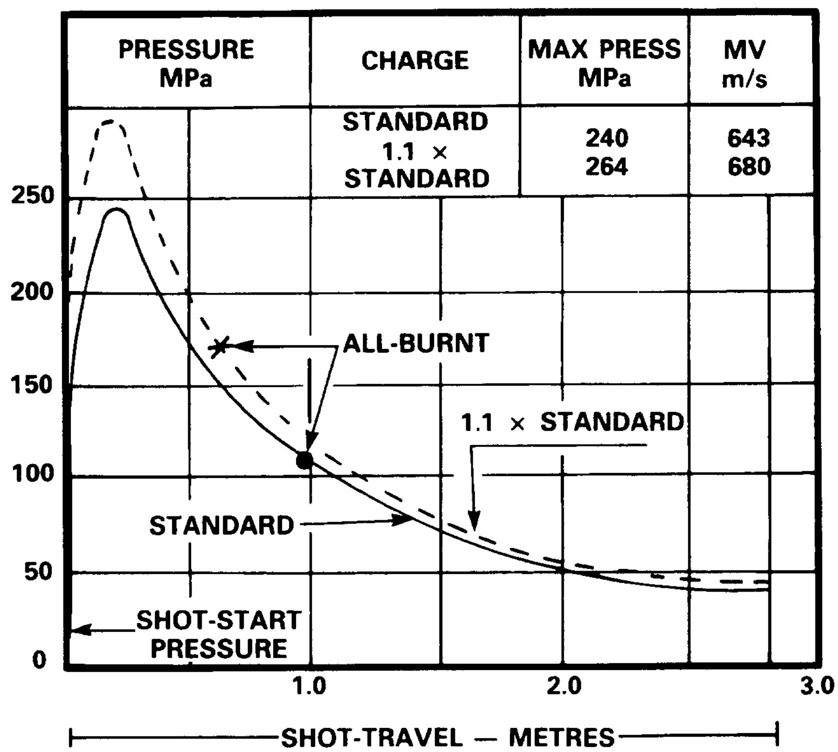


Figure 2-3-2 Variation in Charge Weight

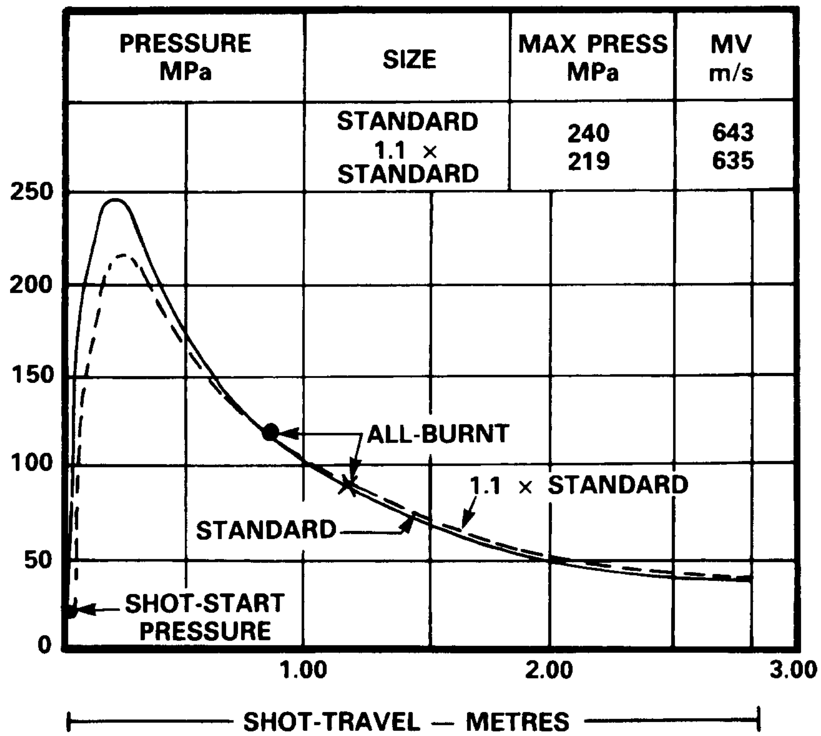


Figure 2-3-3 Increase in Propellant Size

10. For the same charge weight, a decrease in propellant size has the effect of increasing the total initial burning surface of propellant exposed to the gases. Consequently, gas is evolved more quickly; pressure build-up is more rapid resulting in an increase in MV (see Figure 2-3-4).

11. The limit to which the size may be decreased, however, is governed by the maximum pressure the gun will withstand. It is also worth noting that by decreasing the size of the propellant, the velocity is only slightly increased for a comparatively large increase in maximum pressure. Because better regularity in round-to-round MV can be expected with the faster burning, smaller size propellant, it is desirable (for equipment that uses a number of different charges) to use a propellant size that is as small as possible in the lower charges in order to obtain higher pressures.

VARIATION IN PROJECTILE WEIGHT

12. An increase in projectile weight affects the pressure-curve similar to a decrease in propellant size. For the heavier projectile, maximum pressure is greater, the rate of burning is increased; all-burnt is moved closer to the chamber and the area below the curve is increased (see Figure 2-3-5).

13. From observation of the graph, it would appear that for normal barrels the heavier projectile has more energy. On balance, however, the increase in bore resistance to the heavier projectile will outweigh the slight increase in projectile energy resulting in a decrease in MV. For example, from the data in Figure 2-3-1, for a 10 per cent increase in the 155 mm projectile

weights (from 44 kg to 48.4 kg) a decrease of 4 per cent in MV can be expected. Taking the MV for charge 5 - White Bag at 393 m/s, the decrease in MV for the 10 per cent increase in projectile weight is - 16 m/s.

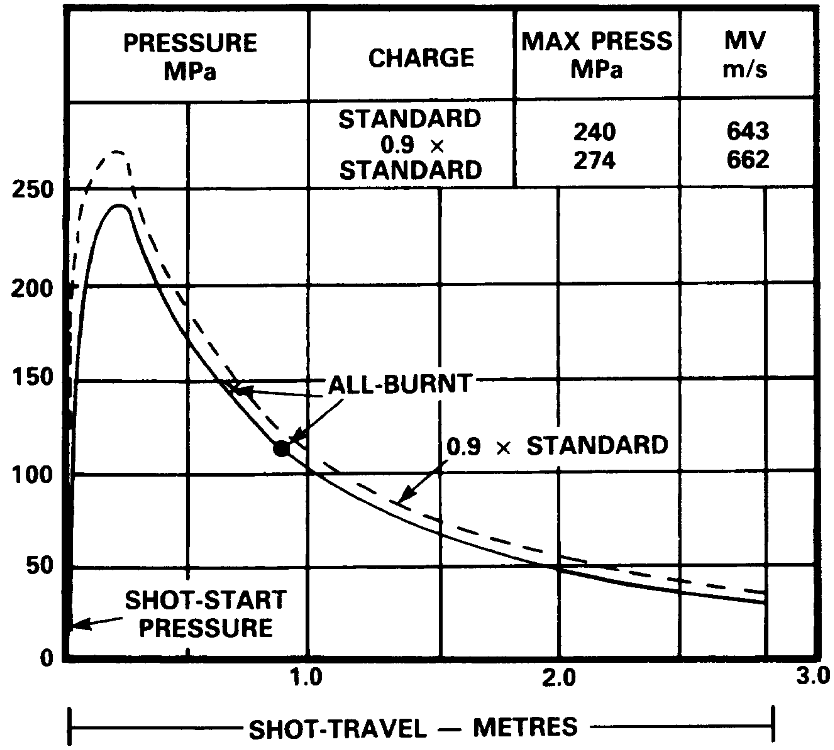


Figure 2-3-4 Decrease in Propellant Size

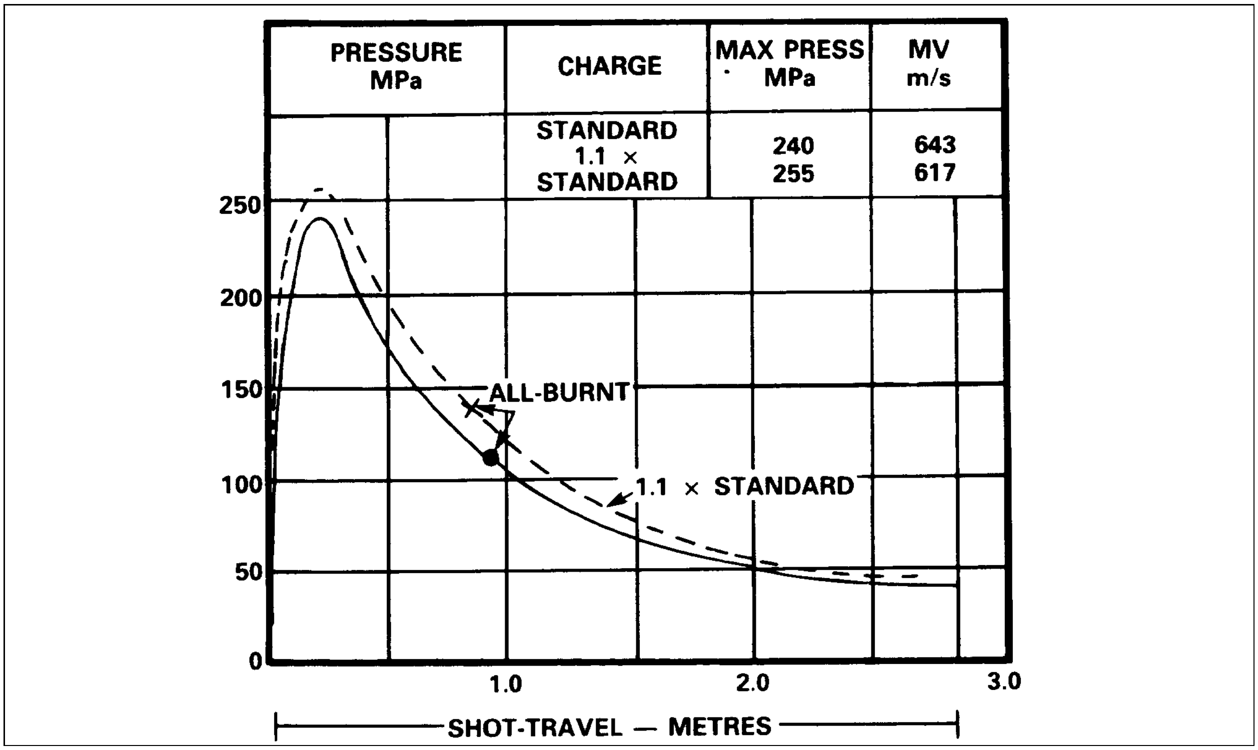


Figure 2-3-5 Increase in Projectile Weight

VARIATION IN PROPELLANT SHAPE

14. A charge made up of a propellant shape presenting a constant or increasing surface area during burning can be expected to give a flatter pressure-travel curve than will a cord charge. With cord, the surface from which the gases evolve is continually decreasing and the drop in pressure is fairly rapid after maximum pressure has been reached, With such shapes as single perforated or multi-perforated, the pressure is much better sustained because the burning surface is nearly constant or even increasing as burning progresses. In Figure 2-3-6, the standard curve represents a charge made up from cord propellant; the dotted curve represents a charge made up from a propellant shape that presents a constant surface area during burning.

15. At all-burnt, the pressure-travel curve given by the cord charge is quite smooth because the burning surface decreases smoothly to a zero value. With neutral burning propellants, there is a sudden change in the burning surface at all-burnt because, at the previous instant there exists the same surface evolving gases as there were throughout burning and then this surface suddenly vanishes. In the theoretical case, this effect will appear as a discontinuity in slope of the pressure-travel curve at this point. In practice, the discontinuity in slope of the pressure-travel curve is not expected to occur because the assumptions made in the theory of burning will not be exactly true and all pieces of propellant will not be exactly all-burnt at the same instant.

16. For the same charge weight and propellant size, the initial burning surface is considerably greater with the cord charge and the initial pressure rise is thus more rapid. With a propellant that presents a constant burning surface, the lesser initial burning surface results in a slower rise in

pressure build-up, reduced maximum pressure and a slower rate of burning. Since the energy available is the same in each case the curves must eventually cross each other and in an infinitely long barrel the area under the curves must be the same. With a normal barrel, however, the area below the curve corresponding to the propellant of constant burning surface is less and sufficient energy cannot be regained, even though cross-over occurs before reaching the muzzle. The result is a reduction in MV. Also, because of the slower rate of burning, the projectile will be further along in the bore at all-burnt, hence, less regularity of MV can be expected. It is worth noting, however, that the fairly small reduction in MV is accompanied by quite a large reduction in maximum pressure.

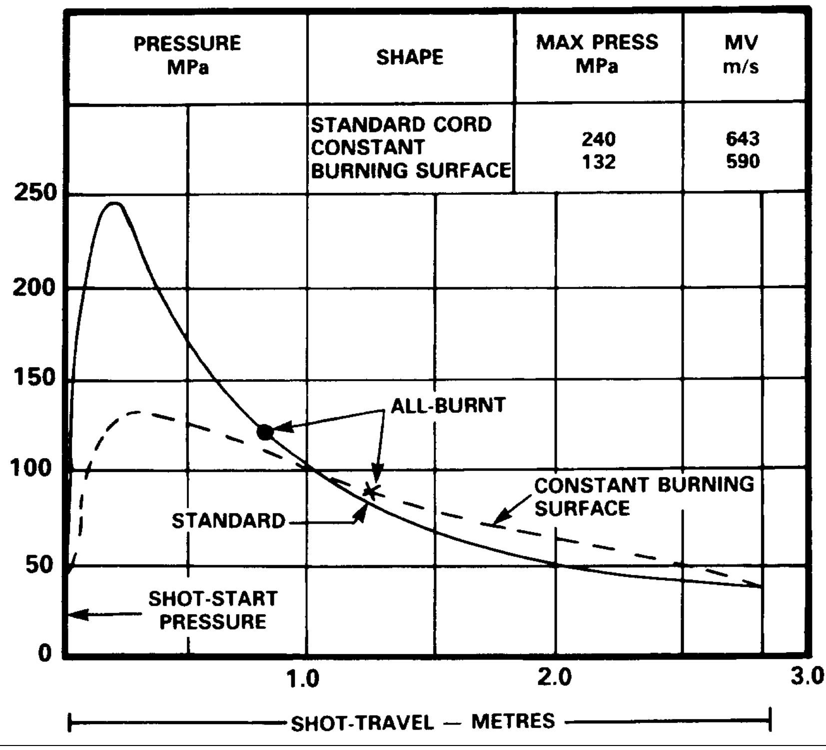


Figure 2-3-6   Variation in Propellant Shape

VARIATION IN CHAMBER CAPACITY

17. Variation in chamber capacity can arise through overramming, alteration in position of shot-seating due to wear and use of a projectile with the driving band further forward than normal, eg the use of streamline projectiles. With an increase in chamber capacity, the pressure rise is initially less steep since there is more space available for the gases. All-burnt is further forward because of the decrease in rate of burning accompanying the lower gas pressure, hence, less regularity in MV can be expected (see Figure 2-3-7). The argument previously derived from energy consideration still applies but, in this particular case, the cross-over point is quite close to the muzzle, consequently, the MV is considerably reduced.

VARIATION IN BORE AREA

18. For a constant projectile weight, an increase in bore area implies a projectile that is shorter and larger in diameter than normal. With an increase in bore area, the pressure curve will always lie below the standard curve as illustrated in Figure 2-3-8. According to the energy arguments used in previous discussions, this statement would seem to be in error. This can be explained by noting that it is the product of the bore area and the area under the pressure-travel curve that determines the energy of the projectile. As the bore area in this example is increased, the area under the curve is **reduced** such that the product of the bore and the area under the pressure-travel curve remain constant. The curves, therefore, need not and, in fact, do not cross. Although the pressure is less with the increased bore area, the MV is increased. The reason for this is that the force accelerating the projectile is the product of the increased bore area and the reduced pressure. The combined effect, therefore, leads to an increased average force.

19. It can be seen that by using a projectile of constant weight but shorter and larger in diameter than normal, approximately the same MV can be obtained with a pressure that is less than with a standard projectile. This type of projectile is thus advantageous from the interior ballistic point of view but, of course, has the disadvantage of bad exterior shape.

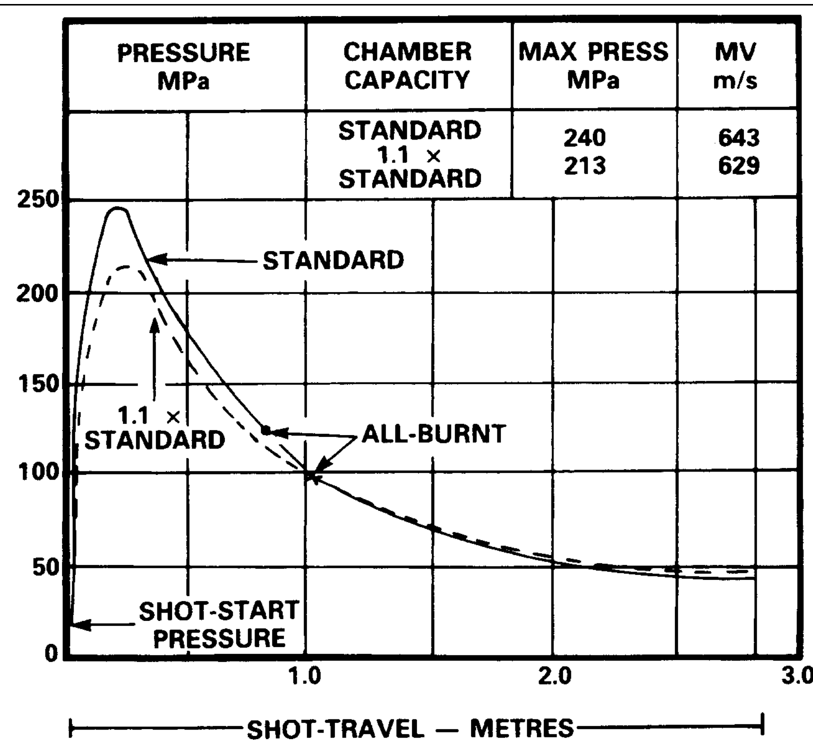


Figure 2-3-7 Variation in Chamber Capacity

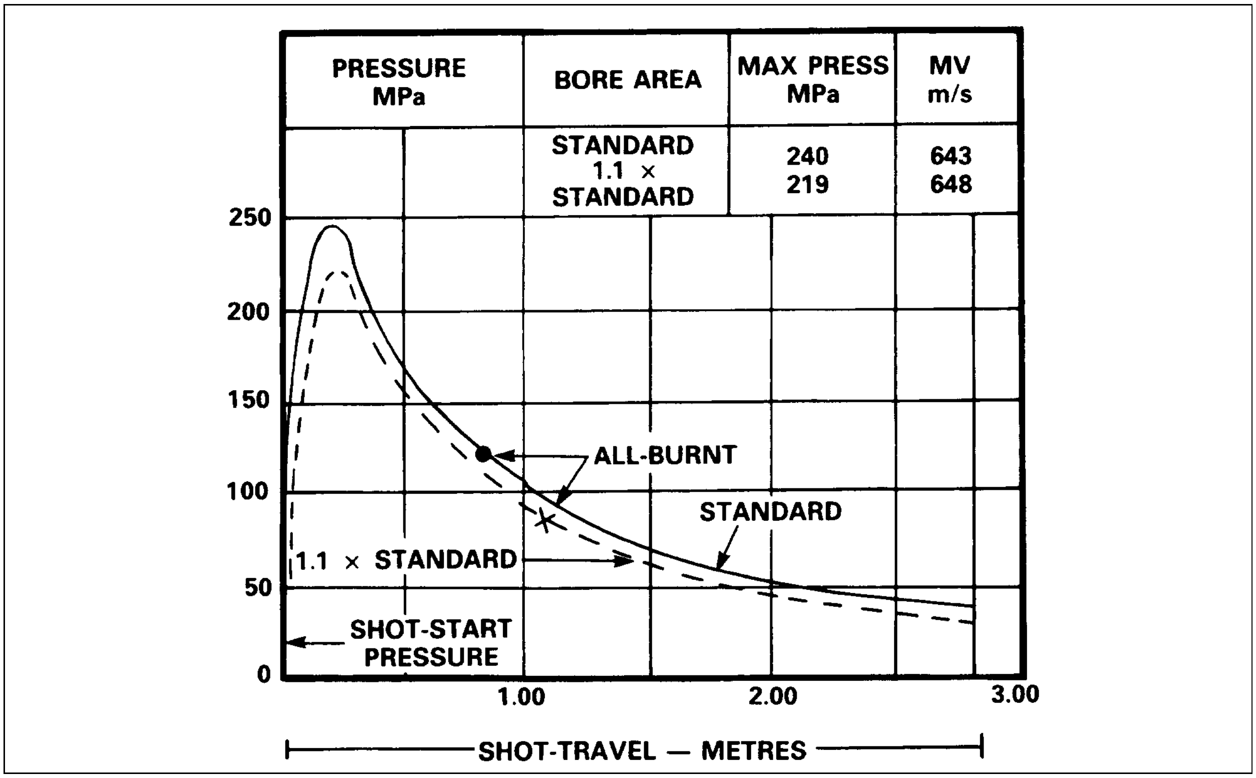


Figure 2-3-8 Variation in Bore Area

20. When the bore area is increased with a constant projectile weight, a shorter projectile is not always necessary. It is possible in many cases to reduce the wall or base thickness which would compensate for the increased weight due to its larger diameter. The projectile could have a similar or improved ballistic shape. The optimum design of a projectile is dependent upon many factors other than weight and diameter.

VARIATION IN SHOT-START PRESSURE

21. The assumption of a shot-start pressure gives a model that enables the complex process of band engraving to be treated simply by mathematical methods. Physical interpretations may well be unreliable and are not attempted here. The initial pressure rise will clearly be greater when the shot-start pressure is increased (see Figure 2-3-9).

22. Energy arguments lead to a cross-over point (again well forward in the case considered here) and increased MV. All-burnt will be brought back owing to the higher pressure during the early stages, hence, greater regularity in MV will be obtained.

VARIATION IN SHOT-TRAVEL

23. The only effect of an increase in shot-travel (increased barrel length) is that the MV is slightly increased. The maximum pressure is, of course, unaffected. It is not usually considered economical to increase the barrel length beyond a certain amount, for the disadvantages of a long

barrel more than outweigh the extra velocity obtained. No separate diagram is given, because the effect on the pressure-travel curve is merely to extend the curve slightly to the right.

VARIATION IN CHARGE WEIGHT, PROPELLANT SIZE AND SHAPE

24. The concern so far has been with the effect of a variation in only one quantity. Pressure-travel curves can, of course, be obtained when two or more quantities are varied at the same time. Figure 2-3-6 shows that in going from a cord shape to one of constant burning surface, a moderate reduction in MV is accompanied by a large decrease in maximum pressure.

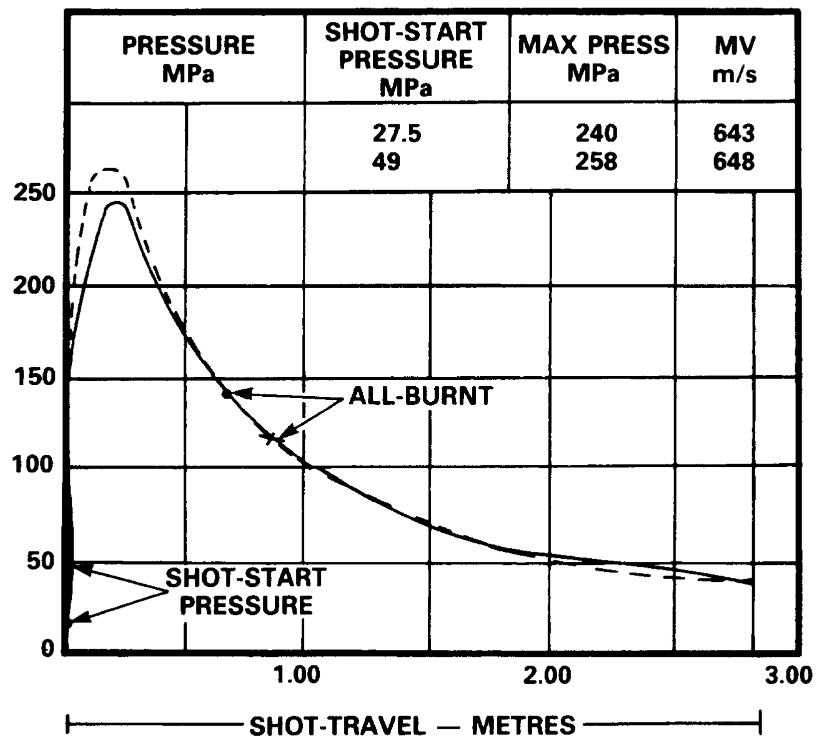


Figure 2-3-9 Variation in Shot-Start Pressure

25. If the charge weight is increased or the size is decreased in such a way that maximum pressure is increased to the value obtained with the cord charge, then an increased MV will result. Alternatively, these quantities could be adjusted to give the same MV resulting in a lower maximum pressure than is given with the cord charge. The results of such a calculation are illustrated in Figure 2-3-10.

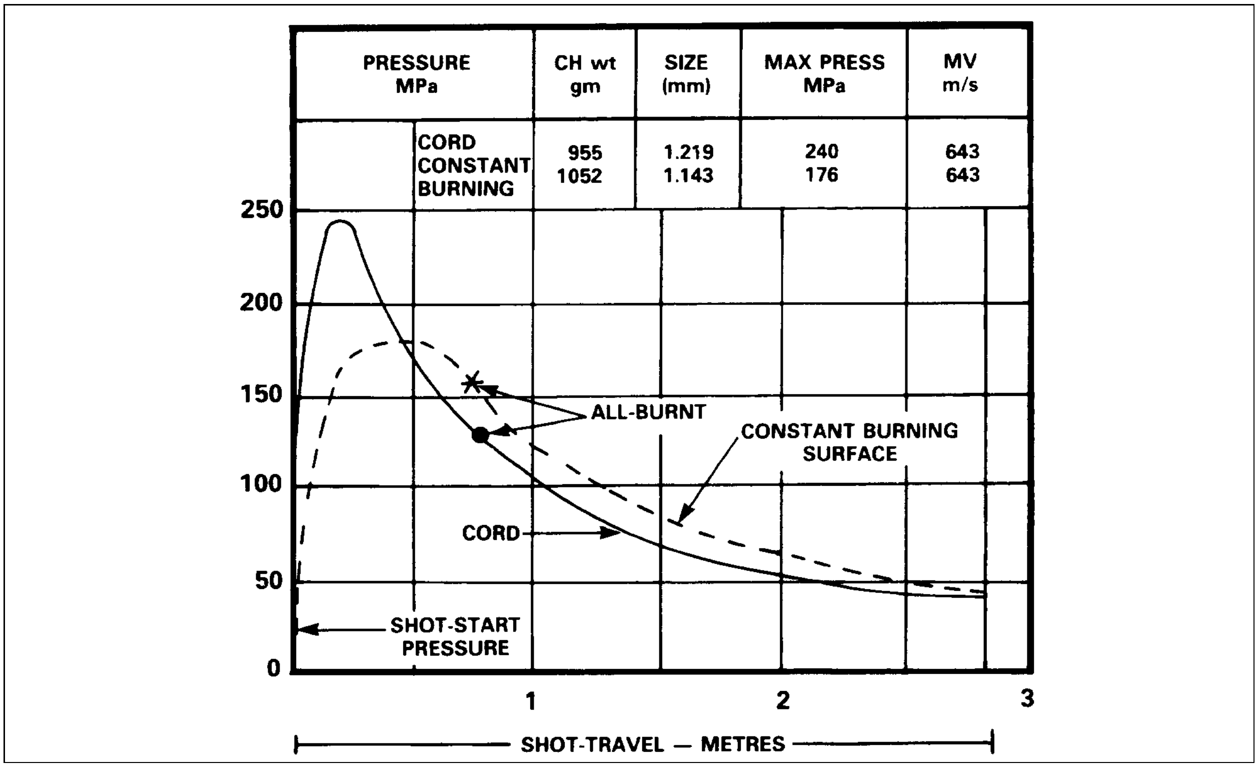


Figure 2-3-10 Alternative Charges of Different Shapes Give Same Muzzle Velocity and Position of All-Burnt

SECTION 4

CHARGE DESIGN AND MUZZLE VELOCITY

CHARGE DESIGN

1. All modern field guns and howitzers are designed to fire a number of charges. Each charge produces a different MV and gives rise to a corresponding range zone. The number of charges plus the ability to fire at both high angle and low angle enables a variety of trajectories to be selected to cater for range and intervening crests between gun and target. In general, a high charge will give better consistency and accuracy than a lower charge at the same range, however, other factors such as equipment stability, barrel wear and carriage fatigue must also be considered when selecting the appropriate charge to be fired in a modern high performance gun.

2. The maximum charge that can be fired, which governs the maximum range, depends upon the strength, weight and stability of the gun. To load more than the prescribed maximum charge is obviously highly dangerous. In most cases, guns and charge systems are so designed that it is physically impossible to load more propellant than the gun will withstand.

3. The minimum charge that can be fired is governed by the phenomenon known as stickers. In some howitzers it is possible for the projectile to stick in the bore when the lowest charge is fired, leaving hot gases trapped in the chamber under pressure. This happens because the gas pressure developed by the lowest charge is not always sufficient to overcome the resistance of the driving band and the projectile lodges in the bore, usually at, or very near, the commencement of rifling (C of R). Because there is only a small percentage of rounds affected, stickers occur infrequently. Danger arises from the fact that a sticker may be mistaken for a misfire by the detachment. If the breech mechanism is opened too quickly, the hot gases will propel the spent cartridge case, or the spent ignition tube, violently to the rear. Special drills are needed to deal with the situation and to clear the gun. In the worst case, a projectile may be stuck in a hot gun with the breech jammed shut. Projectile cook-off then becomes a possibility. For these reasons, charges that may give rise to stickers are either excluded from the charge system or banned for use, except in operational emergency.

4. Charge systems are designed between the limitations imposed by the strength of the gun and the onset of stickers. Within these limits, the charge system has to provide range zones so that there is sufficient range overlap between the charges. A total of seven charges is normally adequate for any charge system, although some modern howitzers may have as many as eight charges. Much depends on the stated requirement for long range combined with a short minimum range in high angle fire. As has been shown, there are internal ballistic problems in achieving this combination in one equipment and the practical limit to the number of charges appears to be eight.

5. **Structure of the Charge**. The burning rate of the propellant has to be adjusted to match the chamber pressure produced. This varies with the charge. Charge systems are, therefore, composed of a number of increments each containing propellant of the appropriate shape, size and chemical composition. During manufacture, the charge increments are assembled into a full

charge (sometimes called a **normal charge**), which is so designed that it can be quickly converted into a lower charge by the removal of one or more increments. In most systems, the highest, or **super** charge is homogenous and designed so that it cannot be broken down, ie M109A2/A3 Charge 8. It is loaded as one cartridge.

6. **Composite Charge Systems**. Composite charges are charges in which different propellants natures/shapes/sizes are included in the increments that constitute the normal charge. An example of a composite charge system is that used with the 105 mm L5 and C1 Howitzer. This consists of a single cartridge that has seven charge increments. There is one grain size for charge increments 1 and 2 and another grain size for increments 3 to 7.

7. **Zoned Charge Systems**. In these systems, only one propellant nature is used in the increments that constitute the full charge, ie M109A2/A3. This method reduces the manufacturing and filling problems associated with composite charges. The faster burning propellant, called Green Bag is used for the lower charges or **inner zone** where the chamber pressures are low. The slower burning propellant called White Bag is used for the higher charges or **outer zone** where the chamber pressure is high. The changeover from Green Bag to White Bag generally occurs in the middle of the range zone covered by the gun. This can create some logistic inconvenience to the user since two separate types of charges are needed at all times. The charge system for the M109A2/A3 is as follows:

Charge Type	**Charges**
M3A1 (Green Bag)	1, 2, 3, 4, 5
M4A2 (White Bag)	3, 4, 5, 6, 7
M119A1 (White Bag)	8 only

8. There is an apparent choice between Green Bag and White Bag for charges 3, 4 and 5. In fact, Green Bag should always be used in preference to White Bag for these charges. This is because the burning rate of the White Bag is not fast enough at the lower pressures to ensure that the position of all-burnt is well back in the barrel. It is found that with White Bag charges 3 and 4, the position of all-burnt is often at, or outside the muzzle; excessive muzzle flash occurs and fall of shot is erratic. When White Bag charge 3 is fired, there is a danger of partially burnt propellant gases burning on exposure to air as the breech opens under its automatic action. This can cause a flash inside the cab. For these reasons, White Bag charges 3 and 4 should not be fired except in an emergency. White Bag charge 5, though not ideal, is satisfactory as regards to burning since the chamber pressure is higher than with charges 3 and 4. Effectively, therefore, there is a choice between Green Bag and White Bag at charge 5 only, but preference should be given to Green Bag.

9. **Spoilers**. One way of solving the problem of stickers and at the same time achieving a short minimum range is to fit a spoiler, or disc, around the nose of the projectile prior to loading. The projectile is fired with a higher charge that ensures the projectile clears the gun. On meeting the air, the increased drag created by the spoiler causes the projectile to range shorter, achieving the equivalent to a very low charge. There is, however, some logistic penalty in the need to supply and hold spoilers on the gun position to be fitted as required.

MUZZLE VELOCITY

10. **General**. MV represents the power or performance of a gun at any given charge. Since the MV varies slightly from round to round, the MV is always taken as the mean of a sample number of rounds fired consecutively, known as a series. Appropriate FTs give the standard value of MV for each charge. These standard values are points of departure, not absolute standards, since they cannot be reproduced at a given instance. That is, a specific equipment/ammunition combination cannot be selected with the knowledge that it will result in a standard MV when fired.

11. Charge velocities are established indirectly by the characteristics of a specific equipment. Equipments capable of high angle fire require a greater choice in number of charges than do equipments capable of low angle fire only. This greater choice is needed in order to achieve range overlap between charges in high angle fire and the desired range/trajectory combination in low angle fire. Other factors considered are the maximum range specified for the equipment and the maximum elevation and charge (with resulting maximum pressure) that the equipment can accommodate.

PROPELLANT MANUFACTURE

12. Manufacturing tolerances allow a slightly different level of a MV for each propellant lot. Even when manufactured in the same factory, propellant nominally of the same composition, shape and size varies slightly in its ballistic properties from lot to lot, and in general, the charge weight for each lot must be adjusted to the same velocity level by the process known as propellant proof. The ballistic property of the propellant in which most of this lot-to-lot variation resides is called **vivacity**, which is a measure of the effective burning rate of the propellant grains.

13. Propellant is a mass-produced commodity and variations in performance must be accepted. Standardization of propellant performance within NATO has reduced significantly the large variation in MV previously experienced between propellants manufactured in different countries. Propellants manufactured in countries are expected to be compatible in their performance to those manufactured in Canada, however, verification of their performance should be confirmed by firing.

PROPELLANT PROOF

14. Manufacturing specifications for propellants include the required velocity performance within certain tolerances. The propellant lots are subjected to firing tests that include measuring the performance of the lots being tested against the performance of a standard lot. This testing procedure is known as propellant proof and its aim is to ensure that the:

a. propellant is safe and suitable for Service use;

b. adjusted charge weight is loadable;

c. propellant is ballistically acceptable; and

d. required propellant specifications are met.

15. Propellant proof is based on the assumption that the ballistics of the standard lot do not change with time and that if two or more lots are fired from the same gun on any given occasion, any circumstance that alters the ballistics of the propellant will have the same effect on all the lots. The foregoing assumption is not entirely correct for the object of propellant proof is to ensure that the performance of the lot is within the limits required by the specifications. This is achieved irrespective of the lot of propellant from which it is taken. The variations experienced in the MV of ammunition under field conditions are not due to proof procedures but are a combination of inadequate calibration, barrel wear, incorrect air or charge temperature, stale or inaccurate meteorology or poor ammunition storage.

PROPELLANT TEMPERATURE

16. Any combustible material burns more rapidly when it is heated prior to ignition. When the rate of propellant burning is increased due to a rise in propellant temperature, the resultant pressure on the projectile is greater and MV is increased. FTs for respective equipments show the magnitude of this change under "Corrections to Muzzle Velocity for Propellant Temperature". Appropriate corrections to gun data can be computed from that table, however, such corrections are valid only as they reflect the true temperature.

17. The temperature of propellants in sealed packing cases remains fairly uniform, though not necessarily standard. Once the propellant is unpacked, its temperature tends to approach the prevailing air temperature. Exposure of ammunition to the weather results in variations in propellant temperature between rounds as well as variation in mean propellant temperature between sub-units. The extent of the variation depends on the time and type of exposure.

MOISTURE CONTENT OF PROPELLANTS

18. Although modern propellants contain additive chemicals that tend to prevent changes in moisture content, handling and storage can cause moisture changes which will affect the velocity. These changes cannot be measured or corrected; however, protection can be afforded against the elements.

POSITION OF BAGGED PROPELLANT IN THE CHAMBER

19. With fixed and semi-fixed ammunition, the propellant has a relatively fixed position with respect to the chamber; the chamber being, in effect, the cartridge case. The position of separate-loading propellants, however, is variable. Trials have shown that the position of the charge in the chamber has an effect on ballistics. It was, however, difficult to determine if the variability of ballistics was due to the position of the charge in the chamber or the effect of ignition. The difference in ballistics was increased when the temperature was lowered and the ignitability of the propellant decreased. Trials with an adequate ignition system have shown that neither the position of the charge nor the temperature has any effect on the comparable ballistics.

AMMUNITION LOTS

20. Each lot of ammunition has its own performance level when related to a common barrel. Although the round-to-round probable error (PE) within each lot is about the same, the mean velocity developed by one lot may be higher or lower than another lot. With separate loading ammunition, both the propellant and the projectile lots must be identified.

21. Variation in projectile manufacture, eg the diameter and hardness of the rotating band, affects MV. Projectile variations have a much more apparent effect on exterior ballistics. Mixed ammunition and propellant lots will result in increased dispersion in unobserved fire, since the probability of hitting a given target is increased. Conversely, if the mean point of impact (MPI) is on the target, the increased dispersion minimizes the number of effective rounds.

WEIGHT OF PROJECTILE

22. The weight of like projectiles varies within certain weight zones and normally the appropriate weight zone is stencilled on the projectile. A projectile with a weight heavier than standard has a reduced velocity and an increased pressure. The increase in weight results in an improved ballistic coefficient (C_O) and at certain velocities and elevations a variation in range will occur. Similarly with a lighter projectile, a higher velocity and a lower pressure will result. This decrease in weight reduces the C_O, which can result in either a gain or loss in range depending upon elevation, velocity and the C_O.

NON-UNIFORM RAMMING

23. The partial effect of a badly rammed round is that it decreases the volume of the chamber and, theoretically, increases the **push** given to the projectile, ie the pressure of a gas varies inversely with the volume. Another effect is improper seating of the projectile, which allows a portion of the expanding gases to escape resulting in a lower velocity. The combined effects are hard to predict and it can only be said that an increase in the dispersion pattern will result. It follows, therefore, that hard uniform ramming is required for all rounds.

24. When fixed and semi-fixed ammunition is being fired, the principles still apply since the obturation of the cartridge case serves as the gas check to the rear in fixed and semi-fixed ammunition. Proper handling and seating of the case is important in reducing the escape of gases in the case of semi-fixed ammunition.

DRIVING BANDS

25. Ideal driving bands (some nations refer to driving bands as rotating bands) allow proper seating, provide obturation, create proper resistance to initial projectile movement to allow uniform pressure build-up and also provide a minimum drag effect on the projectile once motion has started.

26. Dirt or burrs on the driving band cause improper seating, resulting in increased barrel wear which, in turn, contributes to velocity variation. If the **lands** are excessively worn, they may not engage the driving band sufficiently to impart proper spin to the projectile. Insufficient spin reduces projectile stability in flight and can result in short, erratic rounds.

FALL-BACK

27. Fall-back occurs when a loaded projectile fails to remain in its seating when the gun is elevated. It is caused by the failure of the driving band to locate correctly and tightly in the shot seating. This can happen even though the depth of ram have been measured correctly. Fall-back can occur in the following circumstances:

a. If there is a design fault that causes a mismatch between the front taper on the driving band and the taper of the forcing cone in the bore.

b. If there is dirt on the driving band or excessive fouling on the forcing cone.

c. If the mechanical rammer being used is not maintained correctly, or timed correctly, to ensure that the rammer head is applying the correct force to the base of the projectile as it enters its seating.

d. If, during hand ramming, the force applied to the base of the projectile is too weak or is severely misaligned.

28. When the charge has been loaded and the breech closed, it is not possible for the detachment to detect fall-back if it occurs, owing to the noise of the elevating mechanism. In most cased systems, the cartridge case prevents the projectile from failing back more than a very short distance in the chamber. Even if fall-back has occurred, the projectile leaves the bore without any noticeable effect when the gun is fired. In bag charge systems, if fall-back occurs, the projectile is not necessarily held forward by the charge. In fact, where the gun has a large chamber and a small charge is loaded, it is possible for both the projectile and the charge to be in the chamber. If the gun is now fired, one of the following events is likely to occur, depending on the size and nature of the charge and the projectile filling:

a. The projectile will leave the bore and fall short.

b. The projectile will break up as it leaves the muzzle.

c. The projectile will detonate in the bore as it comes violently into contact with the area around the C of R.

29. The situation of a small charge in a big chamber may arise more frequently in future equipments, because of the demand for longer range combined with a short minimum range. One possible solution is to load a spacer of some suitable combustible material to prevent the projectile falling back if it should become unseated. The difficulty here is to prevent excessive debris being formed in the chamber and this can only be resolved by trials. In general, the

potential danger from fall-back can be avoided by good design of the whole system based on rational requirements. Careful attention to maintenance and drills at the gun are also of great importance.

COPPERING

30. When projectile velocity in the bore is high enough, sufficient friction is developed to remove the outside surface of the driving band. The removed metal is deposited as a thin film of copper in the bore. This condition is known as coppering. De-coppering agents such as lead foil, a lead-tin alloy foil and pure tin foil, have all been found satisfactory in reducing coppering. The effect of coppering on modern field artillery weapons is relatively insignificant. Coppering is not considered a problem, at the present time, with artillery equipments in the Canadian Forces.

PROPELLANT RESIDUE

31. Residue from burnt propellant mixed with the expanding gases is deposited on the bore surface in a manner similar to coppering. Unless the barrel is properly cleaned and cared for, this residue will aggravate subsequent barrel wear by causing pitting and augmenting the abrasive action of the projectile.

EFFECT OF BARREL WEAR

32. Barrel wear affects MV. Wear is the gradual removal of metal from the surface of the bore as a result of firing and is caused by the chemical action of hot gases combined with the abrasive action of the driving band that together cause bore enlargement, particularly near the C of R. In general, the greater the wear the lower the velocity. In a worn gun, the initial resistance to the motion of the projectile is less, therefore, there is a decrease in the shot-start pressure. The projectile can be rammed slightly further forward in a worn gun, thus increasing the initial space available for the expansion of the gases, resulting in a lowering of the pressure and a reduction in MV.

33. FTs show the wear/MV relationship, so that a correction can be applied for loss of MV occasioned by wear. However, no gun will exactly conform to the theoretical values given in the FTs. Also, modern artillery guns have very low wear and the correction between wear measurements and equivalent full charge (EFC) is not good.

34. Wear can also have an effect on the performance of a projectile through the air. In a worn barrel, a projectile may develop a yawing motion as it leaves the muzzle. This reduces the steadiness of the projectile in flight which in turn, increases the air resistance. The effect is to reduce the achieved range by more than can be attributed to a straightforward loss of MV. Loss of steadiness varies between equipments.

ABNORMAL INTERNAL BALLISTIC EFFECTS

35. In recent years, a number of abnormal internal ballistic effects have been observed in guns of all types during the course of trials, calibrations and proof firings. The effects give rise to

variations in MV which are quite distinct from the normal round-to-round variations and the occasion-to-occasion effects. It is thought that some abnormal effects are related to the interaction of the projectile's driving band with the bore, since it has been observed that abnormal MV variations are minimized when non-metallic driving bands are used. But, in general, it is true to say that the exact causes of these abnormal effects are not at present understood.

36. It is not possible to describe all the abnormal effects that have been identified, however, those effects that are relevant to first round accuracy are:

a. warmer effect;

b. order of fire effect; and

c. hump effect.

37. **Warmer Effect**. The warmer effect occurs when the first round fired in the day produces an MV that is a few m/s different from the mean of subsequent rounds. The effect is quite common. Sometimes the effect concerns the first two rounds. The effect cannot be predicted with any certainty, in regard to its size or its relation to the mean. However, the tendency is for the MV to be higher than the mean in the case of a low charge and for the MV to be lower than the mean in the case of a high charge. The degree of oiliness of the barrel before firing also appears to be involved in this effect.

38. The warmer effect can be removed by the firing of one or two rounds, preferably at a high charge, after which the gun should perform normally. If the warmer effect is not removed,the effect on the fall of shot would be to create an error in the MPI and an increased spread for the initial rounds. A return to normal would occur as the guns become conditioned by firing. Guns that have been firing at frequent intervals do not suffer from the warmer effect, unless there has been a prolonged break in firing lasting several hours in cold conditions.

39. **Order of Fire Effect**. The order of fire effect refers to the order in which charges in a multi-charge gun system are fired. The effects are confined to the lower charges in the system. In fact, there appears to be two distinct effects:

a. One effect is related to barrel temperature. If a warm gun fires a series of rounds at a high charge immediately followed by a series at a low charge, the mean MV of the low charge series may be several m/s higher than normal. This is not exactly true for all equipment or for all circumstances.

b. The other effect is related to a period of inaction. If a gun, which has not been fired for some time, fires a low charge first, then the mean MV of a series of rounds may be several m/s lower than that expected from the FT. If, after a period of inactivity, a lower charge is fired after a higher charge the MV level for the lower charge is unaffected and is normally as expected from the FT even though the barrel may be cool.

40. Apart from always firing the highest charge first, there is no certain way of eliminating this effect. For this reason, charges are fired in descending order during calibration, ie the highest charge to be calibrated is fired first. It must be emphasized that the order of fire effect concerns only the lower charges in the system. The higher charges, which are the ones most likely to be used in war, are not significantly affected.

41. **Hump Effect**. Ballistic is used to describe the situation where the MV of a new barrel rises rapidly to a peak as more rounds are fired, reaches a maximum value and then falls to a level comparable with the state of wear. Some types of barrel are more prone to this effect than others. Its occurrence is uncertain and its magnitude variable. Only a rough allowance can be made in FTs, assuming data are known. Because the effect may last for hundreds of rounds, it can be a serious source of error if the true MV level is not measured.

42. Where it occurs, hump is inherent in the gun and cannot be cured. The only solution is to measure the MV as often as possible during the hump process and adopt an appropriate MV. This further underlines the value of frequent MV measurement.

OCCASION-TO-OCCASION EFFECT (DAY-TO-DAY EFFECT)

43. It has been found from trials and calibration firings, that all guns experience a random variation in the level of MV from occasion to occasion. On any one occasion the variation is completely unpredictable. No cause for the occasion-to-occasion effect has yet been proved. The effect can be very large and is often of the order of 5 m/s. In this connection the time span of an occasion has not yet been determined but has been taken to be a day until better information becomes available.

44. Although a gun may be calibrated with a particular charge on a particular occasion and an adopted MV determined, it does not necessarily follow that the gun will develop precisely the same MV with the same charge on the next occasion. Inevitably, there will be an error due to the occasion-to-occasion effect. Other effects, such as the lot-to-lot effect, may act at the same time to reinforce or cancel the occasion-to-occasion effect. It can be seen that in order to guarantee that the MV error is kept to a minimum, it is necessary to measure frequently.

CHARGE-TO-CHARGE PROPELLANT PERFORMANCE

45. One of the major problems in gunnery is how to best extend the data developed from firing one charge to all other charges. From the viewpoint of developed MVs only, there is no absolute method based on available data to state that charge-to-charge performance follows a convenient ratio. Since propellants are manufactured to result in standard performance within any given charge, a variation from standard in one charge does not fix a similar or proportional variation in another charge. The velocity level for a charge of a particular lot can be determined only by firing. Once the velocity level is determined, its relative level, with respect to other charges of that lot similarly determined, remains fairly stable.

CALIBRATION

46. For successful predicted fire, it is essential to know, in advance, the MV levels for each charge in the system. The process of establishing these MV levels (or **adopted MVs**) is known as calibration. Broadly speaking, calibration is achieved by the direct measurement of MV by radar velocimetres.

TOLERANCES IN NEW EQUIPMENTS

47. All new equipments of a given calibre and model will not necessarily develop the same MV. In a new barrel, the predominant factors are variations in the chamber and the interior dimensions of the bore. If a unit armed with new guns fired with a common lot of ammunition, a velocity spread of 5 m/s between the guns with the highest MV and the lowest MV would not be unusual. Therefore, equipments must be calibrated even though they are new.

DETERMINATION OF MUZZLE VELOCITY

48. The range of an artillery projectile depends, among other factors, on its MV. The many parameters that determine MV produce velocity differences that can be analyzed as occasion-to-occasion, gun-to-gun and round-to-round variances. The between gun variances are generally regarded as biases and if these could be quantified and allowed for, all guns of a battery would be corrected to a common MV and improved accuracy would be achieved.

49. MV is determined by a large number of parameters that frequently interact in a complicated manner. Many can be closely controlled, eg charge weight. Others, although not controllable, can be measured and corrected, eg charge temperature. There are other factors that influence MV in a way not yet fully understood and that cannot be allowed, eg bore surface conditions. Furthermore, small changes in MV occur in the intermediate zone when the projectile is still under the influence of the propellant gases as they expend rapidly from the muzzle of the gun.

50. If the actual MV variation and velocity error at each time of firing were known, the accuracy of artillery fire would be improved. Full prediction of MV for the next round based upon the known physical and ballistic conditions of the moment is not practical at present since existing knowledge of internal ballistics is not sufficient to explain and, therefore, predict some of the larger MV variations, particularly those between missions or occasions that have been observed. Some of these variations are believed to be associated with the heat input to the barrel from the propellant charge during firing.

51. Continuous monitoring of MV for the purpose of predicting the MV of the next round was evaluated in the United Kingdom (UK). These studies showed that by mounting a velocimeter on each gun, MV could be updated between rounds resulting in a significant reduction in total range errors and a possible saving of 5 per cent in ammunition. The difficulty with this concept is, it is unlikely that the field computer will be able to compute the corrections to the elevation required for each gun between consecutive rounds. Firstly, it is unlikely that it will have the capacity nor will it be available on demand for such computations. Secondly, and

perhaps more importantly, there will be a communication problem in linking the computer with each individual gun in turn within the firing time. The velocimeter will then need to be an **intelligent** unit using its processor to record MV and deduce the corrections to elevations required to allow for the MV error.

VELOCITY TREND

52. Not all rounds of a series fired from the same weapon using the same ammunition propellant lot will develop the same MV. Variations in MV follow a normal probability distribution about the average MV. This phenomenon is called velocity dispersion. Under most conditions, the first few rounds follow a somewhat regular pattern rather than the random pattern associated with normal dispersion. This phenomenon is called velocity trend and includes the warmer effect. The magnitude and extent (number of rounds) of velocity trends vary with the equipment, charge, charge temperature, previous charge and barrel condition at round one of the series.

53. The direction and magnitude of velocity trend vary, regardless of whether the same or different charges follow one another. The between gun and between round differences also vary considerably from fire mission to fire mission - the patterns change from an upward trend to a downward trend and sometimes there is a mixture of both. The following illustrates this point and also highlights the problem involved in attempting an absolute prediction of MV:

a. Two missions were fired at the same low charge following a high charge. The first mission, which fired from a warm gun, showed a downward trend of some 6 m/s over six rounds. The second mission was fired from a cold gun and it showed an upward trend of 6 m/s over six rounds.

b. Two missions were fired at the same low charge following a high charge. Both missions were fired from a warm gun. The first mission showed an upward trend of some 3 m/s over six rounds. The second mission showed a downward trend of 6 m/s over six rounds.

54. Firing trials with oily barrels have demonstrated that the velocity of the first round would be in the order of 15 m/s below that of the following rounds for most equipments. Velocity trends for the 105 mm and 155 mm Howitzers have been determined and this data may be included in FTs in the future. A comparison of velocity trends for a 105 mm Howitzer when a series of rounds is fired, starting with an oily barrel, a barrel cleaned with rags only and a barrel cleaned with soap and water, is shown in Figure 2-4-1. Generally, the magnitude and duration of velocity trend can be minimized when firing is started with a barrel that is clean and completely free of oil.

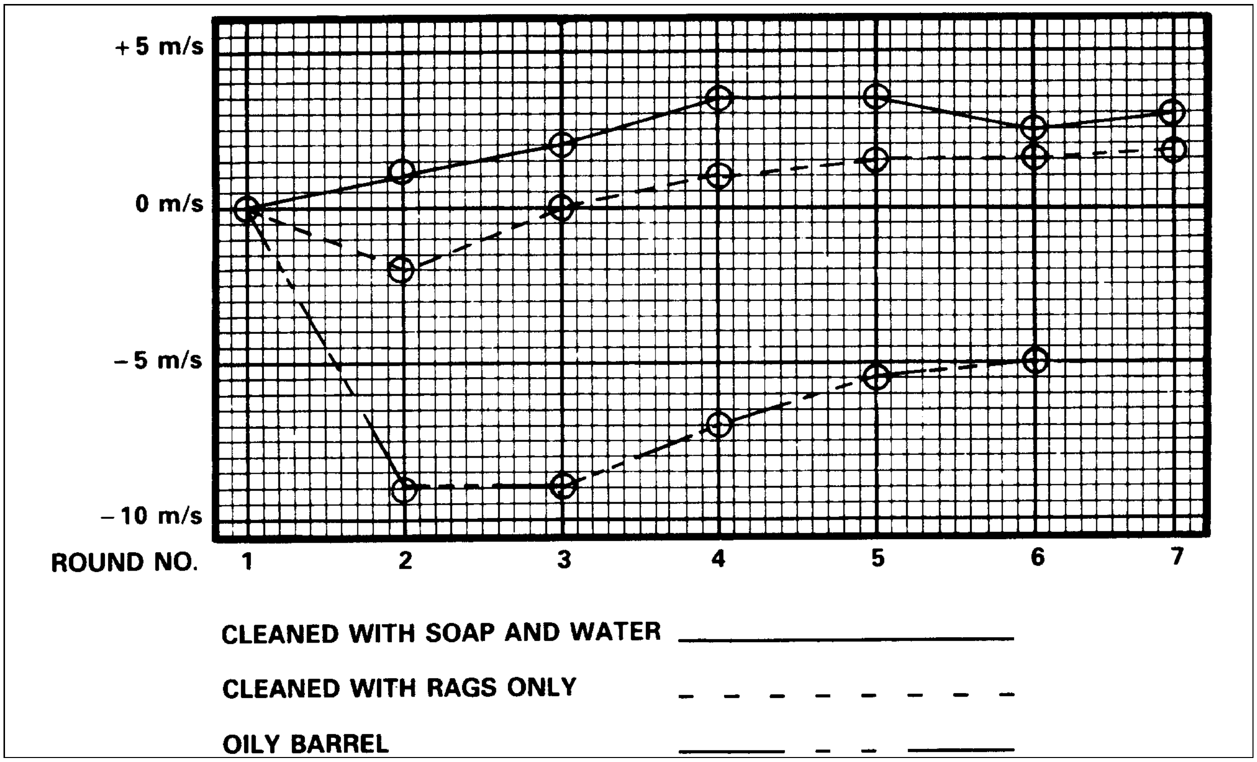


Figure 2-4-1 Velocity Trends - 105 mm Howitzer

CHAPTER 3

EXTERNAL BALLISTICS

SECTION 1

IN-VACUUM/IN-AIR TRAJECTORIES

GENERAL

1. External ballistics is the science that deals with the motion of a projectile from the moment it leaves the muzzle of a gun to the moment of impact or burst. The path followed by the projectile after ejection is called the trajectory. its form depends primarily on:

a. MV,

b. A/D,

c. gravity,

d. air resistance,

e. weight and shape of the projectile,

f. spin of the projectile, and

g. rotation of the earth.

2. Once the MV and A/D have been decided, the two main external influences on the projectile are gravity and air resistance. The study of the motion of the projectile under the influence of gravity alone is called motion **in a vacuum** and the results obtained are useful because of certain similarities between the trajectory in air and the trajectory in a vacuum.

MOTION IN A VACUUM

3. The motion of a projectile in a vacuum is free of the effects of air resistance. Consider a projectile fired at a particular angle of elevation (ø) and MV. Newton's first law of motion states that a body in motion continues to move in a straight line at a constant velocity unless acted upon by an external force. This means that were it not for gravity, the projectile would continue along the line of departure to infinity (see Figure 3-1-2). This does not happen, of course, because the vertical component of velocity of the projectile will be retarded by gravity until it reaches zero velocity at the vertex, and then the projectile will fall back to earth under the acceleration of gravity.

4. As the earth is a sphere, the gravitational acceleration is always acting towards the centre of the earth and its magnitude changes with the square of the distance from this centre. Compared with the dimensions of the earth, the ranges that are usually attained with artillery are so small that, with sufficient exactness, the surface of the earth can be considered as a plane so that the lines of gravitational force are parallel with one another and do not converge on the centre of the earth. Also, in a gravitational field as defined, a constant gravitational force (g) of 9.8 m/s^2 can be assumed. On these assumptions, the trajectory is a parabola as illustrated in Figure 3-1-1. It may be pointed out that the magnitude of g is not the same everywhere on the surface of the earth but depends on the latitude (9.78 m/s^2 at the equator and 9.832 m/s^2 at the poles).

5. The method of examining the shape of a trajectory in a vacuum is to consider the vertical component of velocity (V_v) and the horizontal component of velocity (H_v) separately. Since gravity acts vertically downward, it has no effect on the velocity of the projectile in a horizontal direction. H_v therefore, remains constant throughout the trajectory. V_v however, decreases in the ascending branch of the trajectory by 9.8 m/s every second and increases at the same rate on the descending branch. For example, a projectile fired at an A/D of 300 mils with an MV of 379.5 m/s will have an H_v of 363.2 m/s and a V_v of 110.2 m/s. The effect of gravity for this example is illustrated in Figure 3-1-2. The formulae, with examples, used in calculating a trajectory in a vacuum are given in Annex A.

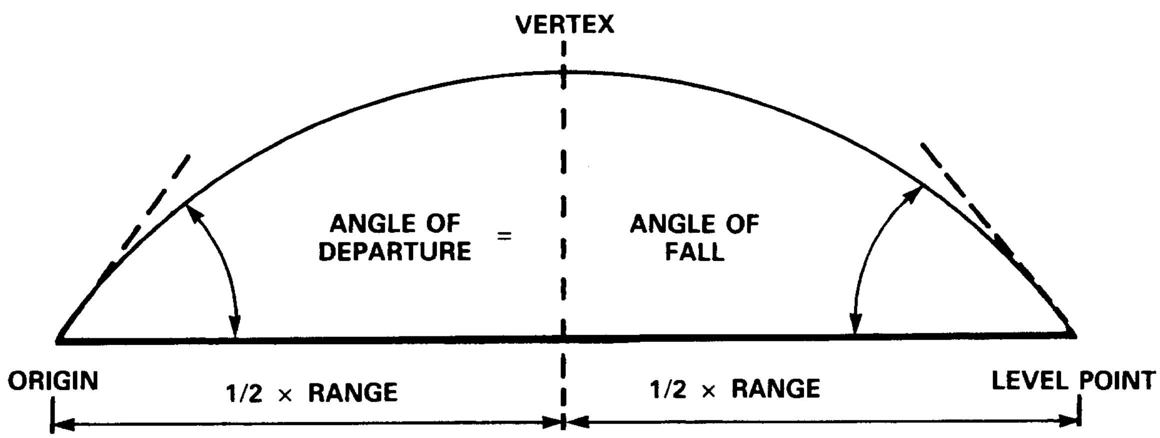


Figure 3-1-1 Parabolic Trajectory

CHARACTERISTICS OF IN-VACUUM TRAJECTORY

6. A trajectory in a vacuum has the following characteristics:

   a. Every point on the trajectory lies on the plane of departure.

   b. Its shape is symmetrical about a vertical line through the vertex and is a parabola.

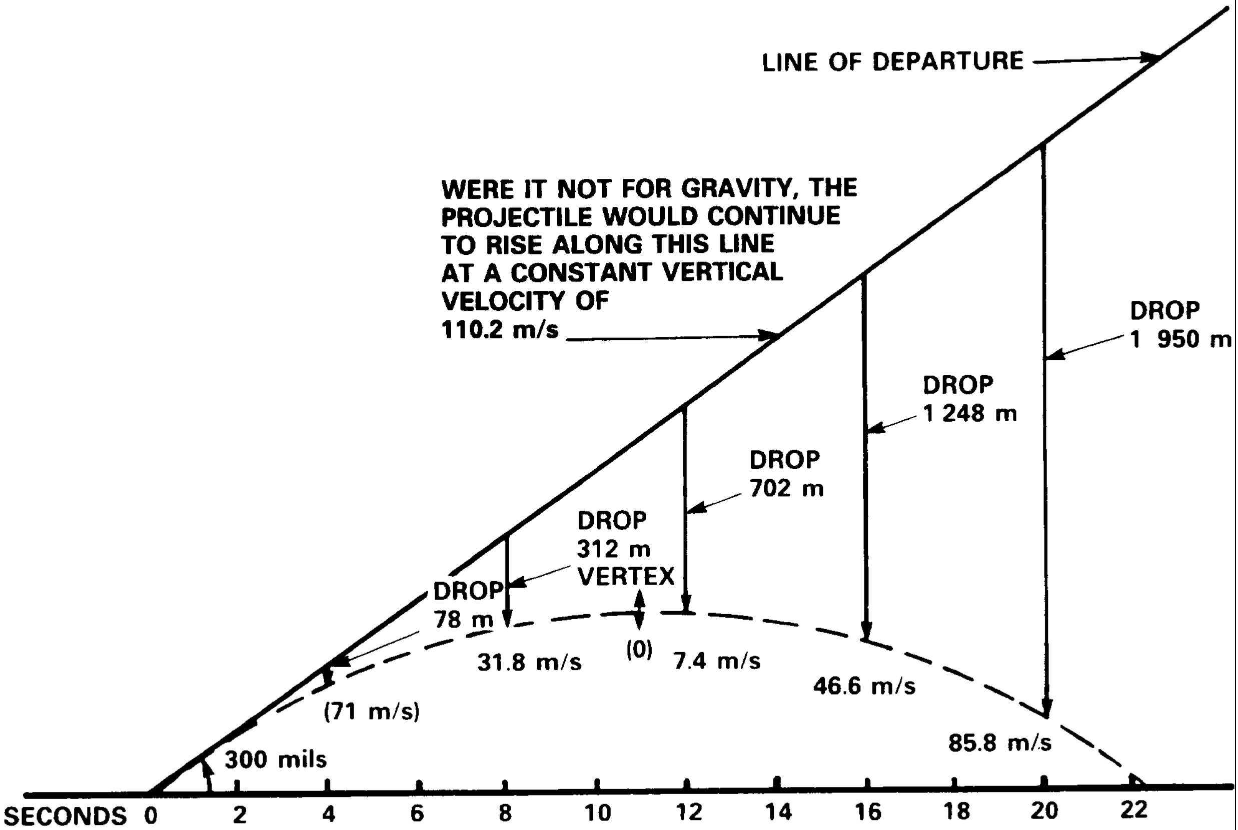
   c. For a given A/D, as MV increases, the maximum ordinate will increase and the range and TOF to the level point will increase.

   d. For a given MV, as A/D increases TOF to the level point and the maximum ordinate increases in value and attains its maximum values when A/D reaches 1 600 mils. Range to the level point will reach its maximum value at an A/D of 800 mils and will decrease to zero at 1 600 mils.

   e. V_v will decrease as the projectile travels up to the vertex and will increase during the descending branch of the trajectory, both at the rate of 9.8 m/s^2.

   f. The angle of fall equals A/D and the remaining velocity at the level point equals the MV. Remaining velocity is zero at the vertex.

   g. The trajectory is entirely independent of the nature of the projectile since air resistance is assumed to be non-existent in a vacuum.



HORIZONTAL VELOCITY — IS A CONSTANT FROM ORIGIN TO LEVEL POINT. IN THIS EXAMPLE THE PROJECTILE WILL TRAVEL 363.2 METRES IN THE HORIZONTAL PLANE DURING EACH SECOND.

VERTICAL VELOCITY — DECREASES ON THE ASCENDING BRANCH FROM 110.2 m/s TO 0 m/s AT THE VERTEX AND INCREASES FROM 0 m/s TO 110.2 m/s ON THE DESCENDING BRANCH BOTH AT A RATE OF 9.8 m/s^2. VERTICAL VELOCITIES ARE SHOWN IN PARENTHESES.

Figure 3-1-2 Effects of Gravity

MOTION IN AIR

7. Air resistance can be considered as a retarding force that is always acting in a direction opposite to the movement of the projectile. As the projectile moves through the air the air around it is set in motion; the faster the projectile moves the more air is set in motion. Since the energy of motion of this air can only come from the projectile, there is a continual drain on the energy of the projectile which shows itself in the form of resistance, hence the projectile loses velocity.

8. In the **in-vacuum trajectory**, V_v was retarded by gravity while H_v remained constant. V_v and H_v are retarded by air resistance acting on the projectile, in addition to gravity, and V_v is reduced to zero more rapidly. H_v is also reduced by air resistance instead of remaining constant as in the **in-vacuum trajectory**. On the descending branch of the trajectory, the air resistance acts to oppose gravity so that the time from vertex to level point is greater than the time from origin to vertex.

9. The most apparent difference between the trajectory in a vacuum and the trajectory in air is the reduction in range. This is mainly because H_v is no longer constant but is continually decreasing due to the retarding effect of the air. Figure 3-1-3 illustrates how greatly the motion of a projectile can be affected by air resistance. For example, with an MV of 565 m/s (charge 7) and an A/E of 800 mils, a projectile fired from the M109A2/A3 Howitzer would attain a maximum range of 32.6 km in a vacuum. In air, the maximum range attained is 14.8 km at an A/E of 760 mils. It is interesting to note that with equal MV, an experimental projectile of especially long design attained a range of 20.2 km, approximately 60 per cent of the range attained in a vacuum.

10. With decreasing MV, the in-air trajectory becomes more and more like the parabola in a vacuum. For equipment with an MV of 180 m/s or less, the ranges attained in air are approximately 10 per cent less than the range attained in vacuum.

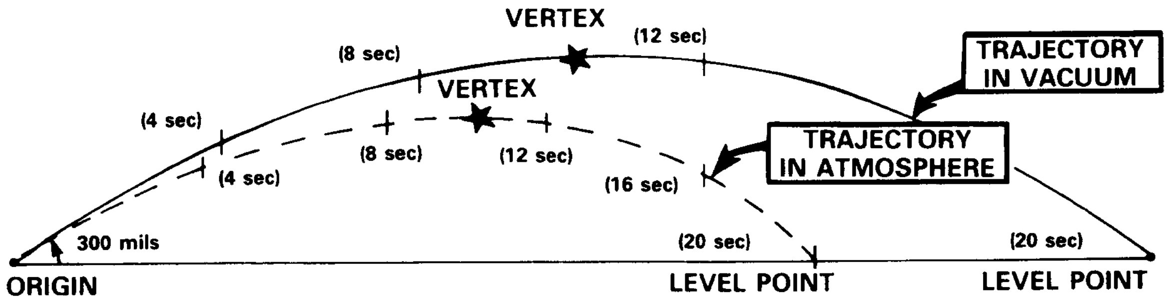


Figure 3-1-3 Comparison of Trajectories

CHARACTERISTICS OF THE IN-AIR TRAJECTORY

11. The trajectory in air has the following characteristic differences from the trajectory in a vacuum:

a. In air, the trajectory is not parabolic.

b. The mean H_v of the projectile beyond the vertex is less than the mean H_v before the vertex, therefore, the projectile travels a shorter horizontal distance.

c. The angle of fall is greater than A/D.

d. The mean V_v is less beyond the vertex than before it; hence, the time of descent is greater than the time of ascent.

e. The range is only roughly proportional to the square of the velocity.

f. The spin initially imparted to the projectile causes it to respond differently because of air resistance.

g. A trajectory in air will be shorter and lower at any specific TOF. This occurs because -

(1) H_v is no longer a constant but decreases with each succeeding time interval,

(2) V_v is affected by gravity and air, decreasing while the projectile is rising and increasing while the projectile falls,

(3) the vertex is nearer the level point, and

(4) the angle of fall is greater than A/D.

SECTION 2

THE ATMOSPHERE

GENERAL

1. In the previous section it was shown that a projectile fired with a given MV at a given elevation would travel farther if there were no air resistance. For flight in the atmosphere, the solution of the ballistic problem is not so simple and clear as for flight in a vacuum because the complex law of air resistance must be taken into account. To assist in understanding the effects of air resistance a certain knowledge of the atmosphere is required.

THE ATMOSPHERE

2. The earth's atmosphere is made up almost entirely of the g gases nitrogen and oxygen. Approximately 78 per cent of the atmosphere is nitrogen while 21 per cent of the atmosphere is oxygen. The other 1 percent is made up of many other gases that exist in very small quantities.

3. The atmosphere is held to the earth by the force of gravity. Close to the surface of the earth the air is very dense; its weight and pressure are at their highest. Further up the air becomes thinner or less dense until about 400 km from the surface there is no air at all. This is the end of the atmosphere.

REGIONS OF THE ATMOSPHERE

4. The atmosphere has three main layers or regions. The region closest to the earth is called the troposphere. The troposphere extends up to an altitude of 20 km over the equator only 8 to 10 km over the poles. In the temperate zones (North America and Central Europe) it extends up to 12 km.

5. The stratosphere is the next region and extends out to approximately 65 km. In this region the temperature is almost always constant, there are steady winds and no weather phenomena. It is in the lower part of the stratosphere that the highest clouds are found. Where the troposphere meets the stratosphere it is called the tropopause. At the tropopause the temperature is approximately - 55 degrees C.

6. Above the stratosphere and extending out to approximately 400 km is the region of the ionosphere. In the ionosphere the temperature increases rapidly, rising from - 55 degrees C at the top of the stratosphere to approximately - 18 degrees C at an altitude of 50 km. It then drops to about - 85 degrees C at an altitude of 80 km. This region is characterized by the influence of gas ions (northern lights and reflection of long radio waves) which in the lower regions occur in a smaller proportion.

7. The regions previously described are illustrated in Figure 3-2-1, showing curves of temperature, density and pressure for the international recognized standard atmosphere.

REGIONS OF CONCERN TO ARTILLERY

8. The regions of the atmosphere that are of concern to field gunners are those regions through which the projectile would pass on its way to the target. Consider the M109A2/A3, firing high angle, charge 8 at a range of 12 000 metres. In this example, the projectile would reach an altitude of 10 000 metres (maximum ordinate). From examination of maximum ordinates listed in the FTs, it can be seen that the troposphere is the region that is of primary interest to the field gunner. This is the region that contains 75 per cent of the weight of the atmosphere and is the region of weather (clouds, precipitation, mist, thunderstorms). In the troposphere, temperature and density decreases with altitude. Also, the barometric pressure at sea level varies from day to day with weather. The standard barometric pressure at sea level is 101.32 kPa (101.25 millibar (mb)).

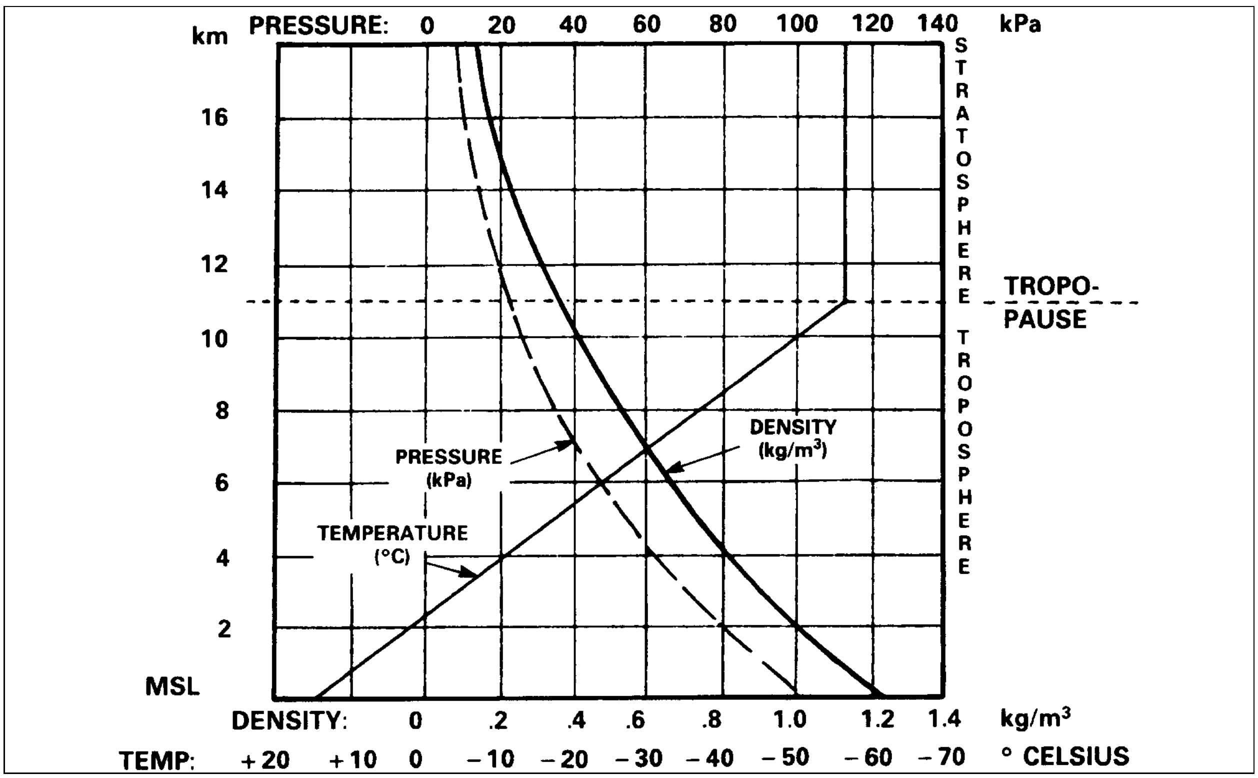


Figure 3-2-1 The Standard Atmosphere

SECTION 3

FORCES DUE TO AIR RESISTANCE

DRAG

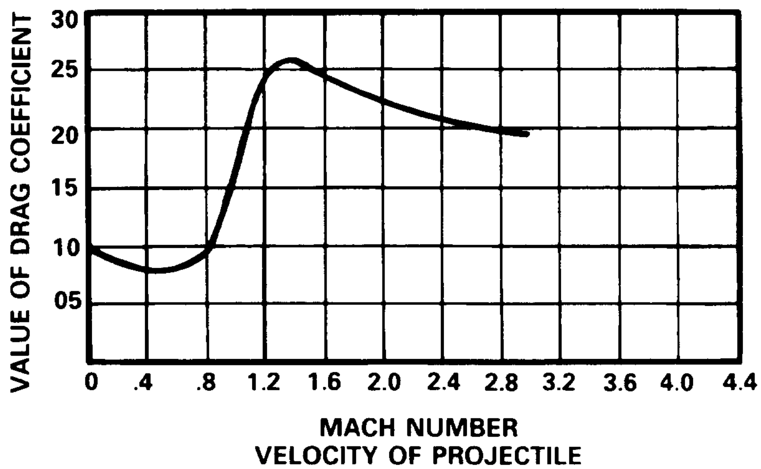
1. Air is **sticky** and resists the motion of objects going through it. A piece of paper will not fall straight downward because it keeps rubbing against the air. The paper will slide edgeways or sideways between the molecules of air. The faster objects move through the air the more air resistance they meet.

2. Air resistance affects the flight of the projectile both in range and direction. The component of air resistance in the direction opposite to that of the forward motion of the projectile is called **drag**. Because of drag, both H_v and V_v are less at any given TOF than they would be if drag were zero, as in a vacuum. This decrease in velocity varies directly in magnitude with drag and inversely with the mass of the projectile. This means in terms of fired range, the greater the drag the shorter the range; the heavier the projectile the longer the range (all other factors being equal).

3. **Air Density**. Projectile drag is directly proportional to air density, which depends on temperature, pressure and moisture content. An increase in pressure or a decrease in temperature will result in an increase in density.

4. Although not as obvious, an increase in moisture content will result in a decrease in density. Since the air density at a particular place, time and altitude varies widely, the standard trajectories reflected in the FTs are computed with a fixed relation between density and altitude.

5. **Air Temperature**. As the air temperature increases, drag decreases, thereby increasing range. This does not hold true as the projectile approaches the speed of sound. Here, drag is related to the Mach number (ratio of the speed of a body to the speed of sound in the surrounding medium) and the relationship changes abruptly in the vicinity of Mach 1 (see Figure 3-3-1).



1. MACH NUMBER = SPEED OF SOUND
2. THE SPEED OF SOUND IS FASTER IN WARMER AIR: HENCE AN INCREASE (DECREASE) IN AIR TEMPERATURE DECREASES (INCREASES) THE MACH NUMBER.
3. A CHANGE IN THE MACH NUMBER CAN CHANGE THE VALUE OF THE DRAG COEFFICIENT EITHER UPWARD OR DOWNWARD, DEPENDING ON THE MACH NUMBER AT WHICH THE CHANGE OCCURS.
4. AN INCREASE (DECREASE) IN THE VALUE OF THE DRAG COEFFICIENT DECREASES (INCREASES) THE DEVELOPED RANGE.

Figure 3-3-1 Effect of Velocity (Mach Number) on Drag

6. **Range wind**. Range wind is that component of the ballistic wind blowing parallel to the direction of fire. In the plane of fire there is a vertical plane that contains the line of elevation. Range wind changes the relationship between the velocity of the projectile and the velocity of the air near the projectile. If the air is moving with the projectile (tail wind) it offers less resistance and a longer range results; a head wind has the opposite effect. The wind component table simplifies the reduction of ballistic wind into its two components with respect to the direction of fire.

VELOCITY

7. The higher the velocity the greater the resistance of the air will be. For a given increase in MV the resulting increase in range is greater at low MVs than those that are higher. For MVs around the speed of sound (approximately 340 m/s) a small variation in MV causes a disproportionate variation in range. For this reason ballisticians, in designing weapons, try to avoid using MVs in this region.

8. As the projectile travels through the air it is affected by three forces as follows:

   a. **Nose Resistance**. Nose resistance is a consequence of pressure drag at subsonic velocities and compressive resistance (wave drag) at supersonic velocities. Nose resistance increases as velocity increases until the velocity reaches Mach 1. Nose resistance peaks near Mach 1 due to the development of supersonic flow and shock waves around the nose (see Figure 3-3-2). Suffice to say that a projectile with a long, slender nose will experience less pressure drag at subsonic velocities and less compressive resistance at supersonic velocities than a projectile with a blunt-shaped nose.

b. **Tail/Base Drag**. Tail drag arises from pressure in the base region of the projectile that acts upon the base. Its effect can be very significant. The stream-line flow around the projectile tends to break away at the base creating a large cavity and wake. This causes the pressure at the base to be less than ambient and results in tail drag. As projectile velocity increases towards Mach 1 the pressure at the base tends to zero.

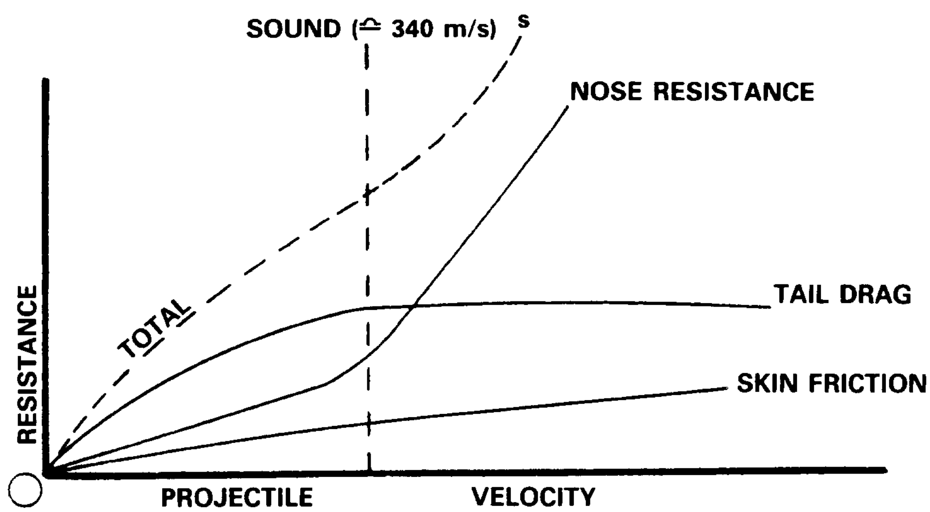


Figure 3-3-2 Factors Affecting Projectile Velocity

c. **Skin Friction**. A rough surface on the projectile will increase resistance, thereby decreasing range. Its effect is normally the least of the three sources of resistance but in the case of a long, thin projectile, such as a rocket body, it can be relatively greater. In general, the effect of skin friction on a projectile is small.

9. The relationship between these three factors for a conventional projectile is shown in general form in Figure 3-3-2 in which the resistance associated with each factor is plotted against the projectile velocity.

10. **Reynold's Number**. The resistance encountered by the projectile as it passes through the atmosphere is directly related to viscosity (the measure of the flow resistance of the atmosphere gases) and is of particular interest to ballisticians. Experiments have shown that if the ratio of the

inertia forces to viscous forces was preserved for similar shaped projectiles in different fluids, then the flow about the projectiles would be identical. This ratio is known as Reynold's number (Re) and is commonly shown as:

$$Re = \frac{V\kappa}{\mu}$$

V = velocity κ = length of projectile

μ = kinematic viscosity (1.45 x 10^{-5} M^2/x at sea level)

11. If Re is very large the inertia forces will dominate and if it is very small, viscous forces will dominate. The importance of the magnitude of Re is not only in knowing the nature of the dominant force but also the axiom: "if geometrically similar bodies experience flows having the same Re, then the surrounding flow patterns will be identical." Knowing this, ballisticians can conduct model tests in wind tunnels and water channels and the model size or test parameters can be adjusted to keep Re the same as the real situation being tested.

12. As the projectile moves through the air, a velocity gradient forms between the undisturbed gases of the atmosphere and those immediately adjacent to the projectile. This gradient grows in thickness from the nose of the projectile; the degree of growth is dependent upon the state of the boundary layer. Generally, when Re is low the flow is orderly and steady (laminar flow). When Re is high the flow is orderly but very energetic (turbulent flow).

13. A knowledge of the magnitude of the Re defines the state of the boundary layer and hence:

a. the effect that protuberance or roughness will have on skin friction;

b. the sensitivity of the flow field to body curvature; and

c. the extent of the cavity in the base of the projectile.

EFFECTS DUE TO VELOCITY

14. **Subsonic Velocities**. If the projectile is travelling at less than the velocity of sound (less than about 340 m/s) the compression at the nose is transmitted away from the projectile in all directions and the resistance due to the compression waves is negligible (see Figure 3-3-3). Most of the resistance at velocities well below that of sound waves in air is due to:

a. the formation of a wake behind the base of the projectile which is known as tail drag (or base drag); and

b. air sticking to the surface of the projectile, which is known as skin friction.

15. For projectiles required to travel at subsonic speed, it is an advantage to streamline the base in an effort to reduce tail drag.

16. **Supersonic Velocity**. At velocities above the speed of sound, large pressure waves are suddenly generated, as from an explosion. These pressure waves propagate into the atmosphere with an increasing velocity because they are compressing the atmospheric gases, raising their temperature and hence the local speed of sound.

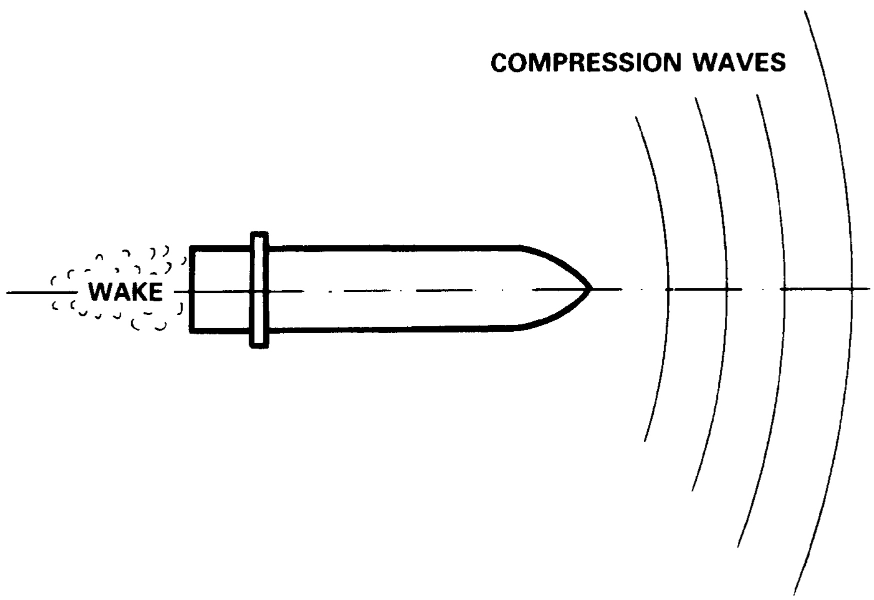


Figure 3-3-3 Compression Waves at Subsonic Velocities

17. The compression waves eventually come together and form a conical shock wave at the nose of the projectile (see Figure 3-3-4). With a projectile that has a long pointed nose, the shock wave forms at the nose, ie is attached. With a projectile having a blunt nose, the shock wave forms ahead of the projectile. The blunter the nose the higher the wave drag and, therefore, the greater the retardation. The angle of the shock cone decreases with the increase of the Mach number and at hypersonic speeds (M>5) the shock wave almost follows the shape of the body.

18. Because the projectile is a finite length body travelling supersonically, the disturbance generated must also be finite, and so a nose shock wave is accompanied by a tail shock wave. The tail shock wave appears to originate from the neck of the wake. This pair of shock waves constitutes the sonic boom heard from bullets, projectiles or aircraft travelling at supersonic velocities.

19. **Transonic Velocities**. The energy to overcome air resistance can only come from the kinetic energy of the projectile. The projectile loses energy at a greater rate when travelling supersonically than when travelling subsonically. At the velocity of sound there is a condition of mixed subsonic and supersonic motion. In this region, the projectile's behavior is unpredictable because the air resistance is changing rapidly. This is known as the transonic zone. In this zone, small changes in the projectile's velocity will cause marked changes in resistance. Small variations in velocity due to wind, air or charge temperature may contribute to these changes in resistance, however, this has not been confirmed.

20. It is important that the projectile is steady when it enters the transonic zone. Since it is common for the projectile to be unsteady just outside the muzzle of the gun due to initial yaw, and the turning moment is strongest in the transonic region, firing of projectiles in the area of the velocity of sound is avoided when possible. Guns that have velocities in the area of the velocity of sound, however, have given adequate accuracy. When the projectile is travelling at the speed of sound, the compression waves and the projectile are travelling at the same velocity (see Figure 3-3-5).

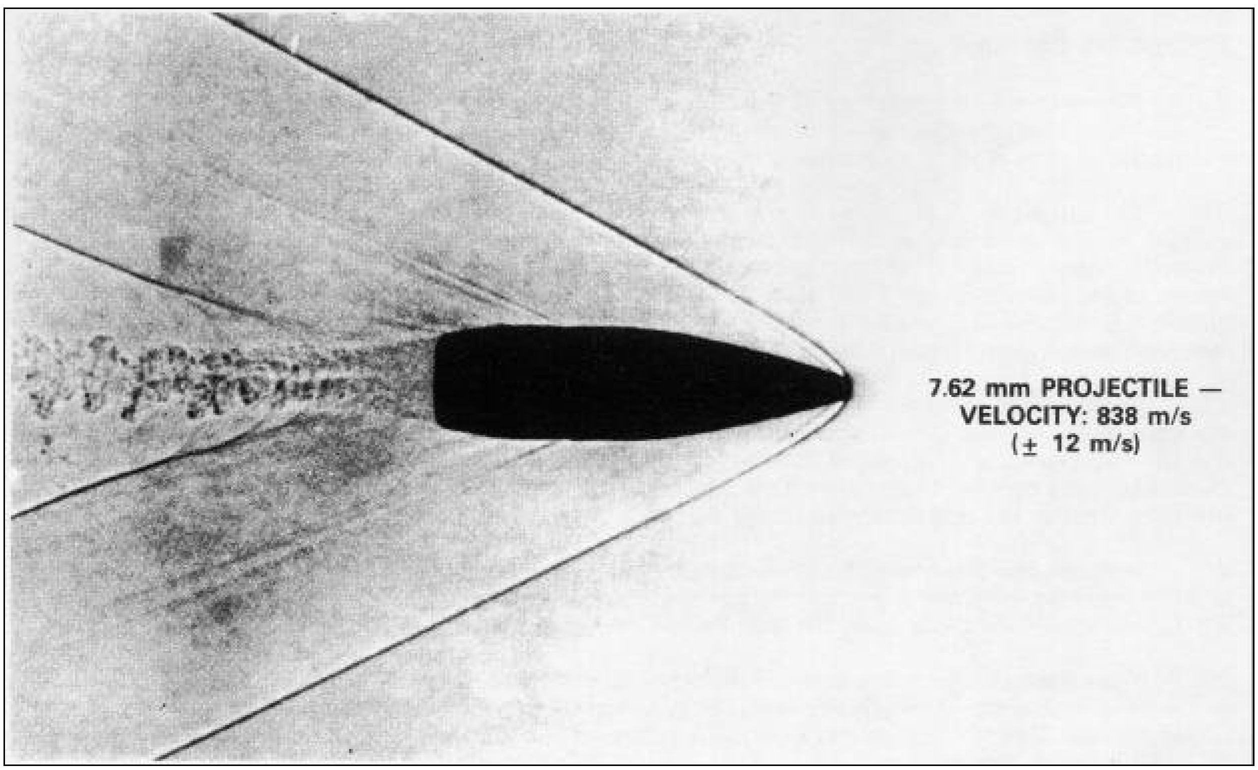


Figure 3-3-4 Compression Waves at Supersonic Velocities

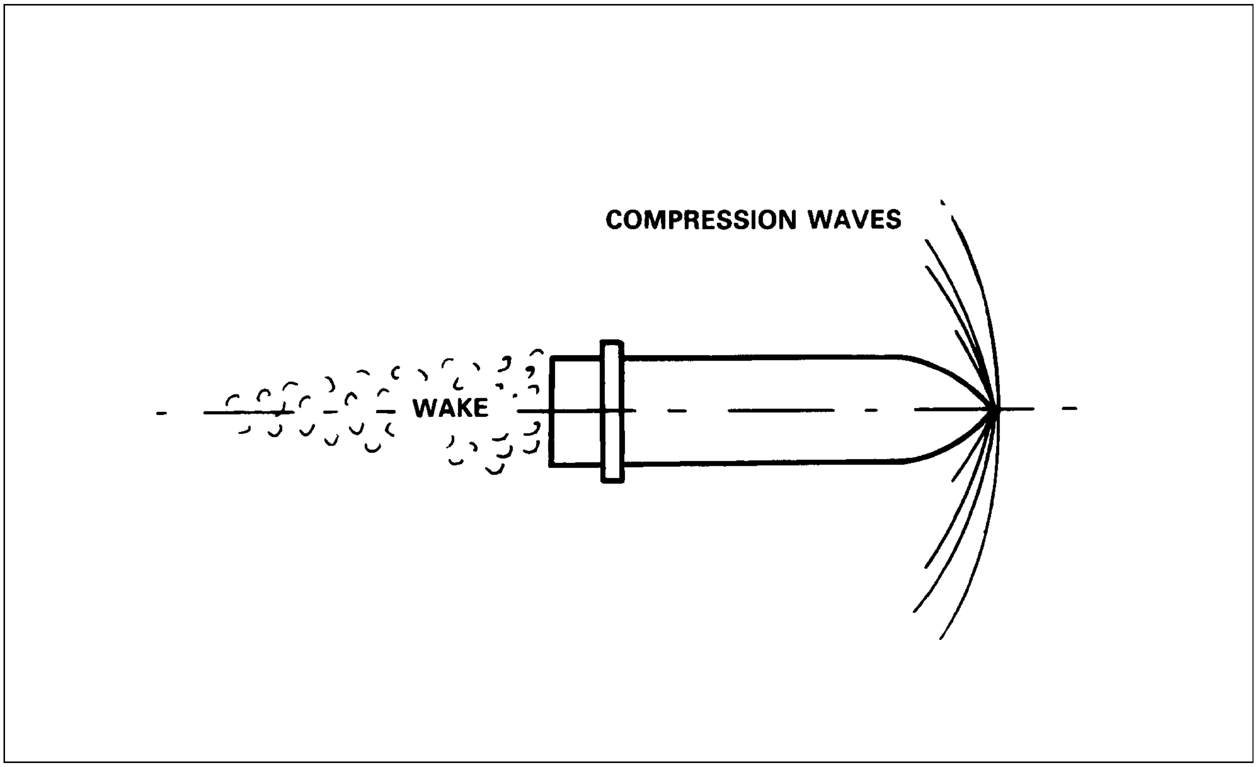


Figure 3-3-5 Compression Waves at Transonic Velocities

PROJECTILE DESIGN

21. **Diameter**. Two projectiles of identical shape but of different size will not experience the same drag. For example, a larger projectile will offer a larger area for the air to act upon, hence, its drag will be increased by this factor. The drag of projectiles of the same shape is proportional to the square of the diameter.

22. **Base Design**. A projectile with a boat-tail base (streamlined) encounters less drag than one with a cylindrical base, especially at velocities below the speed of sound. As the air moves over the cylindrical base projectile, there is no external force to change its direction so the air flow separates at the base and a vacuum forms, as shown in Example 1 of Figure 3-3-6. A streamlined design changes the direction of the air flow, as shown in Example 2 of Figure 3-3-6, thereby reducing the size of the vacuum. A streamlined projectile also offers less base area, which further reduces base drag.

23. A considerable reduction in the amount of drag can be achieved by the emission of a jet of gas from the base of the projectile. A study was made in Sweden on the use of base bleed for increasing the range of the 105 mm projectile. The results showed that at Mach 2, base drag was reduced by about 50 per cent and range improved by over 20 per cent. This principle is utilized in the **Base Bleed** option being developed with the experimental 155 mm Extended Range Full Bore (ERFB) projectile.

24. Drag can also be reduced by spoilers, deliberately designed into the projectile near or at the base. These spoilers break up the smooth and orderly (laminar) flow of air and cause it to be turbulent, as shown in Figure 3-3-7. The turbulence tends to fill the area behind the projectile with air, thereby reducing drag.

25. **Nose/Head Design**. The shape of the projectile nose is expressed in terms of Calibre Radius Head (CRH) and is defined in terms of length and radius of curvature of the ogive, both expressed in calibres. Figure 3-3-8 shows a simple CRH of 2 calibres and a compound CRH with the same length of head but the curvature is reduced by using a radius of 3 calibres.

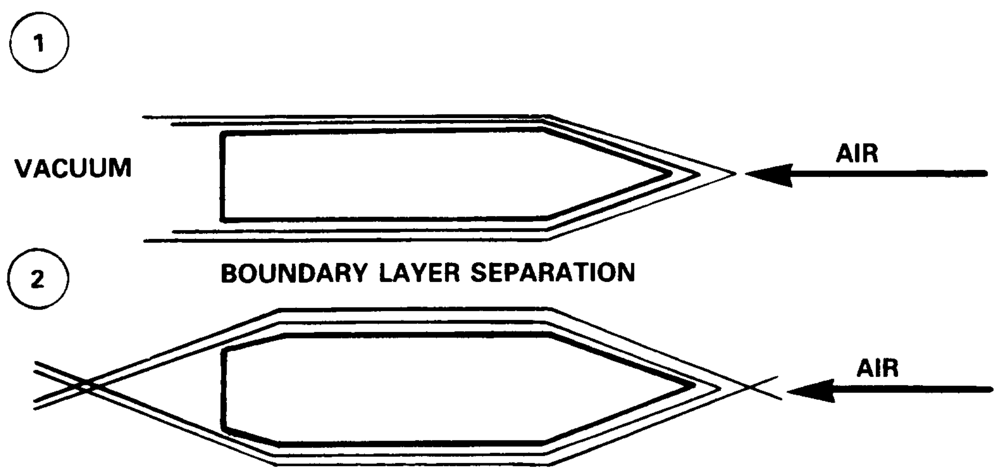


Figure 3-3-6 Effects of Base Design on Air Flow

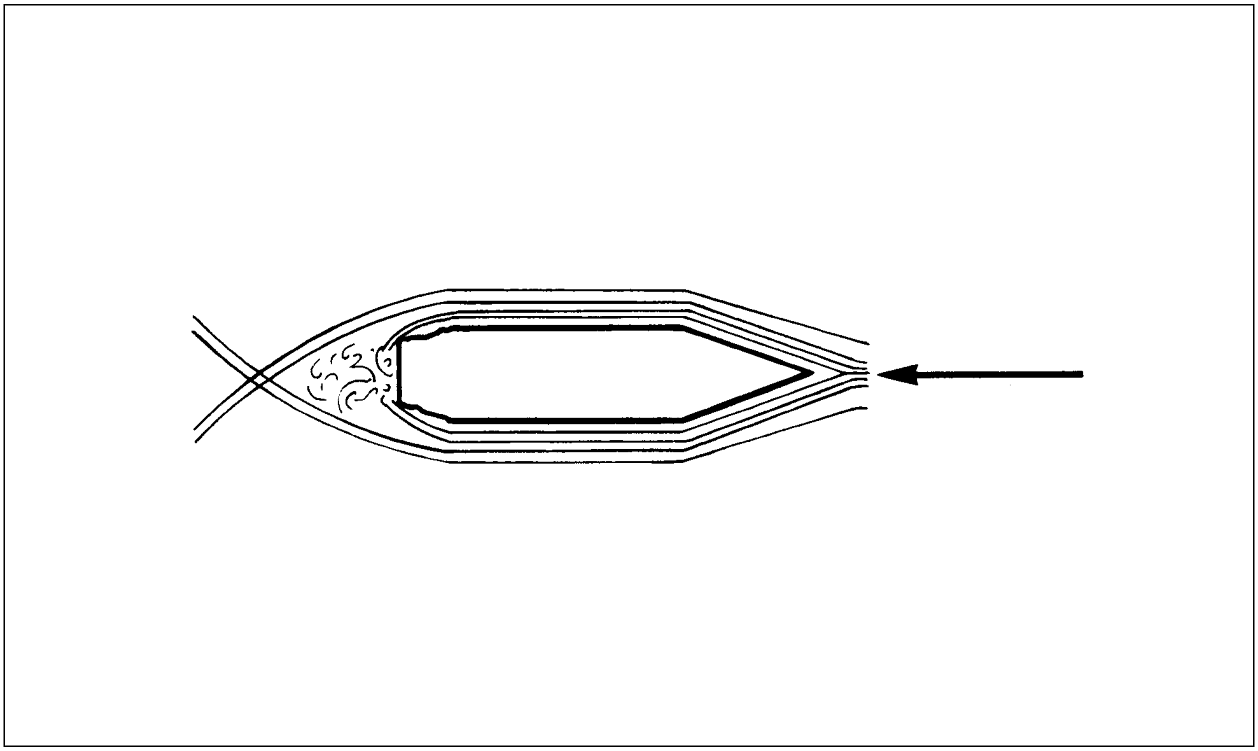


Figure 3-3-7 Air Turbulence Caused by Spoilers

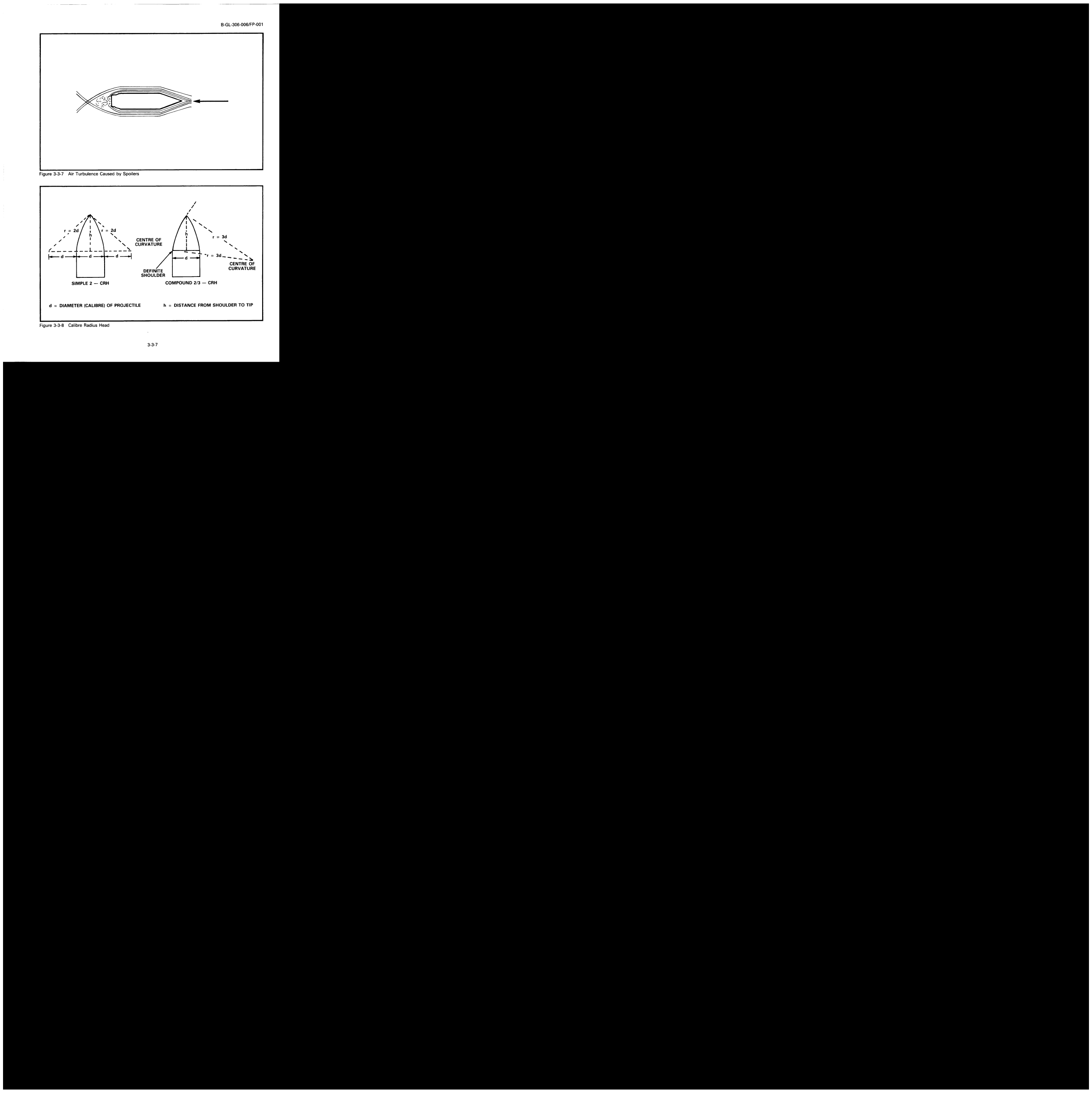


Figure 3-3-8 Calibre Radius Head

26. The limits of length for a conventional gun-fired projectile, which must be observed with respect to stability, is between 4.5 and 6 calibres. If length "x" is reserved for the cylindrical body, and length "y" is reserved for designing the base, the remaining length can be used for shaping the nose. For example, the nose of the 105 mm high explosive (HE) M1 projectile is formed to a long ogive of 6.18 calibres.

Total length of projectile	= 4.5d
Length of streamlined base	= 0.5d (dimensions are approximate.)

Length of cylindrical body	= 1.3d
Length available for shaping the nose	= 2.7 d

The nose profile can be illustrated as follows (see Figure 3-3-9):

a. a horizontal base line is drawn of length "d";

b. a second line is drawn perpendicular from the centre of the base line of length 2.7d. This line represents the nose length;

c. using a compass, an arc is scribed at a radius of 6.18d from the left edge of the base line;

d. a second arc is scribed at a radius of 6.18d from the top of the vertical line at a point 2.7d from the base line;

e. from the point where the two arcs intersect, an arc is scribed at a radius of 6.18d such as to intersect the left edge of the base line and the top of the vertical line; and

f. the right side of the nose profile is drawn in the same manner.

The sketch reflects the long nose ogive of the M1 projectile (see Figure 3-3-9). This nose design is known as a fractional ogive.

27. The decision to use a CRH, a fractional head, or a conical head is determined by some or all of the following: projectile length; chamber length; stowage length; size of turret; stability; range required; MV; yield of steel available; etc. For example, mortar bombs fired at subsonic velocities have fractional heads; high explosive antitank (HEAT) projectiles fired at supersonic velocities have conical heads. It is unusual to find howitzer projectiles of modern design having other than a fractional ogive.

28. The optimum use of the length available for the ogival head, parallel portion and the base depends on the use for which the projectile was designed. For projectiles that are fired at supersonic velocities, but may travel at subsonic range, a streamlined base is required. Anti-aircraft or anti-tank projectiles are fired at supersonic velocities and are supersonic throughout their operational range, hence, a streamlined base is not required and a cylindrical base is used. A streamlined base is found on projectiles that travel at subsonic velocities for a significant portion of their flight and is always used when maximum range is a requirement.

29. From the previous paragraphs, a projectile with a tapered base to overcome tail drag and a long pointed head to overcome nose resistance would seem ideal. A long thin projectile, however, does not stand up well to the stresses in the bore and requires a high rate of spin, or fins, to keep it stable in flight. A tapered base allows the propellant gases to escape at shot

ejection in a way that may cause instability and is the reason why high velocity projectiles normally have a cylindrical base. Also, a long head on a projectile of fixed overall length results in the projectile being inadequately supported in the bore (because of the short walls). This would cause high initial yaw and loss of stability.

30. Where a projectile has a secondary role, ie anti-tank or illuminating, separate FTs are provided. The projectile could be designed to match the primary round but this is not desirable as separate FTs would still be required and in some cases, performance would be degraded. Current design philosophy is to use the same CRH and base design on the complete family of projectiles.

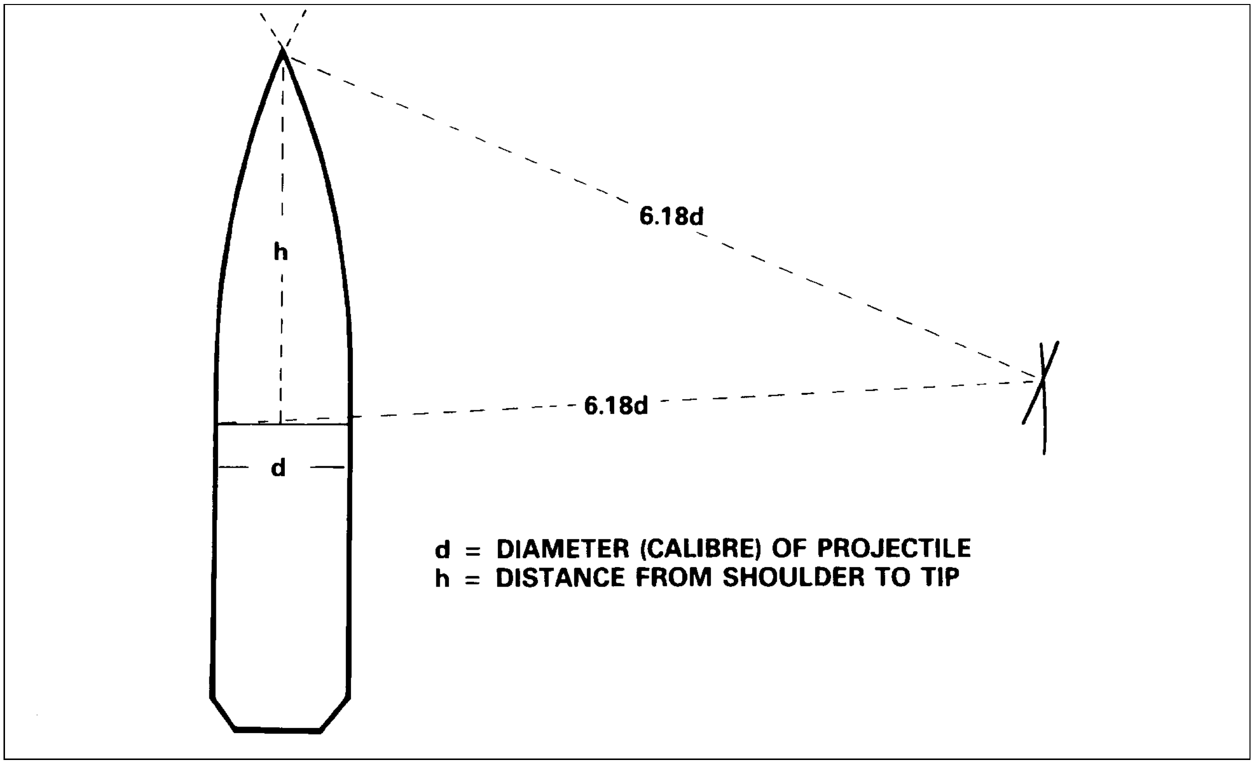


Figure 3-3-9 Long Nose Ogive of the 6.18 Calibres

BALLISTICS COEFFICIENT

31. Because of their physical characteristics, some projectiles are more effective in penetrating air than others. Those projectiles that perform well in air can be said to have a better **carrying power**. If two different projectiles are projected at the same velocity under the same conditions, the projectile with the better **carrying power** will travel further. To illustrate the point, it is common knowledge that a baseball will travel further than a tennis ball when thrown in the same direction with the same velocity.

32. The energy available to overcome the resistance of the air is derived from the kinetic energy of the projectile, that is, from the mass and velocity of the projectile. For a given velocity and type of atmosphere, the **carrying power** must depend on the following physical characteristics of the projectile:

a. **Mass (M)**. The greater the mass, the greater the energy and the greater the carrying power.

b. **Diameter (d)**. The greater the size of the **hole** the projectile must **bore** through the air, the greater the resistance and the less the carrying power. The size of the **hole** varies as d^2.

c. **Shape**. This is deduced by **K** (kappe). In fact, it has been found impossible to separate the effect of this factor from a steadiness factor, o (sigma). Their product Ko is used as a single factor and is determined by trial firings. K∗ is **1** for the standard shape for which the drag law has been obtained but any degradation of this shape, eg by a fuze profile that is less sharp than the standard, will give a value of a K∗ greater than **1**. The greater the value of K∗, the less the carrying power.

33. In summary, for a given velocity and atmosphere, the carrying power of a projectile is proportional to its mass M and is inversely proportional to K*** d^2. That is to say:

$$\text{Carrying power} = \frac{M}{K{*}d_2}$$

This ratio is called the Standard Ballistic Coefficient (C_o):

$$C_o = \frac{M}{K{*}d_2}$$

Where C_o is the ballistic coefficient in a standard atmosphere,

M is the projectile weight,

d is the projectile diameter,

K∗ are two coefficients that represent shape and degree of stabilization.

34. The numerical value of C_o depends on the units of measurement. Defined in this way, C_o is a universal measure of ballistic performance. No matter what the projectiles are, if they have the same value of C_o they will behave identically in flight in the same atmosphere.

35. A projectile becomes considerably heavier with only a small increase in diameter d, since for a given material the weight varies as d^2. Thus a large projectile will normally have a larger (better) value of C_o than a smaller projectile. However, if a small projectile is made of dense material so that its mass M is comparatively large, this projectile may have a C_o as good as, or better than, the C_o of a larger projectile of normal density. This is an important consideration in connection with modern composite armour-piercing shot.

36. C_o is an essential ingredient in the make-up of an FT for a gun system. The shape and steadiness factor (Ko) is not constant since it varies with velocity and A/D. Consequently, the value of C_o is not constant. When an FT is built up for new equipment, range and accuracy (**R and A**) firings take place at proof and experimental ranges to establish the best mean value of C_o, which represents the behaviour of the projectile over a particular trajectory. Values of C_o are fed into a specially programmed computer to produce the basic FT.

37. Whereas the in-vacuum trajectory is mathematically simple, the mathematics of the real trajectory are much more complex. FTs have to be based on trial firings. The construction of FTs experimental firing is described in Chapter 8.

ANGLE OF YAW

38. The axis of a projectile in motion through the air does not, in general, lie exactly along the trajectory, which is the path of its centre of mass. The angle between the axis of the projectile and the tangent to the trajectory is known as the angle of yaw (see Figure 3-3-10).

39. As a result of yaw, the force of air resistance will not, in general, act either along the trajectory or along the axis of the projectile. This force may be thought to have two components - one known as the drag along the trajectory and the other known as the cross-wind force perpendicular to the trajectory in the plane of yaw (see Figure 3-3-11).

40. If the force of air resistance does not act through the centre of mass (G) but instead acts through a point known as the centre of pressure (P) then the forces acting on the projectile will tend to rotate the projectile about an axis through its centre of mass. This is known as the turning moment.

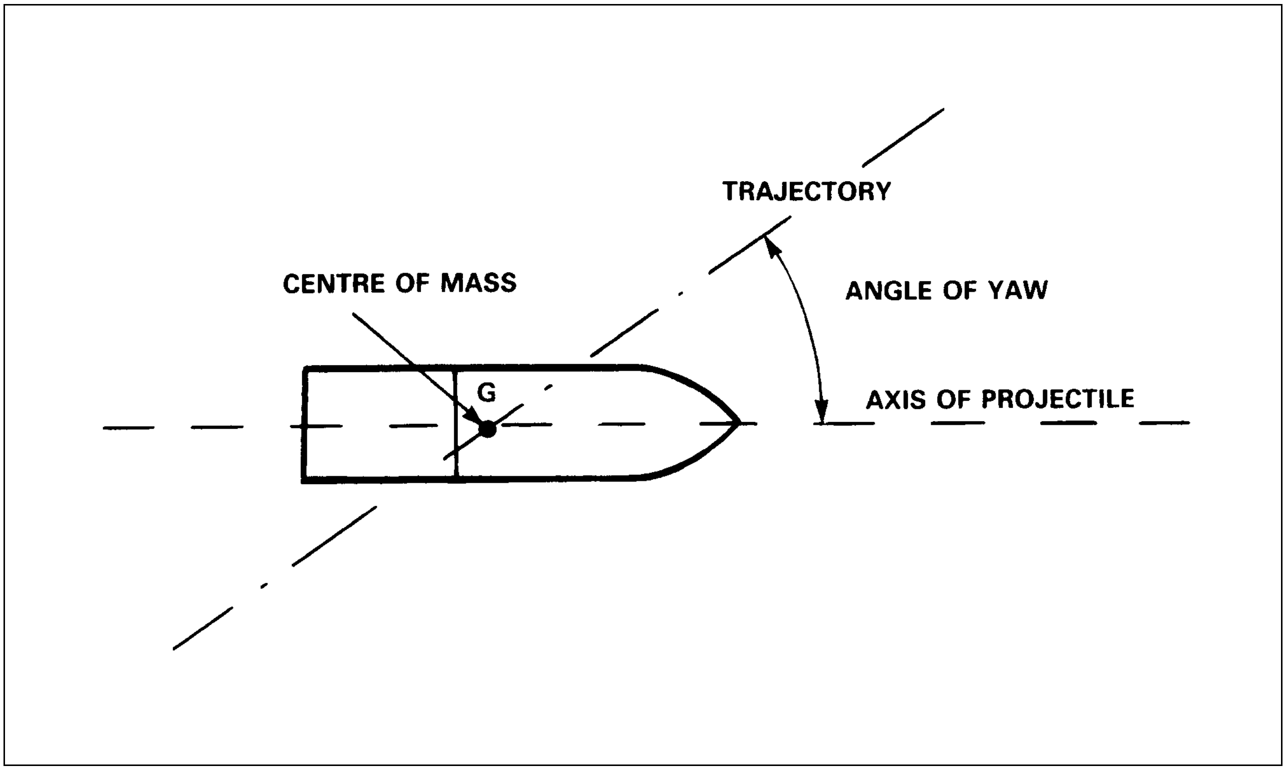


Figure 3-3-10 The Angle of Yaw

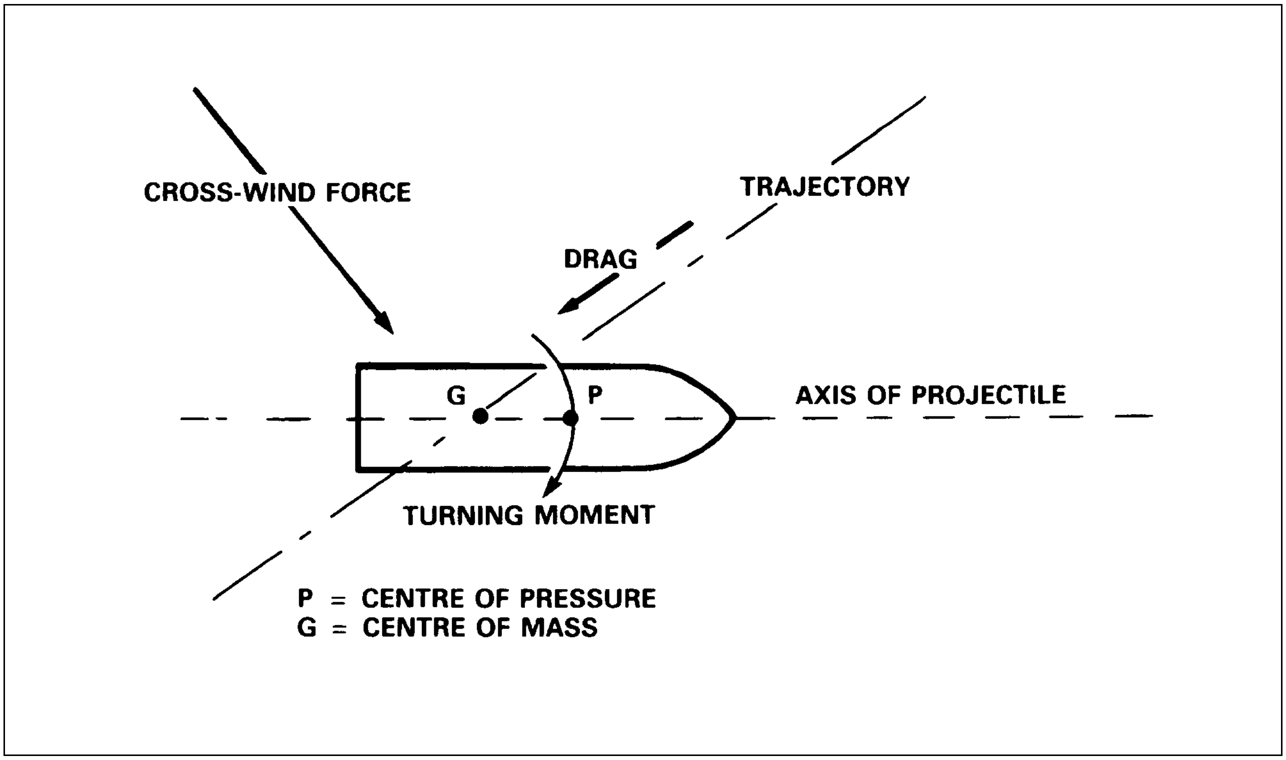


Figure 3-3-11 Forces Due to Air Resistance that Affect Stability

STABILIZATION

41. It can be seen that if an unrotating projectile acquires a small yaw, there will be:

a. increased drag;

b. a deviating force tending to alter the direction of motion; and

c. a turning moment that may increase or decrease the yaw, depending on the design of the projectile.

42. Clearly, in view of subparagraph 39 a, which reduces range, and subparagraphs 39 b and c, which adversely affect accuracy, it is necessary to find some means of keeping the yaw down to a minimum, thereby ensuring that the projectile flies through the air nose first.

43. Arrows, javelins, etc, were probably the first elongated projectiles used by man. With them came the problem that still exists today, that of ensuring the projectile will travel point foremost throughout its flight. In the case of the arrow, the solution is to concentrate its mass towards the head and provide a tail and fin towards the rear. In Figure 3-3-12, G is the centre of mass of the arrow. If the arrow gets out of its true course, ie yaws, so that it begins to move obliquely, then owing to the larger surface toward the rear, the resultant air pressure acts through a point P near the tail and so swings the arrow back onto the trajectory at G.

44. Mortar bombs, long rod penetrator, aeriel bombs and bomblets are distinguished from most other projectiles the presence of fins, flares or streamers protruding from their bases. These serve to bring the centre of pressure behind the centre of mass (centre of gravity) of the projectile, giving it aerodynamic stability (see Figure 3-3-12).

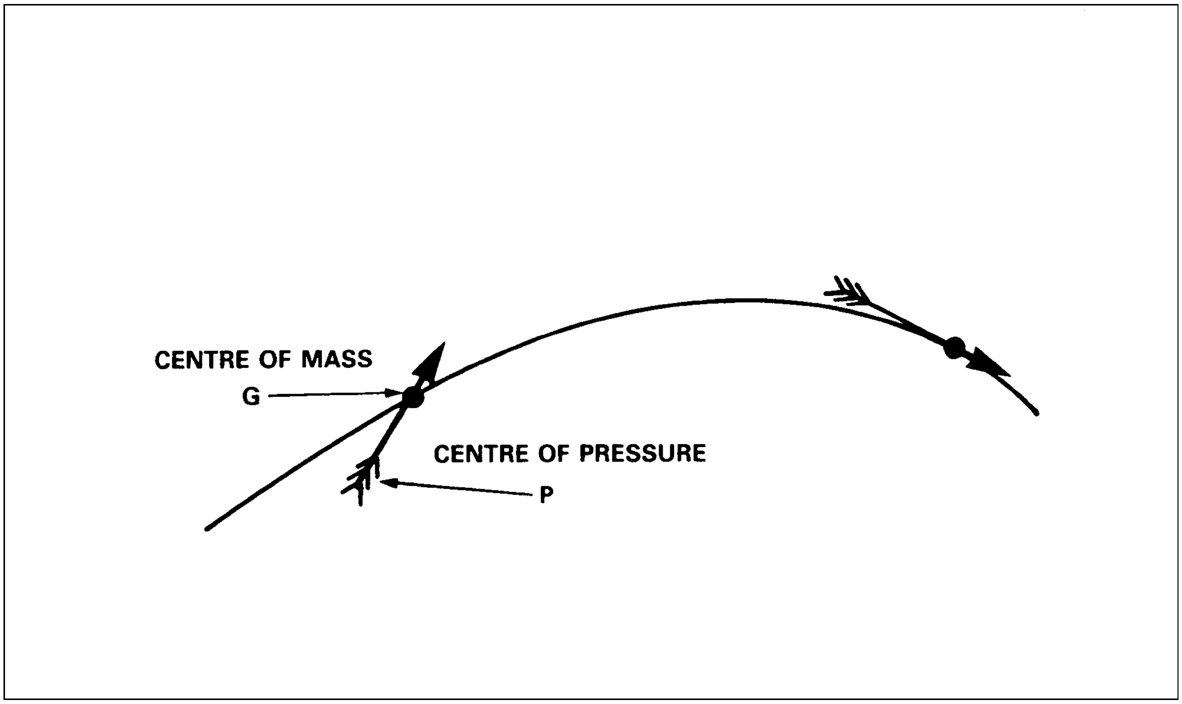


Figure 3-3-12 Stabilization by Fins

45. Conventional projectiles have their CG so close to their base that the centre of pressure is ahead of the CG. The projectile is, therefore, aerodynamically unstable and can only be stabilized in flight by spinning it about its longitudinal axis at a very high rate. The spin is imparted by the driving band on the projectile engaging in the rifling of the bore. The pitch of the rifling, together with the MV, determine the spin rate of the projectile as it exits the muzzle. Spin rate is usually defined as 1 in n, which implies that the projectile makes one complete revolution as it moves n calibres and so rotates through 2n V/nd. Therefore, N = 2n V/nd where:

N = spin rate (radians/second);

V = muzzle velocity;

n = twist of rifling (in calibres); and

d = the weapon calibre (in metres).

Example: find the spin rate of the projectile fired from a 105 mm Howitzer at an MV of 300 m/s.

$$N = \frac{2 \times 3.1416 \times 300}{20 \times 0.105}, \qquad N = 897.6 \text{ radians/second.}$$

to convert radians/second to revolution/second, multiply by 0.1592. 897.6 x 0.1592 = 142.9 revolutions/ second

Simplified: spin = $\frac{V}{n\,d} = \frac{300}{20 \times 0.105} = 143$ revolutions/second.

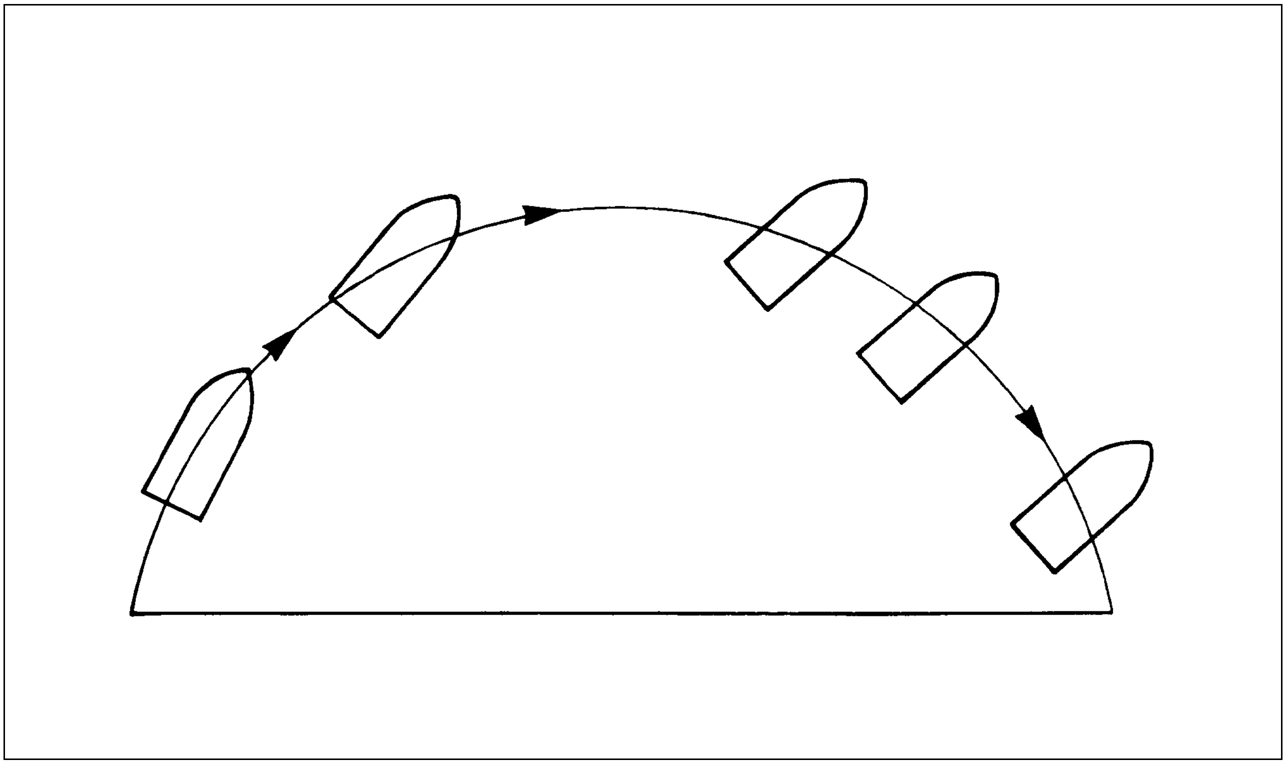


Figure 3-3-13 Over-Stabilized Projectile

OVER-STABILIZED AND UNSTABLE PROJECTILES

46. If a projectile is over-stabilized (too high a spin rate) the axis of the projectile will remain approximately parallel to its original direction as it travels along the trajectory. Consequently, the nose of the projectile will not follow the trajectory. In this case, it would land base first, as illustrated in Figure 3-3-13. Too low a spin rate will cause the projectile to be unstable and it will tumble.

SECTION 4

DRIFT

GENERAL

1. When a projectile is fired, it does not go straight to the target but tends to veer off in the direction of its spin. This effect is called drift and it has a number of causes, the most important one being gyroscopic motion.

GYROSCOPIC CONSIDERATIONS

2. There are three gyroscopic properties that are of interest to the gunner:

   a. spatial rigidity,

   b. precession, and

   c. nutation.

3. **Spatial Rigidity**. Consider a top spinning in an upright position. As long as it is spinning it will remain upright on its point. As it begins to spin slower, it will lose its tendency to remain upright. Gradually, it will lean to one side until it topples over. Obviously, it stood upright because it was spinning. If the top is spun on a plank of wood and the plank is tilted to the side, the top, if it is spinning fast, will not tilt with the plank but will remain upright. The tendency of the top, or any spinning object to resist any change to the direction of its axis of rotation is called spatial rigidity. The faster the object is spinning the greater its spatial rigidity will be. This is the principal on which gyro instruments are based.

4. **Precession**. For this illustration, visualize the point of the top fitted into an arrangement such as a ball and socket, which in turn is fixed to a firm base. With this arrangement, the top will be free to spin and at the same time its upper portion will be free to rotate about the vertical axis. When the top is spun, it will behave as in Section 4, paragraph 3 of this chapter. If, while the top is spinning, a force is applied in a manner which would tend to move the axis of the top in a horizontal direction, the top, because it is spinning, will behave in quite a predictable manner. The applied force will cause the upper part of the top to rotate in a circle about its vertical axis. The rotation of any spinning object about its vertical axis is called precession (see Figure 3-4-1).

5. **Nutation**. Consider a spinning top (with its point fixed) in a state of regular precession (stable). If this stable state is now disturbed by giving the top of the axis at "A" a small push in the direction of "B" (Figure 3-4-2), "A" will no longer move steadily around the original circle but will oscillate with respect to this circle. Its motion will be equivalent to moving around the perimeter of a small circle while this small circle moves around the perimeter of the large circle. The smaller motion is known as nutation and is illustrated in Figure 3-4-2.

GYROSCOPIC MOTION OF A SPINNING PROJECTILE

6. For the purpose of this argument, assume that at the instant of firing the projectile's axis coincides with the projectile's trajectory (see Figure 3-4-3). This is like a top in the vertical position. This condition does not last long because the trajectory soon begins to change direction as it falls back to earth while the spin stabilized projectile tries to keep pointing along the path on which it started (spatial rigidity). The result is that some vertical yaw is developed (see Figure 3-4-4). The projectile now tries to rotate or precess around its trajectory like the top does around the vertical.

7. With the top, the vertical remains fixed in the same position. In the case of the projectile, the trajectory continues to change direction as it gradually curves around toward the target. Thus the top can precess quite easily about its fixed vertical but the projectile, when trying to do likewise, only manages about a quarter of the journey around the trajectory and then finds that its efforts to continue are offset by the downward movement of the trajectory.

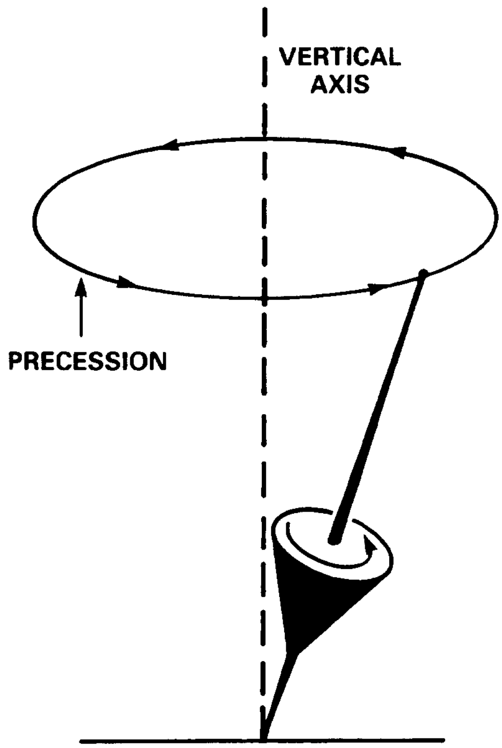


Figure 3-4-1 Precession

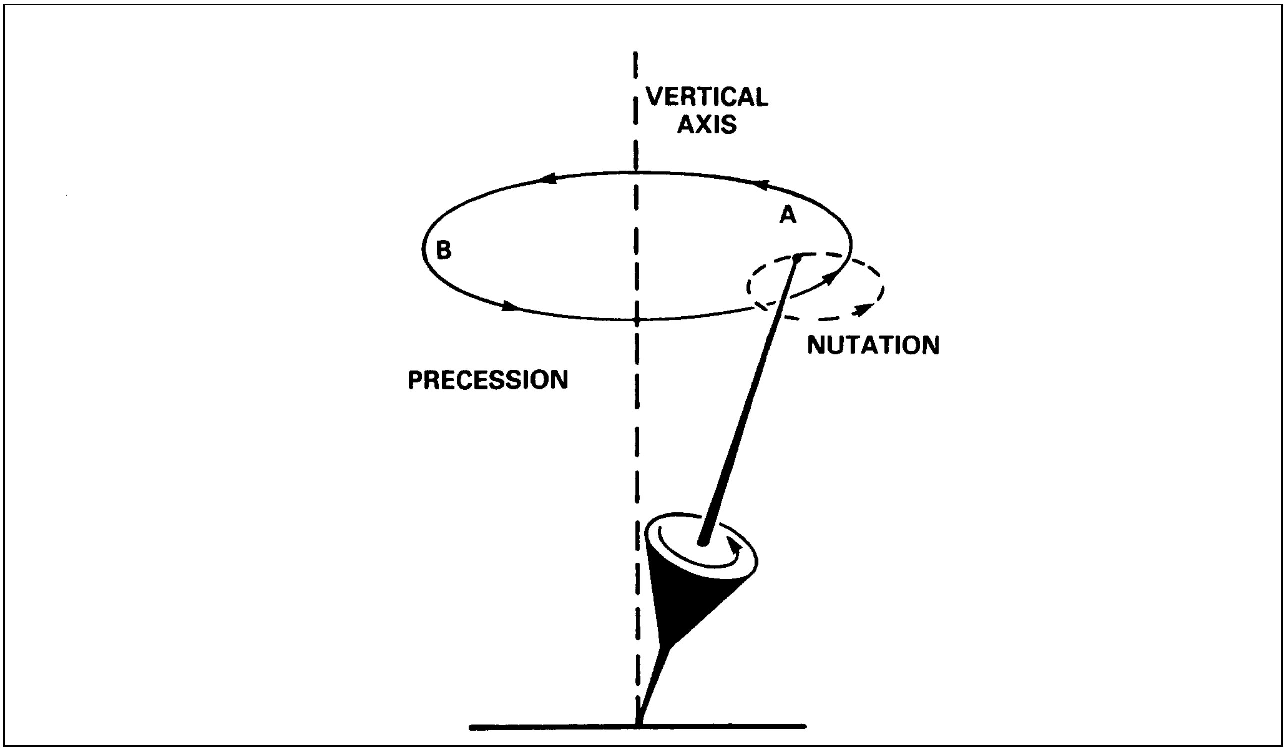


Figure 3-4-2   Precession and Nutation

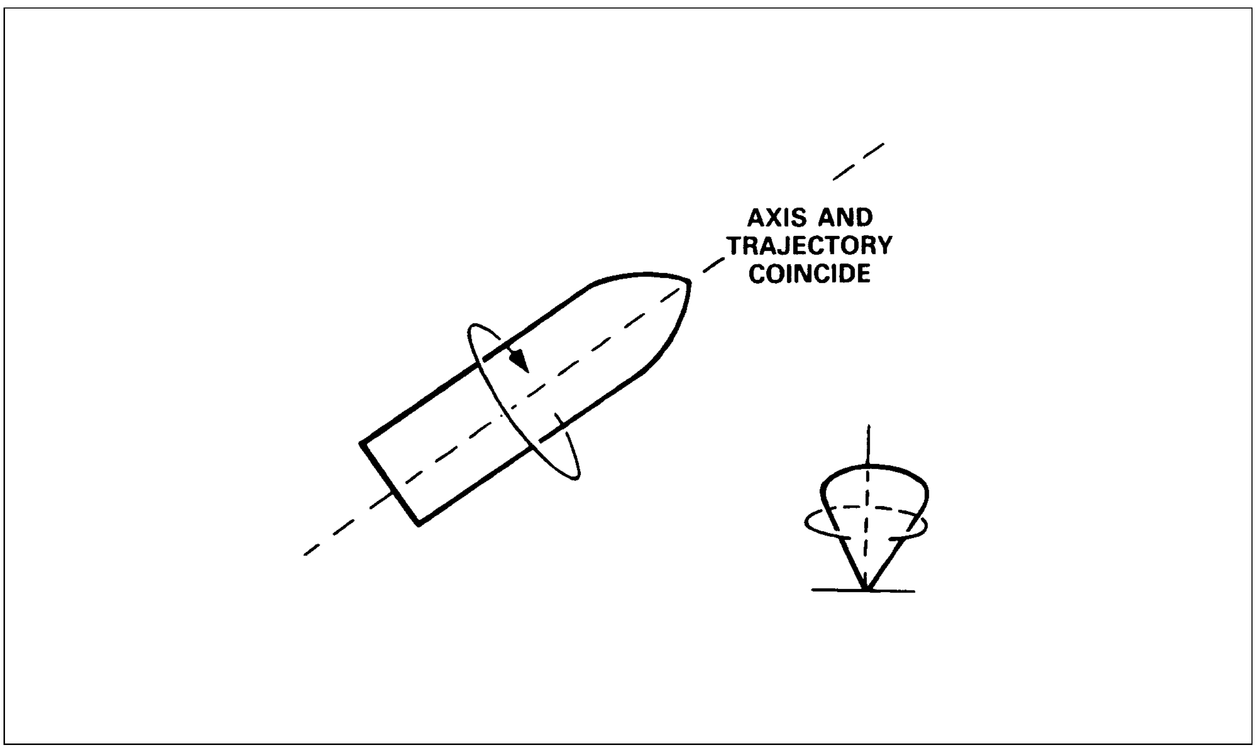


Figure 3-4-3   Projectile Axis and Trajectory Coincides

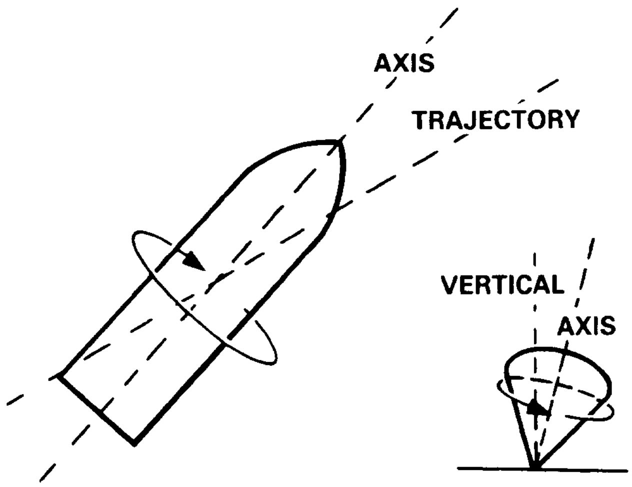


Figure 3-4-4 Projectile Begins to Precess Around the Trajectory

8. Looking at the nose of a projectile as it travels over its trajectory is difficult to imagine and is illustrated in Figure 3-4-5. Unlike the fixed vertical in the example of the top, the trajectory is seen to move downwards (relative to the observer's horizontal vision) and this prevents the nose of the projectile moving around it in a circle, as is the case of the top.

DRIFT DUE TO EQUILIBRIUM YAW

9. Soon after being fired, the projectile develops some vertical yaw due to the falling away of the trajectory. This condition will result in an increase of air pressure under the nose of the projectile. This increase of air pressure will tend to push the nose of the projectile up, that is, to increase the vertical yaw. Because a spinning projectile is gyroscopic, the force exerted by the air pressure will cause the nose of the projectile to move to the right. At this point the force exerted by the air pressure will act on the left side of the nose and tend to push it to the right but the gyroscopic effect will move the nose down. Now the air pressure, acting on top of the nose, will tend to push it down but the gyroscopic effect will move the nose to the left. The net result is the nose of the projectile, with its pivot point at the CG will precess around the trajectory.

10. Because the trajectory is continually falling away, the nose of the precessing projectile will point above the trajectory more so than below it. The result is that a certain degree of force is continually being exerted under the nose of the projectile. The dominating gyroscopic effect is to keep the nose of the projectile pointed to the right. This condition in which the projectile always points to the right of the trajectory is called **equilibrium yaw** (see Figure 3-4-6). The air stream, which can be imagined as coming towards the projectile, will bounce off to the left and at the same time, push the projectile to the right. This is the main cause of drift.

11. It should be noted from Figure 3-4-6 that the amount of equilibrium yaw depends on the curvature of the trajectory being greatest where the trajectory is most curved. During the first half, the trajectory moves downward faster than the nose of the projectile. Around mid-point they move at the same rate. In the last half the nose moves a little faster than the trajectory and the gyroscopic force acts to draw them together again. As the trajectory straightens out, equilibrium yaw tends to disappear.

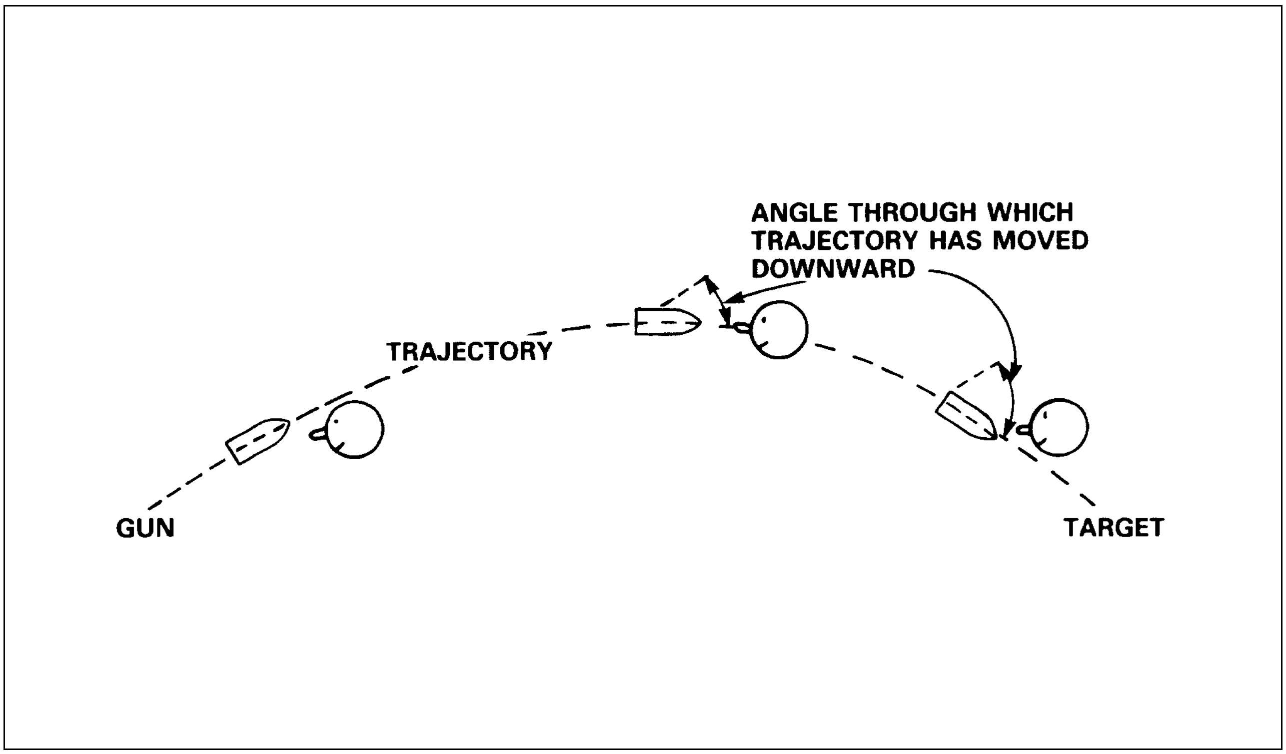


Figure 3-4-5 Horizontal View of the Trajectory

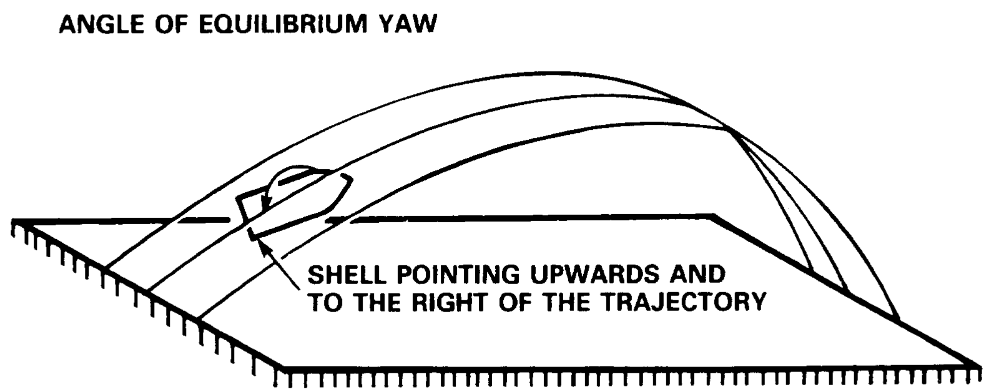


Figure 3-4-6 Equilibrium Yaw

12. Equilibrium yaw is characteristic of a well designed projectile. If the projectile is not well designed it will either lack stability, or conversely, it will have too much stability (see Section 3, paragraph 39). The nose of the overstabilized projectile fails to follow the trajectory and, thereby, greatly increases the air resistance, reduces the range, hits the target base first and is inaccurate.

13. During the flight of a spinning projectile over a high angle trajectory, the problem of overstability can be serious. At the top of the trajectory where the curvature is greatest, it is desirable to have relatively low stability (or high **tractability**) to enable the projectile to easily follow the curve, nose first. Unfortunately, it is at this point that the stability of the projectile tends to be at its best. The density of the air and the remaining velocity are both reduced so that the gyroscopic effect, which brings the nose around, is at its weakest, while the stabilizing spin has lost very little of its initial value. Once over the vertex, the instability begins to grow with increasing velocity, air density and the slow decrease in spin. The violent instability (precession and nutation) can be easily recognized when heard. Although the nose of the projectile manages to go completely around the trajectory, on one side its movement is opposed and precession is rapid with only a small yaw. On the other side the direction of movement is the same and for rapid precession to occur the angle of yaw must be large. Angles as high as 600 mils have been measured. Because of these large versus small angles of yaw, the resulting drift is predominantly to the right, as in the more normal case. If instability is too great, the projectile does not have the precessional and mutational movements, but, like a top with almost no spin, it falls over in the air and continues to do so with results which, like overstability, are inaccurate.

CORIOLIS EFFECT

14. The next important factor in drift is Coriolis acceleration. Unlike the gyroscopic effect, this particular acceleration does not depend on the resistance of the air. It would be present if the projectile were fired in a vacuum. It does, however, depend on the latitude and gearing of the gun and on its range. Its effect is opposite north and south of the equator. For long range guns it is sometimes almost as great as the gyroscopic effect.

15. The trajectory of a projectile is always measured using the firing range or some other part of the earth's topography as a frame of reference. The frame of reference is considered fixed with the projectile doing all the moving. This is a false assumption, since the earth is not fixed but is rotating on its axis once a day. In reality, therefore, the frame of reference is uniformly accelerated, which for normal latitudes means it is being swung in a giant curve.

16. Figure 3-4-7 (A) and (B) illustrates what happens to the projectile and the frame of reference in the northern hemisphere. To an observer on the moon (A) the projectile goes in a straight line from G to T while the gun, because of the earth's rotation, goes in a curve line from G to P. To an observer on earth (B) the gun does not appear to move so that the observer considers G and P to be the same. The projectile, however, appears to curve mysteriously over to the right. Actually it is not the projectile swinging to the right but the earth (frame of reference) swinging to the left which produces this result.

17. The difference in the length of the trajectory is due to the velocity imparted to the projectile by the rotation of the earth, which the moon observer adds in but the earth observer leaves out. Drift from Coriolis acceleration is maximum at the poles and negligible at the equator. The acceleration also affects range, but in the opposite sense, being maximum when fired along the equator and negligible at the poles.

MAGNUS EFFECT

18. Another cause of drift is the Magnus Effect which is well known for its action on a sliced golf ball. When a cylinder rotates sideways in a moving stream of air, the pressure is unequal on opposite sides and it will, therefore, drift (see Figure 3-4-8). The air passing the cylinder is assisted at the top and opposed at the bottom by the air that is being moved by the surface of the rotating cylinder (small arrows). The assisted air at the top moves faster and further than the opposed air at the bottom. As a result, the molecules become spread out on the wide sweep around the top of the cylinder and the air pressure there drops. This occurs because pressure is a result of molecular collisions and these are reduced when the distance between molecules is increased.

19. To understand why the Magnus Effect takes place refer to Figure 3-4-4. From observation of this Figure, it can be seen that for most of the time, the nose of the projectile points above the trajectory. This introduces a small vertical component which is the equivalent to that illustration in Figure 3-4-8. The effect would be quite pronounced if the projectile was overstabilized, and is always more pronounced in high angle trajectories where stability and the curvature near the top of the trajectory tend to make the vertical component more pronounced. If A/D is less than 700 mils, the effect on a well designed projectile is almost negligible.

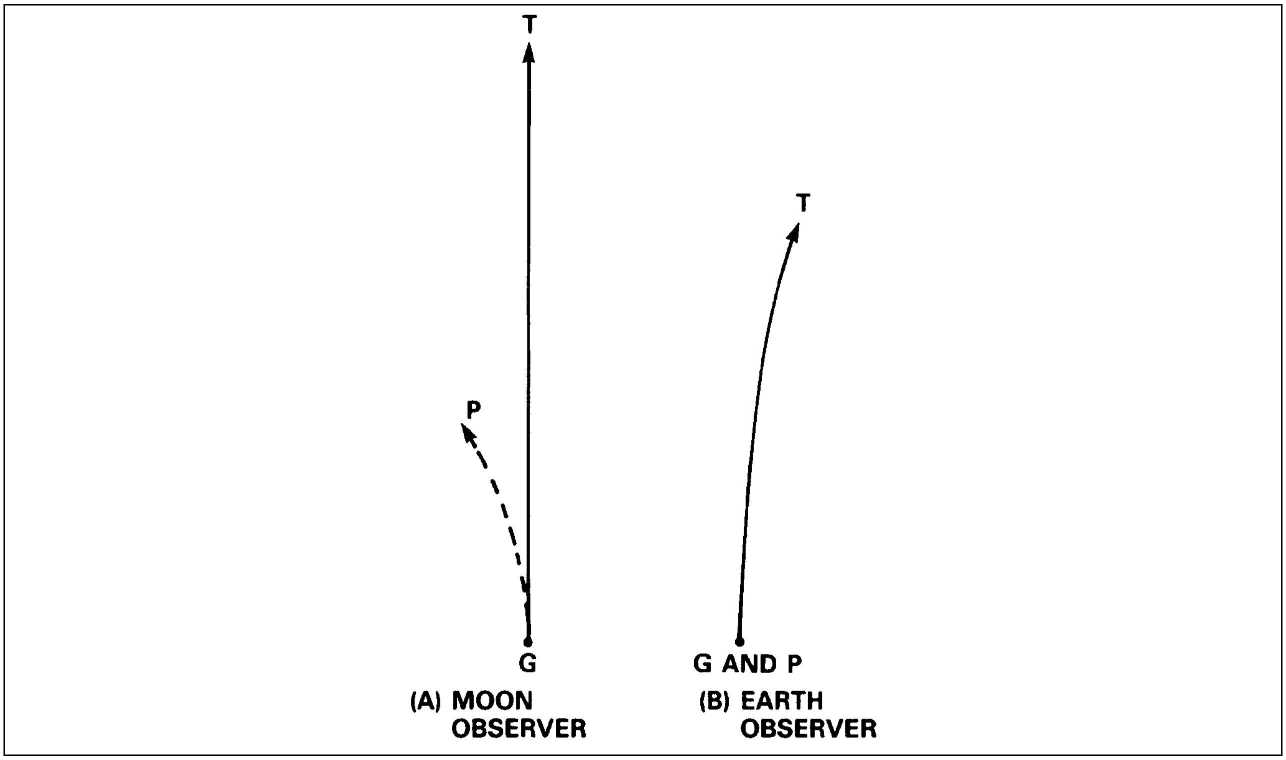


Figure 3-4-7 Trajectory Viewed from the Moon and Earth

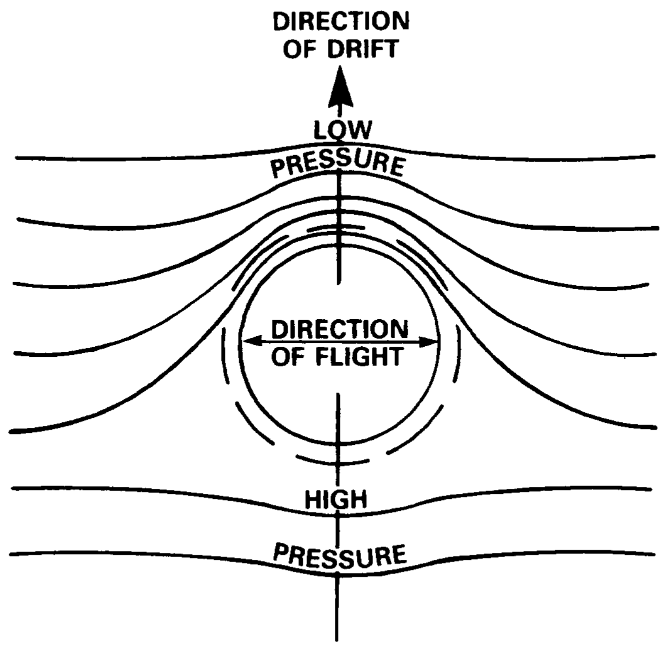


Figure 3-4-8   Magnus Effect

20. If a rotating projectile lay directly in the trajectory, there would be no Magnus Effect. In fact, however, the nose of the projectile is above the trajectory throughout most of its flight because the trajectory is continually falling away and the nose is being forced up by the air pressure. This Magnus Effect is very slight and is entirely masked by the drift to the right due to the equilibrium yaw.

POISSON EFFECT

21. Another minor cause of drift, which also depends on the nose of the projectile being above the trajectory, is the Poisson Effect. This, if it occurs at all, acts in the same direction as the gyroscopic drift and is even less important than the Magnus drift. It supposes that the up-tilted nose of the projectile causes an air cushion to build up underneath it. It further supposes that there is an increase of friction between this cushion and the projectile so that the latter, with its spin, will tend to roll off the cushion and move sideways (see Figure 3-4-9).

22. This simple explanation is quite popular. There is, however, no evidence to show that increased pressure means increased friction and unless this is so, there can be no effect. Even if it does exist it must be quite insignificant compared with the gyroscopic and Coriolis drifts.

23. Both the Poisson and Magnus Effects will reserve their directions of drift if the nose falls below the trajectory. When the nose is off to one side, as in equilibrium yaw, these effects will make minute alterations in range.

LATERAL JUMP

24. Lateral jump is caused by a slight lateral and rotational movement of the barrel at the instant of firing. It has the effect of a small error in bearing. The effect is ignored, since it is small and varies from round to round.

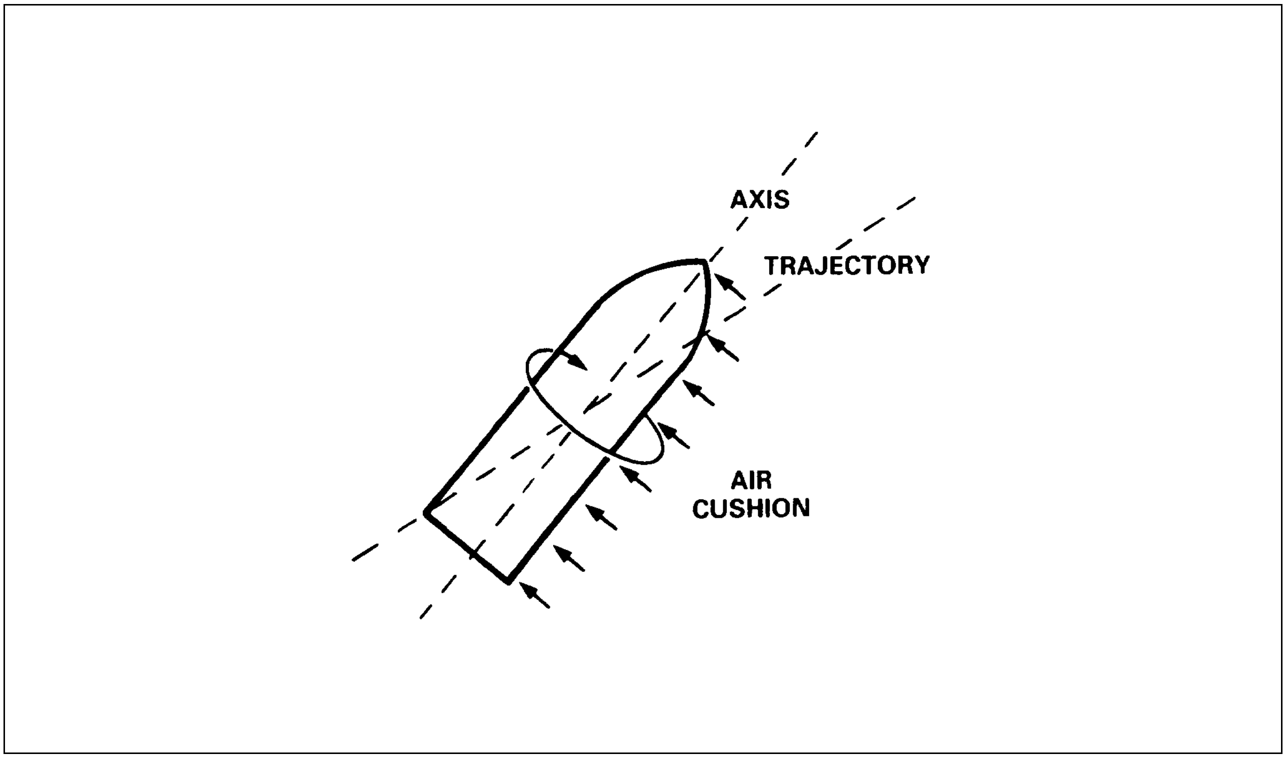


Figure 3-4-9 Poisson Effect

DRIFT CONSTANT

25. A practical method of allowing for drift is to assume that the drift is proportional to the tangent of the angles of projection, ie angular deviation due to drift = constant x tan A/D. This constant, called the drift constant, no longer holds true as A/D increases above 800 mils as drift increases more rapidly. It also depends on the MV and shape of the projectile.

26. At very high angles of departure, the nose of the projectile may fail to follow the trajectory at the vertex and the projectile may fall base first at a reduced range, with a marked drift to the left. The A/D at which this occurs varies between 1 200 mils and 1 400 mils, depending on the equipment and the projectile.

CROSS-WIND EFFECT

27. Cross-wind is that component of the ballistic wind blowing across the direction of fire. Cross-wind tends to carry the projectile with it and causes a deviation from the direction of fire. However, the lateral deviation of the projectile is not as great as the movement of the air causing it. Wind component tables simplify the reduction of ballistic wind into its two components with respect to the direction of fire.

SECTION 5

ROTATION OF THE EARTH

GENERAL

1. Although the earth rotates at a constant rate, the correction for rotation varies with a number of factors and, therefore, rotation is more readily considered a non-standard condition. Factors influencing the effect of rotation of the earth on the travel of a projectile are:

   a. direction of fire,

   b. A/D,

   c. velocity of projectile,

   d. range to target, and

   e. latitude of the gun.

2. The correction tables provide all the data needed to compensate for rotation in the gunnery problem, however, some background theory of rotational effects may assist in an understanding of their application.

EFFECTS OF ROTATION ON RANGE

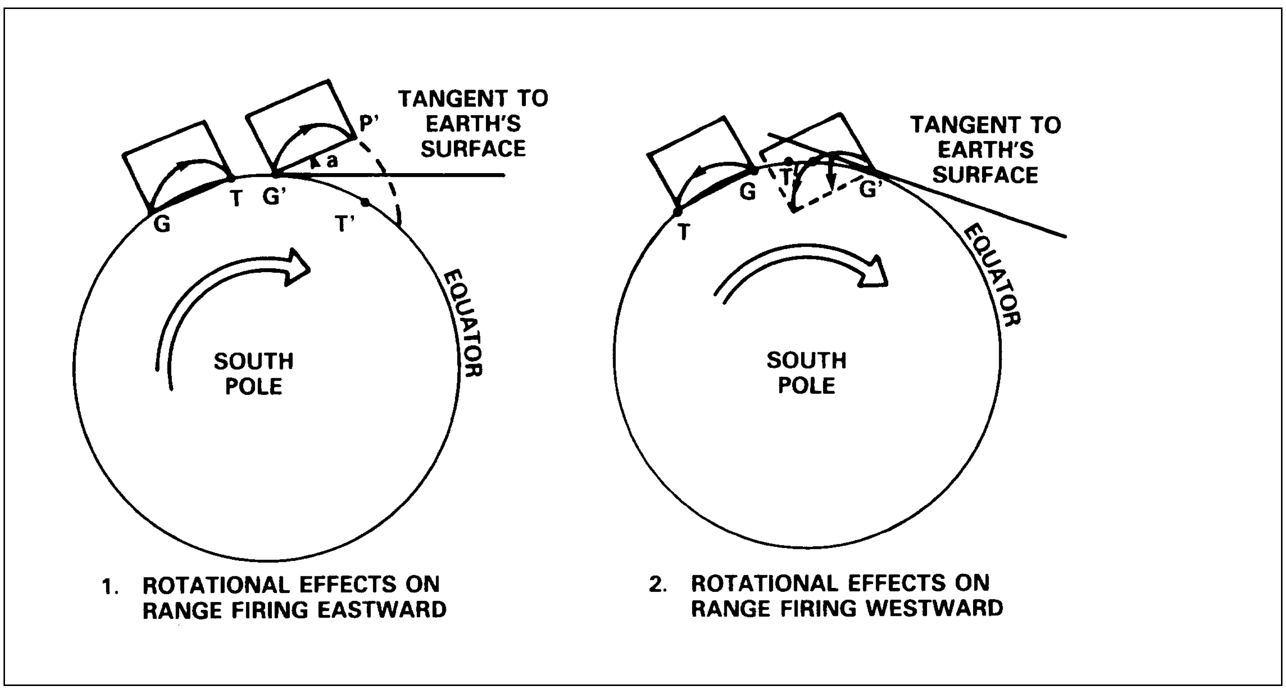


Figure 3-5-1 Rotational Effects on Range

3. Because of rotation of the earth, a point on the equator has an eastward linear velocity of approximately 457 m/s. This linear velocity decreases to zero at either pole. Consider a gun on the equator firing due east at a target (Example 1, Figure 3-5-1). During TOF of the projectile, the gun and target will travel from G to G' and T to T', respectively, along the circumference of the earth. The projectile, however, travels in a vertical plane, the base of which is parallel to the original plane of departure established at the time of firing; that is, it is pivotal to the circumference of the earth at the gun but not at the target. At the end of a given TOF, the projectile will be at P' when the target is at T'. Hence, the projectile will continue along an extended trajectory and land farther east or, in this instance, beyond its target. The normal trajectory of the projectile is interrupted.

4. Consider the same gun firing westward (Example 2, Figure 3-5-1). Again, the projectile falls to the east of the target, but in this instance east is short. The effect in each example is as if the QE fired has been in error by the amount of angle "a", which is the angle formed by the base line G' P' and a tangent to the earth at G'. When the gun is firing eastward, angle "a" is plus (range long); when the gun is firing westward, angle "a" is minus (range short).

5. A second effect on range is known as projectile lag. This is best explained by use of a diagram (see Figure 3-5-2). Assume that a projectile is fired straight up into the air, ie at an A/D of 1 600 mils. When the projectile is fired, it will have a horizontal velocity equal to the rotational velocity of the earth. During the time that the projectile is in flight the earth rotates moving the gun from G to G' and the projectile moves through an arc P to P'. As this occurs in the same time, and the horizontal velocity of the gun and projectile are the same, distance G to G' equals distance P to P'. However, P to P' is further away from the centre of the earth and the angle subtended is less, therefore, the round lands at "X". Furthermore, the effect of gravity on the projectile is acting through the centre of the earth causing the projectile to lag.

6. Tabular Firing Tables list a single range correction for rotation of the earth that combines the rotation effect and the lag effect. These two effects are opposing and they reach their maximum values at different angles of departure as follows:

a. At an A/D of approximately 530 mils the rotation effect reaches its maximum.

b. At an A/D of approximately 1 070 mils the two effects are equal and cancel each other.

c. At an A/D of 1 600 mils, the effect of projectile lag reaches its maximum.

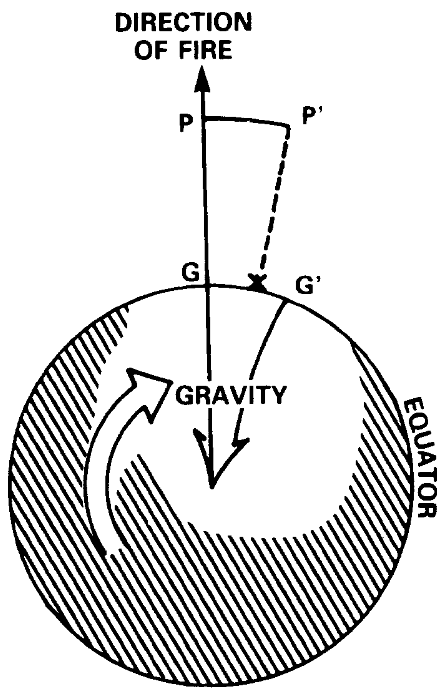


Figure 3-5-2 Projectile Lag

7. A third consideration is the curvature effect. Curvature effect exists because of the use of a map range for which the surface of the earth is assumed to be flat, but the actual range is measured on a sphere. The gun-target (GT) range is computed for a plane tangent to the surface of the earth at the gun. When the projectile reaches this range, it is still above the curved surface of the earth and will continue to drop, resulting in a slightly longer true range than desired. This effect is less than 1 metre in 1 000 metres and is of little significance except at very long ranges. It is disregarded when FTs are used, since FT ranges include curvature effect.

ROTATION EFFECTS ON BEARING

8. A final rotational effect is described as the latitudinal effect. When the gun and target are at different latitudes, the eastward rotational velocity imparted to the projectile and target is different. For example, if the gun is nearer the equator, the projectile will travel faster and, therefore, further to the east than the target (see Example 1, Figure 3-5-3). The reverse is true if the target is nearer the equator.

9. When the gun and target are at the same latitude the projectile will also be deflected away from the target. This is because the projectile tends to travel in the plane of the great circle containing the gun and the target at the time of firing. Because of the rotation of the earth, this great circle plane is continually changing with respect to its original position. As viewed from above, it would appear that the great circle containing the gun and target is turning with respect to the great circle followed by the projectile (see Example 2, Figure 3-5-3). In the northern hemisphere the latitudinal effect is to the right; in the southern hemisphere it is to the left.

APPLICATION OF CORRECTIONS

10. The effects of rotation of the earth are listed in Tabular Firing Tables. In manual computations, rotational effects are not applied in Canadian gunnery procedures at ranges under 15 000 metres, as the additional accuracy achieved does not justify the time expended.

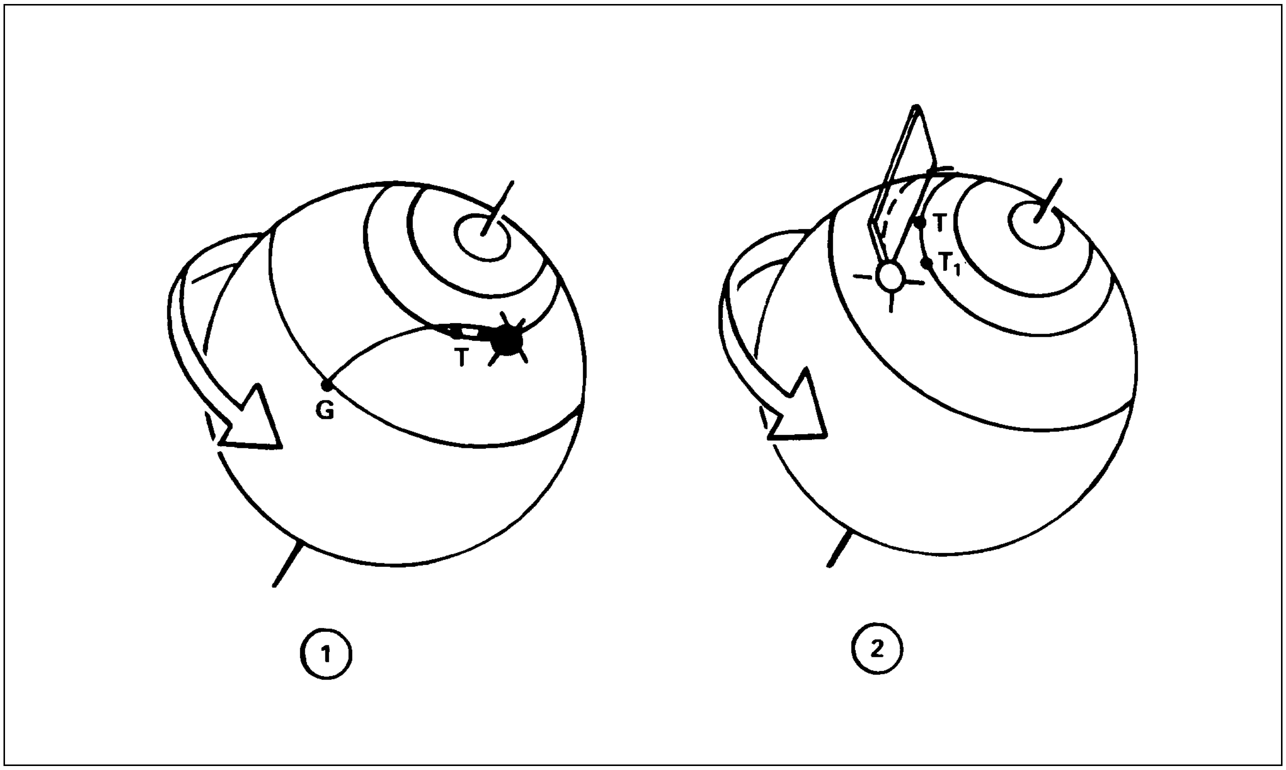


Figure 3-5-3 Latitudinal Effects

CHAPTER 4

TERMINAL BALLISTICS

SECTION 1

INTRODUCTION

GENERAL

1. Terminal ballistics is the science that deals with the motion of a projectile and parts or fragments thereof from the moment of impact or burst. In designing weapons and ammunition, maximum terminal effect is the desired objective. A proper balance among many factors is essential to accomplish this purpose. The most important of these factors are:

   a. terminal velocity;

   b. shape, weight and material used in the projectile;

   c. type and weight of explosive charge; and

   d. fuzing system.

2. Against light targets, minimum delay or super quick (SQ) fuzes are extremely important because the position of the projectile, with respect to the target at the instant of detonation, determines to a great extent the amount of damage caused. This is true against personnel where a certain fragment pattern is desired.

3. Current HE projectiles fired against heavy concrete and armour are relatively ineffective. For example, during trial firings, to obtain at least one perforation of a pillbox wall 5 feet thick at a range of 3 660 metres (4 000 yards) required 750 rounds of 105 mm HE M1 projectile and 45 rounds of 155 mm HE M107. All rounds were fitted with a special fuze that had half the delay of current fuzes.

4. To obtain the best results the type of projectile and type of fuze must be selected carefully to fit the type of target.

SECTION 2

TERMINAL EFFECTS

GENERAL

1. For purposes of analysing terminal effects, projectiles may be classified under three categories:

   a. HE projectiles,

   b. carrier shell, and

   c. anti-tank projectiles.

HIGH EXPLOSIVE EFFECT

2. The HE projectile utilizes blast and fragmentation to give the required effect at the target.

3. **Blast**. Blast is the shock caused by the detonation of the HE filling and is accompanied by a flash and flame. The effects of both are very localized and if damage by either is to be expected a direct hit must be achieved. Blast can be effective if the projectile penetrates the surface before detonation, because the blast, being largely contained, causes a disruptive action. Such features are useful when engaging buildings or fortifications or when a cratering effect is required. Blast is effective against personnel at relatively short distances, whereas fragments (fragmentation) may travel great distances and cause casualties.

4. **Fragmentation**. Under the action of the HE filler, the projectile body is broken up into a number of pieces of varying sizes, which are thrown outwards at high velocities. These fragments are effective against personnel and soft targets over a considerable area but have little effect against hard targets. The effectiveness of fragments is dependent on fragments size and velocity. Tests have shown that the optimum size of fragments to achieve maximum effect against personnel and soft targets is approximately 1.4 g. If the fragments are too large there will not be enough of them and conversely if too small they will lack carrying ability. Tests have shown that fragments will achieve velocities in excess of 1 000 m/s. In Figure 4-2-1, X-ray shadow graphs show the bursting of a projectile into fragments.

5. **Fragment Velocity and Direction**. In order to effectively use an HE projectile to its greatest advantage, the manner in which fragments are distributed must be understood. This can best be done by observing three theoretical situations:

   a. **Projectile at Rest**. If a projectile were suspended nose down on the end of a string and detonated, the following would be observed -

      (1) The greatest number of fragments would fly out at right angles to the body.

(2) The fuze, more or less intact, would be blown downwards with a few fragments from the shoulders.

(3) The velocity achieved by the fragments would be in excess of 1 000 m/s (see Figure 4-2-2).

b. **Projectile in Flight**. If the projectile were taken in an aircraft and fired straight down at a velocity of 500 m/s and detonated in the air, the fragments' direction would be substantially altered. This is a result of combining two velocities -

(1) Downward projectile velocity equals 500 m/s.

(2) Horizontal fragment velocity equals 1 000 m/s.

c. This combined velocity will affect the fragmentation pattern as follows -

(1) Fragment velocity will remain at 1 000 m/s.

(2) The downward velocity of the projectile (500 m/s) will cause the fragments to project outward and downward, as illustrated in Figure 4-2-3.

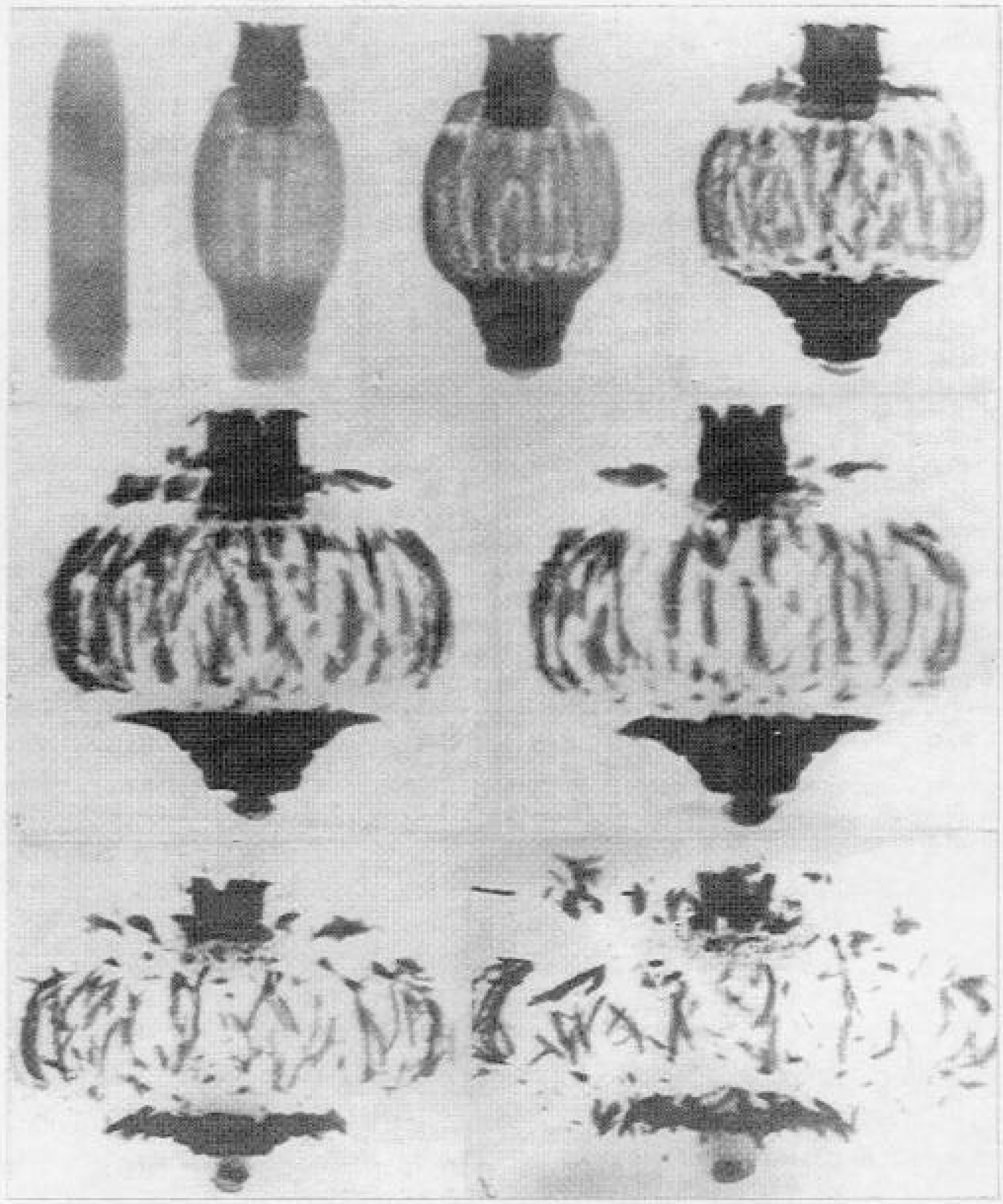


Figure 4-2-1 X-ray Shadow Graphs of a Detonating Projectile

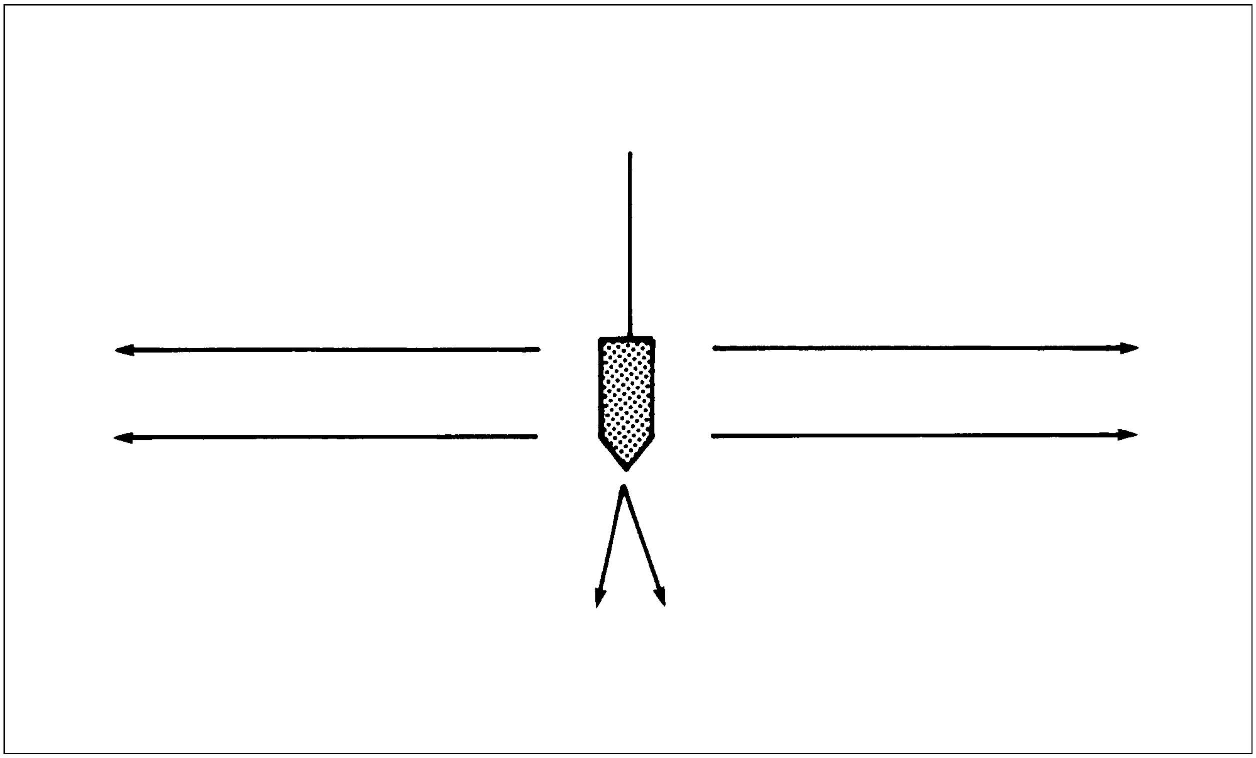


Figure 4-2-2   Detonation of a Projectile at Rest

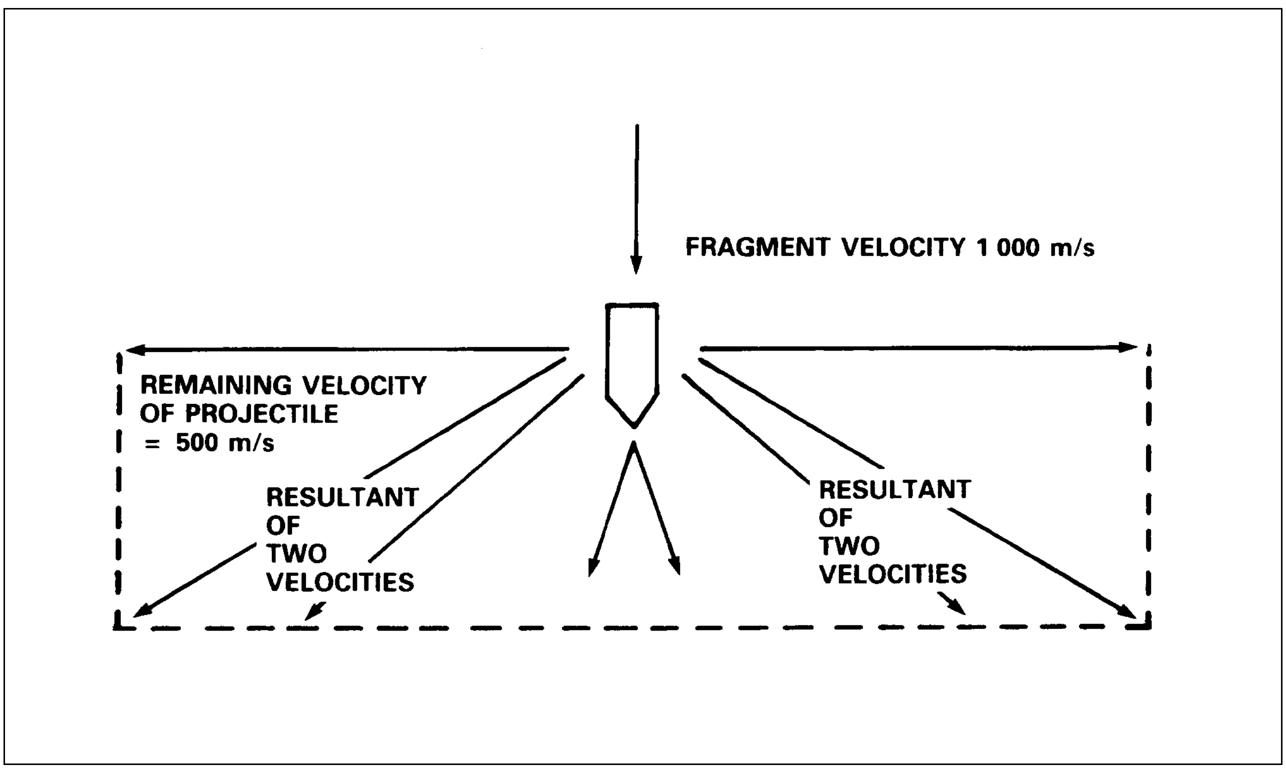


Figure 4-2-3   Detonation of a Projectile in Flight

d. **Actual Detonation in Flight**. In flight, some fragments are thrown faster and further than others due to their size and weight. This means that a general pattern or area can be expected to be covered by fragments. The following velocities have been used to illustrate the fragmentation pattern shown in Figure 4-2-4 -

(1) projectile velocity equals 500 m/s.

(2) fragment velocity equals 700 to 1 200 m/s.

FRAGMENT PATTERNS

6. The fragment pattern of a projectile will depend on:

a. the remaining velocity;

b. the angle of impact and nature of ground, in the case of a ground burst; and

c. the attitude of the projectile and height of burst (HOB), in the case of an airburst.

7. Only a portion of the fragments from a bursting projectile are useful. In the case of a ground burst those fragments projected horizontally or nearly so will be useful. In the case of an airburst, only those fragments projected downwards will be useful. Fragment patterns for ground bursts and airbursts at an effective height are illustrated in Figure 4-2-5.

8. The patterns shown represent the area of fragmentation where unprotected personnel have a 50 per cent risk of being hit. The shapes illustrated apply to all calibres, however, the size will increase proportionately to the calibre in use. As a very rough guide, the distance "X" is about 15 metres for the 105 mm HE M1 projectile and 30 metres for the 155 mm HE M107 projectile.

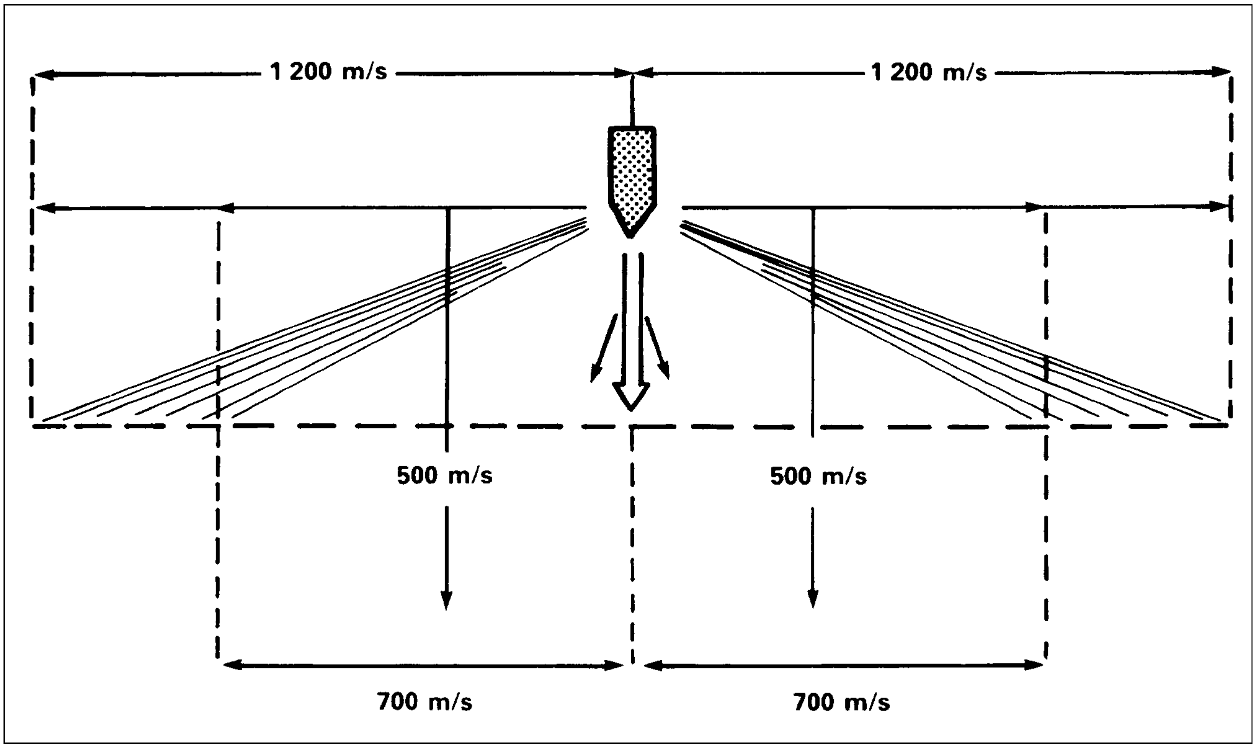


Figure 4-2-4   Actual Detonation of a Projectile in Flight

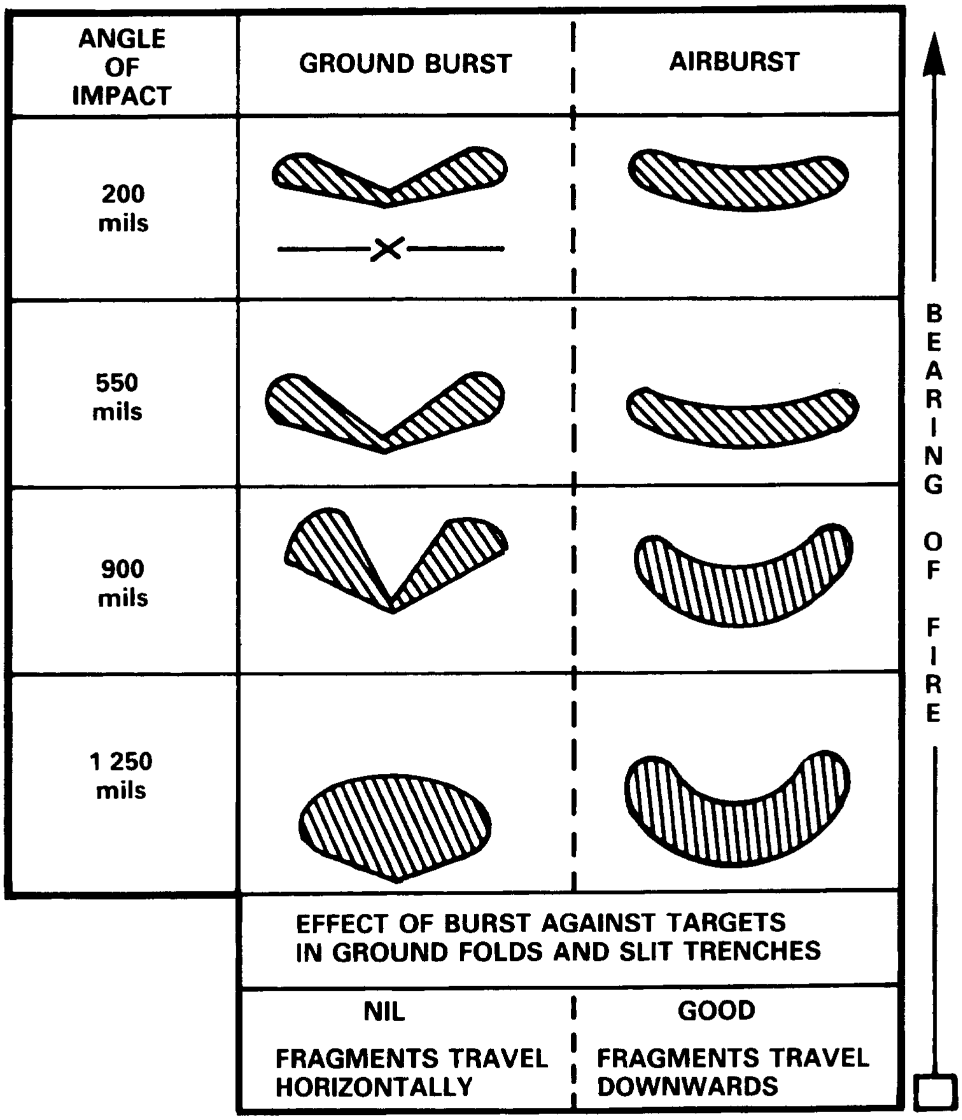


Figure 4-2-5 Fragment Patterns of Ground and Airburst

EFFECTS ACHIEVED

9. **Impact Burst**. Impact bursts are most effective when the fuze activates the instant the ground is struck. If the fuze is slow in acting the projectile will partially bury itself with the result that the majority of fragments will be driven into the ground. For this reason, fuzes are designed to have an instantaneous action. Most impact fuzes will also have a selective delay element in their components that, if used, will effect a cratering action because the projectile will penetrate the target before bursting.

10. **Airburst**. Airbursts are most useful because their fragments are directed downwards. This enables effective engagement of targets that are dug in or in folds in the ground. To achieve the maximum effect from airburst, the angle of impact must be taken into account. As the angle of impact increases the HOB should be lowered. This will be clear by referring again to Figure 4-2-5. Control Variable Time (CVT) fuzes automatically cause detonation of the projectile at "X" metres above the ground. Fuzes M513 and M514 burst at 20 metres and the M732 fuze bursts at 7 metres above the ground. HOB is more consistent when CVT fuzes are used with large angles of impact.

11. **Orientation of Projectile**. With a conventional HE projectile, the most effective distribution of fragments will be achieved when the axis of the projectile is vertical. As the axis moves away from the vertical, an increasing number of fragments are either lost in the ground or projected relatively harmlessly into the air.

12. **Effects of Ground**. The effects achieved with ground bursts will differ depending on the type of ground about the target. This refers not only to ground features, eg folds, hillocks, but the nature of the soil itself. Very hard ground is best because it allows the fuze to detonate the projectile before it buries itself and also allows fragments to ricochet. When firing into soft ground, snow, mud, sand, etc, the fragment pattern of the projectile will be greatly reduced.

13. **Ricochet Fire**. This can be likened to skipping a flat stone on water and can be achieved by firing HE projectiles with the fuze set to delay. In order to achieve a high percentage of airbursts, the ground used to ricochet from must be flat and hard. Ricochet bursts can be achieved with the 105 mm C1 Howitzer with all charges at ranges from 1 000 to 18 000 metres and from 1 000 to 10 000 metres with the 155 mm M109A2/A3 Howitzer.

14. **Backward Effect**. By examination of Figure 4-2-5 it can be seen that fragment patterns of ground bursts are projected forward in the bearing of fire and few fragments, if any, are projected rearward. This enables troops to be relatively close to a target that is to be engaged with HE impact. Another advantage is that, depending on the acuteness of the angle formed by the line of fire when it crosses the forward line of friendly troops, the safe distance can be very small.

CARRIER SHELL

15. Carrier shells are fitted with a small explosive charge designed to open the projectile and to free its contents. Depending on the type of fuze used, it may function on impact or in the air. Typical fillings are:

a. smoke (colored, white or white phosphorus);

b. chemical;

c. illuminating;

d. anti-personnel (bomblets or grapeshot); and

e. leaf let.

16. Carrier shells are of two main types:

a. **Bursting Shell**. A bursting shell is designed to rupture on impact under the action of an impact fuze activating the burster charge. The exception is the Beehive projectile, which is activated in the air by a time fuze. The force generated to rupture the projectile body is also employed to scatter the contents. As with HE impact projectiles, the contents are carried forward and as a result the full effect of the burst is often lost.

b. **Base Ejection Shell**. A base ejection shell is designed to expel its contents along the trajectory under the action of a time fuze that activates the bursting charge. The gases expand, forcing the baffle plate to the rear, allowing the contents to be freed. In effect, the baffle plate and contents are blown out. In some cases the flash from the burning propellant in the bore is used to ignite the contents.

ANTI-TANK PROJECTILE

17. There are two main types of anti-tank projectiles which, by virtue of their action, can be classified as either shot or shell.

18. **Shot**. Shot defeats armour by means of kinetic energy imparted by velocity and weight. As shot is fired at high velocity it is necessary that it has a good ballistic shape so that in flight loss of velocity is kept to a minimum. The use of high velocities is a user advantage in that corrections for moving targets are normally small. There are, however, certain disadvantages inherent in their use. High MVs may increase barrel wear and usually, anti-tank (AT) guns are comparatively heavy because of the higher chamber pressure involved. Most shot contains a tracer element to assist in observation and others will also contain a small explosive charge that will act after impact/penetration.

19. **Shell**. HEAT and HEP, defeat armour by virtue of the action of their explosive content. The highest possible velocities are required in order to improve the chance of a hit with both kinetic energy (KE) and chemical energy (CE) projectiles. The performance against armour of both HEAT and HEP projectiles is independent of range. The performance of HEP ammunition is not degraded by the angle of attack while the performance of HEAT ammunition follows the cosine law. The probability of a hit is degraded with range for all KE and CE projectiles.

20. A more detailed description of the design and functioning of anti-tank projectiles is covered in Chapter 9.

SECTION 3

THE EFFECTIVENESS OF FIRE

GENERAL

1. No definite rules can be given for the ammunition expenditure required for any given task. Such factors as the details of the tactical plan, the morale of the enemy and our own troops and the logistic situation must be considered in addition to the purely technical aspect of the problem.

EFFECTIVENESS OF GUN AND MORTAR FIRE

2. Gun and mortar fire produces lethal and morale effects. While these effects are obviously connected, their relative importance varies with circumstances, for example:

a. **Troops Slit Trenches**. Gun and mortar fire has a reduced lethal effect against troops in slit trenches. Airbursts are recommended against this type of target.

b. **Troops in the Open**. The lethal efficiency of gun and mortar fire is at an optimum when firing against standing troops on flat terrain with no shielding. Lethality decreases significantly when troops are prone or in a rolling area.

3. For gunfire to have any effect, a sufficient proportion of the rounds must strike the target area. There will be some rounds that will fall outside the target area and an allowance must be made for this in assessing the weight of fire required to produce the necessary effect.

4. In order for the infantry to reach the objective as soon as possible after the fire has lifted, the safe distance from the HE burst must be as small as possible. One method of ensuring a small safe distance is to use a small number of guns and a small projectile, but this conflicts with the methods of artificially increasing the beaten zone of the gun in an effort to overcome the inherent errors of predicted fire.

5. From the results of analysis of past operations and of experimental firings, it is possible to arrive at a guide to the number of hits required to give a certain effect, eg immediate neutralization, lasting neutralization, collapse of morale, lethal effect, destruction of materiel, etc.

6. The law of distribution implies a need for time on target (TOT) engagements whenever possible, for example:

a. If 80 rounds fall on 100 infantry in a 100 metre square, the following casualty rate could be expected -

(1) from the first 40 rounds 50 casualties; and

(2) from the second 40 rounds 25 casualties and so on.

b. In fact the number of casualties from the second 40 rounds would be much less because the remaining infantry would "go to ground" after the initial salvo. On the other hand, if the 80 rounds fell all at the same time, 100 casualties might be expected.

7. An intelligent use of airburst instead of ground burst is essential. The effect of airburst against troops in slit trenches is well known. The effects of low airburst with a large angle of impact (mortar bomb or high angle fire) against troops in the open is also appreciable.

8. The overall problem is considered in this section under two main headings:

a. the number of hits required in the target area in order to achieve a given degree of neutralization (Immediate Neutralization); and

b. the number of rounds that is necessary to fire in order to achieve a given number of hits (Lasting Neutralization).

9. **Immediate Neutralization**. Figure 4-3-1 gives a guide to the number of rounds required to fall within each 50 m^2 portion of the target area in order to secure a reasonable degree of immediate neutralization.

Nature of Target	Equipment	Numbers of Rounds to Fall 50 m^2			Remarks
		Minimum	Maximum	Average	
Troops in open	105 mm Howitzer 155 mm Howitzer	3 2	7 4	5 3	HE airburst is more effective.
Entrenched troops	105 mm Howitzer 155 mm Howitzer	15 7	35 19	25 13	

Figure 4-3-1 Number of Rounds Required for Immediate Neutralization

10. **Lasting Neutralization**. Figure 4-3-2 may be used as a guide to the number of 105 mm Howitzer rounds per hour that must fall on troops in the open to achieve lasting neutralization. The lasting effect of immediate neutralization cannot be assessed because it depends on the nature of the target, the morale of the enemy troops, etc. The general rule is that, unless immediate advantage is taken of the effect of this type of artillery support, the ammunition expended may be largely wasted.

Size of target	Equipment	Number of Rounds per Hour		
		Minimum	Maximum	Average
50 × 10 metres 1 000 × 1 000 metres	105 mm Howitzer (ground bursts)	2 800	8 3 200	5 2 000

Figure 4-3-2 Number of Rounds Required for Lasting Neutralization

11. **Demoralization**. A collapse of morale may be achieved against troops in open trenches, by using, as a guide, the number of 105 mm Howitzer rounds shown in Figure 4-3-3. For operations lasting between 15 minutes and 4 hours, the number of rounds may be found by interpolation. Other factors that must be considered when using this table are the condition and training of the troops, the type of operation, the degree of exposure of troops to previous fire, etc.

Equipment	Size of Target	Rate of Fire	Duration	Total Number of Rounds
105 mm Howitzer (ground bursts)	50 × 50 metres	10 rounds per hour 100 rounds per hour	4 hours 15 mins	40 25
	1 000 × 1 000 metres	4 000 rounds per hour 40 000 rounds per hour	4 hours 15 mins	16 000 10 000

Figure 4-3-3 Number of Rounds for Demoralization

EQUIVALENT FOR OTHER GUNS

12. The Figures given in Figures 4-3-2 and 4-3-3 are for the 105 mm Howitzer. The number of rounds required for other guns may be found by dividing by the following factor:

a. 5.5 in. (80 lb projectile) 2.6

b. 155 mm Howitzer 2.8

c. 155 mm Gun 2.8

d. 7.2 in. Howitzer 4.0

e. 4.2 in. Mortar 1.4

f. 8 in. Gun 3.4

g. 240 mm Gun 5.5

SECTION 4

CRATER ANALYSIS

GENERAL

1. It is often possible to examine a shell crater and determine valuable information such as:

   a. the bearing to the hostile fire unit to within about 40 mils (2 degrees);

   b. the angles of impact that can be used to produce a choice of ranges depending on the number of charges in use by the hostile fire unit;

   c. the calibre of weapon responsible (though frequently not the exact type of gun or mortar, due to considerable interchangeability of ammunition between weapons of the same calibre); and

   d. in conjunction with other information available to counter bombardment (CB) staff, the location of the hostile fire unit.

EXAMINATION OF SHALL CRATERS

2. The pattern of a typical shell crater on dry level ground is shown in Figure 4-4-1.

3. It can be seen that the most distinctive feature consists of two **wings** thrown out to either side of the crater and angling away from the direction of fire. These **wings** are marks on the ground (or in the grass and undergrowth) made by shell splinters, the majority of which are thrown out in these two directions. They may also be strewn with earth carried out of the crater by the splinters.

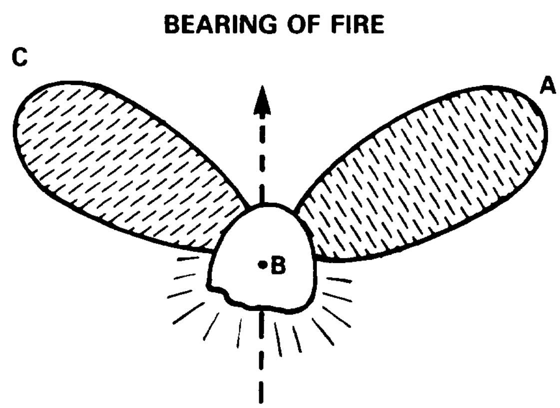


Figure 4-4-1 Typical Shell Crater

4. A peg is placed at the tip of each **wing** and in the centre of the crater. These are pegs A, B and C in Figure 4-4-1. Peg B is the centre of the crater. Bearings are then taken with a prismatic compass of known compass variation from B to A and B to C and the following calculations are carried out:

a. magnetic bearing B to A = 710 mils,

b. magnetic bearing B to C = 5 330 mils,

c. angle ABC = 1 780 mils,

d. bearing of fire = 5 330 + 1 780 = 6 220 mils,

e. magnetic bearing to fire unit = 6 200 - 3 200 = 3 020 mils, and

f. grid bearing to fire unit = 3 020 ± compass variation.

5. If a group of craters is known to have been produced by the same gun, a mean bearing can be produced by examining several craters. If a number of rounds is known to have been fired at the same bearing and elevation, then the dispersion pattern can be examined by drawing a straight line that symmetrically bisects the craters in a longitudinal direction. From this the bearing of fire can be determined.

6. In some cases a crater will have a pronounced oval shape, its greatest axis being in the direction of fire. In such cases its bearing can be measured directly with a compass.

EXAMINING MORTAR BOMB CRATERS

7. Weapons such as mortar bombs that impact at a steep angle will produce oval shaped craters. The long axis will indicate the bearing of fire.

8. An angle of fall may often be obtained from a mortar crater due to the fact that fuze and fins follow each other into the earth at the front end of the crater, forming a tunnel of which the axis is identical with the trajectory at the moment of impact. This is shown in Figure 4-4-2 where the following points should be noted:

a. The edge farthest from the mortar has turf undercut, while the nearer edge is short of growth and very much serrated by splinter grooves.

b. When fresh, the crater is covered with loose earth which, when cleared, discloses the firm inner crater A. This shows signs of burning.

c. The fins and fuze are buried in tunnel B, often at a considerable depth. The tunnel is full of soft earth but its sides can easily be felt when removing the soft earth by hand.

9. To find the angle of fall, a peg is driven into the centre of the firm crater A until the top is about 1 inch above the surrounding ground. The top of the peg represents the point of detonation. The entrance to tunnel B is carefully cleared of loose earth and a stick is inserted, as shown in Figure 4-4-3. The angle of fall is measured with a protractor and plumb bob. The bearing of the stick will also give an indication of the direction of the mortar.

10. It should be noted that the bearing of fire at the moment of impact is not exactly the same as the bearing of fire at the muzzle, due to the effects of drift (in the case of rifled equipment) and wind.

SHELL IDENTIFICATION

11. Generally speaking, the best way to identify the calibre and type of shell is by examination and measurement of the rotating band groove or grooves. These contain a series of serrations, or teeth, which assist in preventing slippage of the rotating band. A knowledge of the various types and sizes used by each country will help to identify the country of manufacture and type of shell.

12. Fuzes are generally not reliable for identifying the type and calibre of shell as they generally have many varied uses. However, they might have some distinctive feature that would indicate the country of manufacture. Invariably, mortar bomb fins survive the explosion and can easily be measured to obtain the calibre of the bomb.

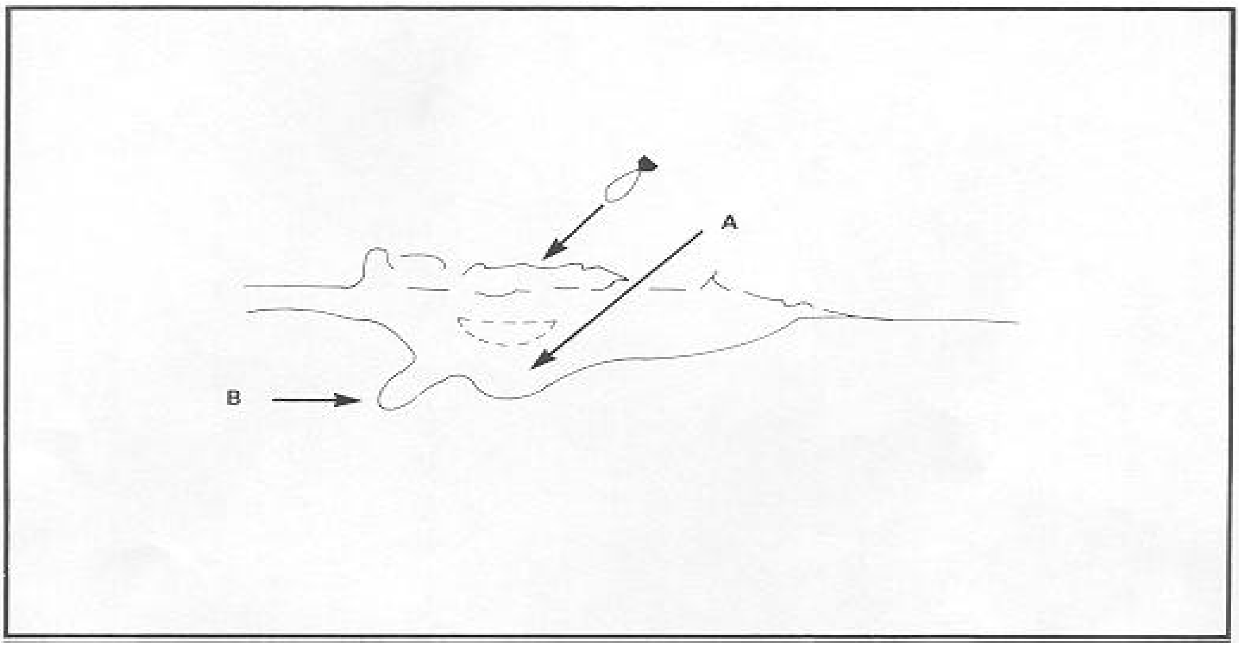


Figure 4-4-2 A Typical Mortar Crater

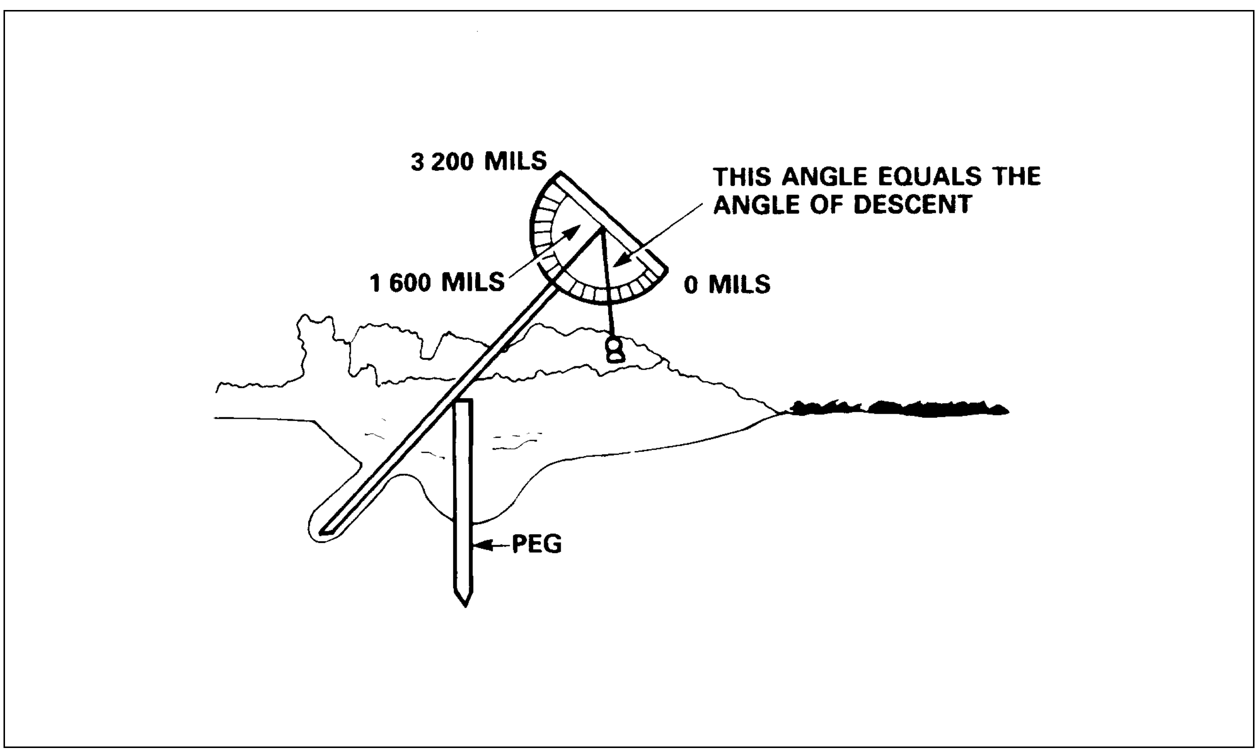


Figure 4-4-3 Mortar Crater Analysis

CHAPTER 5

BALLISTIC METEOROLOGY

SECTION 1

INTRODUCTION

GENERAL

1. In Chapter 3, it was seen that the flight of a projectile depended on the condition of the air through which it passed. Accurate knowledge of the state of the atmosphere and application of appropriate corrections to gun data enables the gunner to:

   a. adjust more quickly with fewer rounds in observed fire; and

   b. apply the MPI more closely to the target in unobserved fire.

ATMOSPHERIC PROPERTIES (See Chapter 3, Section 2)

2. The characteristics of the atmosphere that affect the trajectory are:

   a. wind direction and speed,

   b. density of the air, and

   c. elasticity.

3. **Wind Direction and Speed**. A head wind will impede the passage of a projectile through the air and a tail wind will assist it. A cross-wind blowing from left to right will cause the projectile to deviate to the right and vice versa.

4. **Density of the Air**. Dense air will offer greater resistance to the projectile flight.

5. **Elasticity**. Elasticity is a measure of the compressibility of the air and is dependent on air temperature. Elasticity is intimately connected with the speed of sound, which has an effect on the total drag force on the projectile. Temperature can influence the behaviour of the projectile in two ways:

   a. A higher temperature reduces density.

   b. Elasticity of the air is dependent on temperatures.

6. Density is compensated for in the content of the meteorology message. Elasticity is compensated for by the FT values for temperature variations.

SECTION 2

THE DETERMINATION OF BALLISTIC MET DATA

DETERMINATION OF MET DATA

1. Measurement of upper air conditions is normally made by a balloon-borne radiosonde. As it ascends, it measures:

   a. pressure,

   b. temperature, and

   c. relative humidity.

2. These values are transmitted to a ground receiver. The radiosonde, tracked during ascent by a radio direction finding antenna, provides data from which can be determined:

   a. wind direction, and

   b. wind speed at various levels in the atmosphere.

3. From this data the ballistic meteorologist determines the values of wind, density and temperature for the required zones. The values of temperature and density are compared with the standard atmosphere and expressed as a percentage of the standard.

4. This data is circulated in the form of a met message, which gives the gunner the data for the trajectory to be fired. The line numbers and associated heights of the top of zones are shown in Figure 5-1-1.

HEIGHT	LINE NUMBERS		HEIGHT	LINE NUMBERS	
Metres	NATO	Computer	Metres	NATO	Computer
Surface	0	0	7 000	10	13
200	1	1	8 000		14
500	2	2	9 000	11	15
1 000	3	3	10 000		16
1 500	4	4	11 000	12	17
2 000	5	5	12 000		18
2 500	6	6	13 000	13	19
3 000		7	14 000		20
3 500	7	8	15 000	14	21
4 000		9	16 000		22
4 500	8	10	17 000	15	23
5 000		11	18 000		24
6 000	9	12	19 000		25
			20 000		26

Figure 5-1-1 Structure of Atmospheric Zones

5. The line number to be used is the one at the height closest to the maximum ordinate of the trajectory to be fired. The line number is determined from Table B of the FTs, using range and difference of the height of the gun to the height of the target as arguments for entry. Table A can also be used with the argument for entry being QE. The data given in the line is the weighted average of wind direction, wind speed, air temperature and air density for all zones from the surface.

6. Figure 5-1-2 illustrates two trajectories, one that just reaches line five height and one that reaches line three height. From inspection, it can be seen that the lower trajectory spends a greater proportion of time in the region of zone two than the higher trajectory. When the ballistic meteorologist prepares the message, the data from each zone is weighed in proportion to the time the trajectory is affected by the met conditions in that zone. To produce line three and line five, the ballistic meteorologist would weigh the data as shown in Figure 5-1-3.

7. The weighted values obtained by the previous mentioned procedure are known as the ballistic wind, ballistic density and ballistic temperature. They are assumed constant for the whole of the trajectory thus avoiding the necessity of making a separate calculation during prediction for each zone of met encountered. For example, air density might be determined by the meteorologist in each zone to be the following percentages:

a. Zone one is 108,

b. Zone two is 106,

c. Zone three is 110,

d. Zone four is 109, and

e. Zone five is 107.

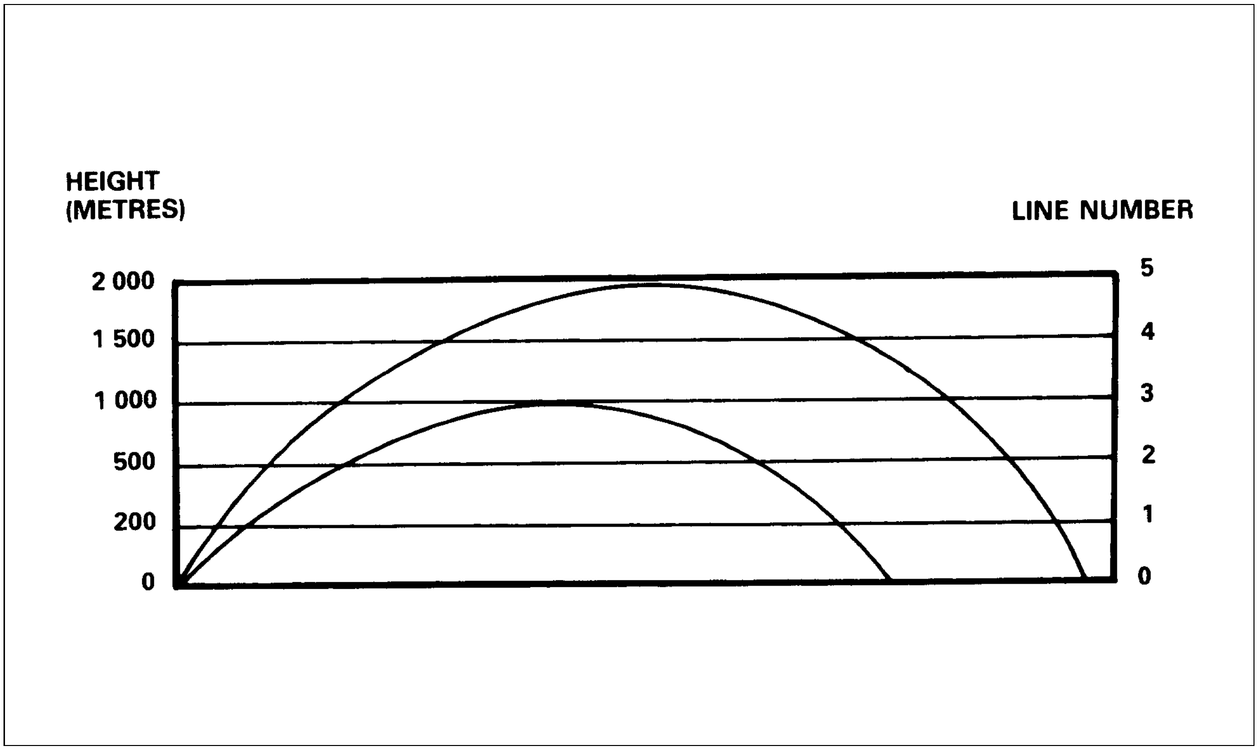


Figure 5-1-2 Relationship of Trajectory to Line Number

Data Measured At	Data Required for					
	Line Three			Line Five		
	Wind Speed	Density	Temp	Wind Speed	Density	Temp
Zone One	9%	22%	13%	4%	11%	5%
Zone Two	19%	31%	20%	8%	17%	10%
Zone Three	72%	47%	67%	15%	25%	20%
Zone Four	—	—	—	20%	22%	21%
Zone Five	—	—	—	53%	25%	44%
Total	100%	100%	100%	100%	100%	100%

NOTE

Similar, wind vectors for each zone (bearing and speed) are averaged through the use of charts and overlays to produce a weighted wind direction.

Figure 5-1-3 Hypothetical Weighting Factors

8. To predict for a trajectory that has a vertex at the top of zone five, a height of 2 000 metres, and using the weighting factors from Figure 5-1-3 the meteorologist would compute a ballistic air density as follows:

108 x 11% =	11.88
106 x 17% =	18.02
110 x 25% =	27.50
109 x 22% =	23.98
110 x 25% =	27.50
	108.88

9. The meteorologist would send the ballistic message to the gunner showing a ballistic air density at line five of 108.9. In the prediction process, this value is assumed to be constant throughout the whole trajectory.

10. The actual values of wind velocity used are adjusted by zone and weighted. The standard ballistic atmosphere assumes no wind, therefore, the wind condition encountered by the projectile will have a total effect. The gunner can deduce whether the wind assists, hinders or deflects the projectile by comparing the bearing of fire with the wind bearing. The process can be summarized as the:

a. determination of wind, air density and air temperatures at each line number;

b. conversion of temperature and density values into a percentage of the standard atmosphere; and

c. weighting of these values (depending on the line number to be fired) to obtain a ballistic value.

11. The ballistic values are defined as:

a. **Ballistic Wind**. Ballistic wind is a wind of assumed constant speed and direction that would have the same total effect on a projectile during its flight as the varying winds actually encountered.

b. **Ballistic Density**. Ballistic density is an assumed constant density that would have the same total effect on a projectile during its flight as the varying densities encountered.

c. **Ballistic Temperature**. Ballistic temperature is that which produces a temperature structure that has the same effect on a projectile as the actual temperature structure encountered. The ballistic temperature circulated in the met message has been corrected for humidity.

12. A detailed explanation of a message is given in the introductory portion of the FTs. Further information may be obtained from the applicable STANAGs and QSTAGs.

COMPUTER MET MESSAGES

13. The increased use of computers in the field artillery has automated the weighting process. The message is fed into the computer by tape rather than by computation or graphs. Basic data of wind temperature and density values derived from the atmosphere sounding are converted to units acceptable to the computer. These values are typed either directly into the computer or via a telecommunications network to which the computer is connected.

SECTION 3

VALIDITY OF MET

GENERAL

1. The validity of the met message is extremely important to artillery commanders and staff officers. There are two broad factors that affect the validity of met message data:

   a. the accuracy of the weather measuring system; and

   b. the variability of the atmosphere.

2. Met sections are capable of obtaining very accurate measurements of the atmosphere through which the radiosonde travels, however, these measurements pertain only to one location and one instant in time. The values of wind, air density and air temperature continuously undergo complex and inconsistent variations in both time and space (distance). On occasion, these weather variables may change abruptly over a very short distance or over a brief interval of time. On other occasions and in other geographical areas, the change may be extremely gradual with respect to both distance and time. The trajectory of the artillery projectile will always be some distance from where the weather elements were actually measured. Also, some time will elapse between the measurement of atmospheric conditions and the firing of the weapon. This lapse of time is due to the time required for completion of the radiosonde flight, computation and transmission of the message and the determination of appropriate met corrections to be applied to the weapon. Thus, the validity question arises.

SPACE VALIDITY

3. In general, the validity of a message decreases as the distance increases from the met sounding site. Local topography has a pronounced effect on the distance to which met data may be reasonably extended. For instance, mountainous terrain particularly influences the wind, causing large variations over short distances. This effect on wind frequently extends to heights much greater than the tops of the mountains. It would be impossible to compute a valid distance for every combination of weather and terrain which might exist, however, the following general rules may be used as a guide:

   a. Over fairly level terrain such as the Prairies, a message is considered valid up to 30 kilometres.

   b. In mountainous terrain, the valid distance should be reduced by approximately 50 per cent.

4. The proximity of large bodies of water will have an effect on both the time and space validity of met messages due to the existence of land and sea breezes and the effect of humidity on density (increased humidity decreases air density). Therefore, the space validity of a message should be reduced to 20 kilometres when operating along coast-lines.

TIME VALIDITY

5. Because of the changing nature of weather data, the validity of a message will decrease with the passage of time. With the present equipment, it is extremely difficult for the met section to provide ballistic met messages more frequently than every 2 hours. Experience has shown that met messages provided more often than once every 2 hours gives only marginal improvement to artillery fire.

6. There are no specific rules by which the valid time may be specified. The valid time is a function of the characteristics of the atmosphere. When the weather pattern is variable, the valid time is also variable. If the passage of a weather front is forecast for the area, the valid time of the message should not extend beyond the time forecast for the arrival of the front in the area. When the weather pattern is stable, ie during the middle of the day or night, the valid time may be extended to a maximum of 4 hours.

CRITERION FOR SELECTION OF MET DATA

7. Over the past few years there has been a number of studies on the validity of ballistic density obtained from various sources. From these studies, it was determined that the order of accuracy of the various sources is as follows:

a. current met message from local observation station;

b. current met message from any station within 30 kilometres of the local station;

c. current met message from any station or a 2-hour-old message from a station within a 30 kilometre radius; and

d. current met message from a station 80 to 112 kilometres distant, or a 2-hour-old message 30 to 48 kilometres from a station, or a 4-hour-old message from the local station;

CHAPTER 6

VARIATIONS AND CORRECTIONS

SECTION 1

NATURE OF VARIATIONS

GENERAL

1. Standard trajectories give the path of a projectile under certain conditions, which for the most part will represent an average of all actual conditions that may occur. The calculation of the standard trajectory is the primary and fundamental problem of external ballistics.

2. The second stage of the ballistic problem involves considering in what respects and to what extent the actual conditions can differ from the standard conditions and in particular, the effects of changes in these conditions. The variables with which the gunner is most concerned are range to level point, TOF, bearing and vertex height.

3. The effects that are produced by small changes in the initial conditions (MV, C_o and A/D) are called **first order variations**. It must be clearly understood that changes in the initial conditions must be small. The numerical limits usually fixed for first order variations are that a change in:

a. MV must not exceed 25 m/s;

b. C_O must not exceed 10 per cent; and

c. A/D must not exceed 30 mils.

4. Within these limits the variations may be considered to have additive and proportional properties.

DEFINITION

5. A variation is an effect on range, bearing, vertex height or TOF of a projectile caused by a change in some standard condition. Some of these variations can be measured and corrections can be made to compensate for them.

STANDARD CONDITIONS

6. The standard atmospheric conditions for which trajectories and FTs are calculated are those of the International Civil Aviation Organization (ICAO) standard atmosphere. They are:

a. A/S - ZERO;

b. propellant temperature - 21 degrees C (70 degrees F);

c. ballistic wind - ZERO;

d. MV - as laid down for the equipment and charge used;

e. air temperature at mean sea level (MSL) - 15 degrees C (59 degrees F);

f. air density at MSL - 1 225 g/m^3;

g. projectile weight - as stated in the applicable FTs; and

h. barometric pressure at MSL - 101.32 kPa (1 013.25 mb).

VARIATIONS IN RANGE, TIME OF FLIGHT AND VERTEX

7. **Change in Angle of Projection**. As A/P increases from zero the range increases, reaching a maximum of about 800 mils. At A/P greater than 800 mils (high angle) range decreases, but TOF and vertex continue to increase up to 1 600 mils. Figures 6-1-1 and 6-1-2 show variations in range and vertex height for low and high angles respectively.

8. **Rigidity of the Trajectory**. In order to neutralize a certain target at low angle fire with an A/S of zero, a certain A/P is required. In order to neutralize another target vertically above (or below) the first target it is necessary to increase (or decrease) the A/P by the amount of A/S to the second target, provided the A/S is small (less than the equivalent of 20 metres vertical interval). Thus, the A/P in the two cases is the same. This principle is called the rigidity of the trajectory, ie the trajectory can be swung rigidly up or down without appreciably altering its form. This principal is illustrated in Figure 6-1-3.

9. **Non-Rigidity of the Trajectory (Low Angle)**. When large angles of sight are introduced (greater than the equivalent of 20 metres vertical interval) significant error is encountered because the form of the trajectory changes and becomes non-rigid, ie the trajectory cannot be swung rigidly up or down without its form altering.

10. In Figure 6-1-4, if the same A/P required to hit a target T1 at zero A/S was applied to Target T2 at a positive A/S, the projectile would range short of T2 and pass through T3. There are three reasons for the trajectory not passing through T2:

a. **Slant Range**. The distance along the LOS from gun to T2 is greater than the horizontal range from gun to T1.

b. **Horizontal Component of Velocity**. In the higher trajectory, the horizontal component of velocity is less than in the lower one, therefore, the range is decreased.

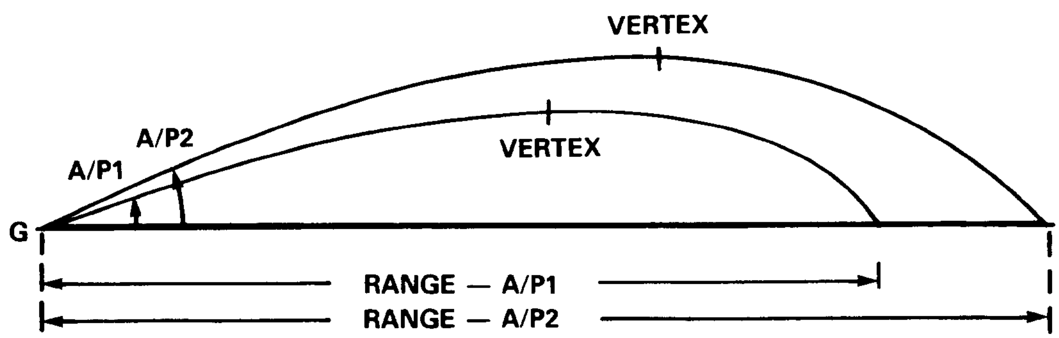


Figure 6-1-1 Variations Due to Change in A/P (Low Angle) Elevation View)

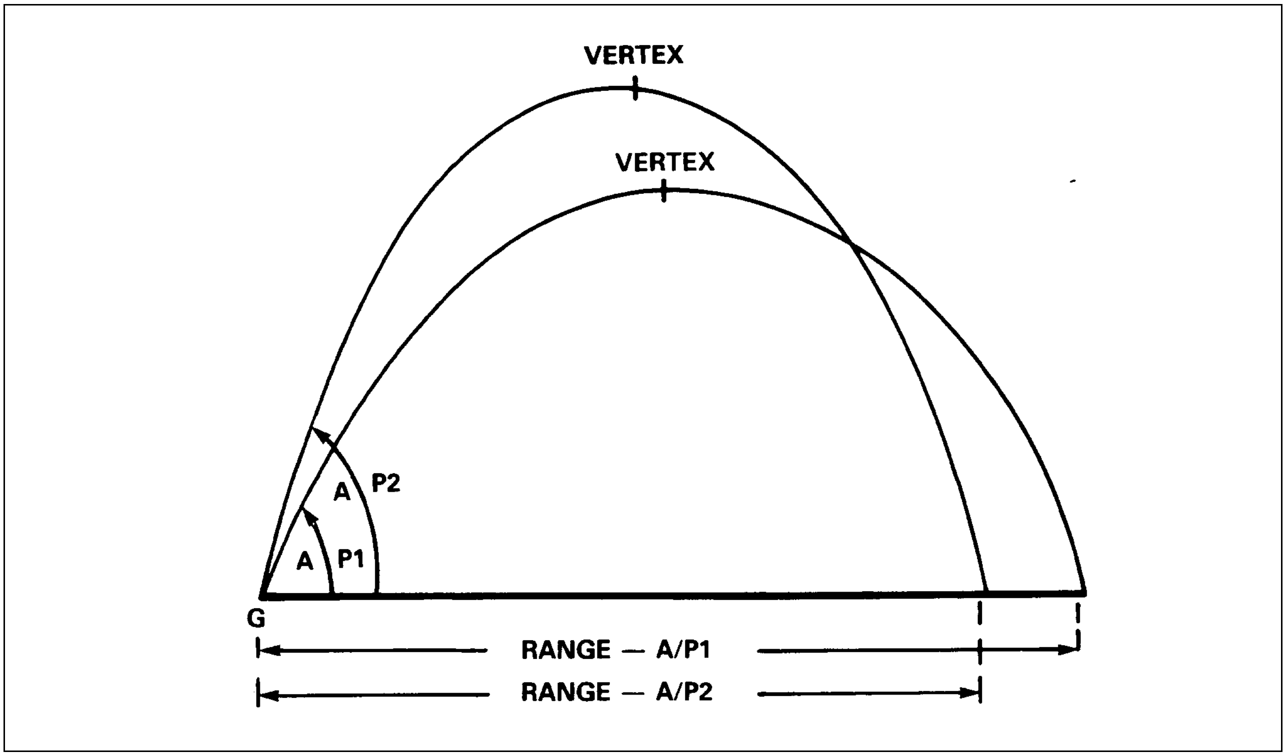


Figure 6-1-2 Variations Due to Change in A/P (High Angle) (Elevation View)

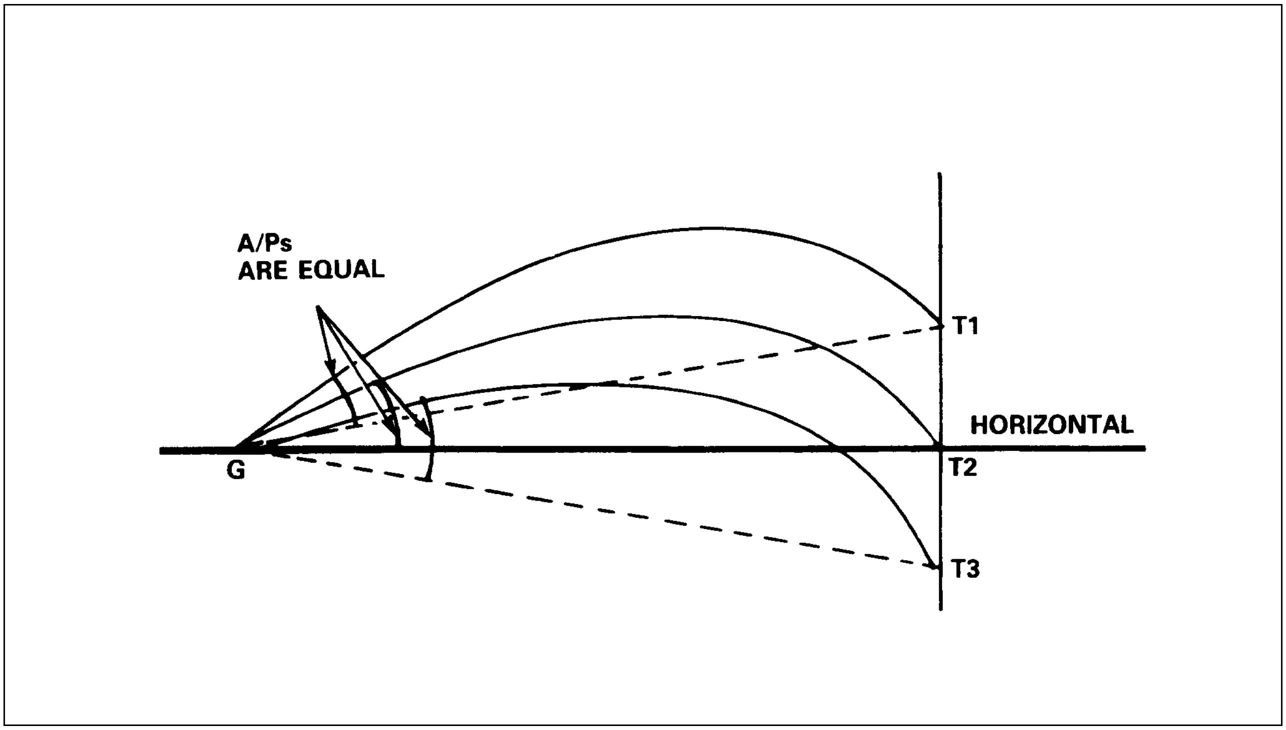


Figure 6-1-3 Rigidity of the Trajectory (Low Angle) (Elevation View)

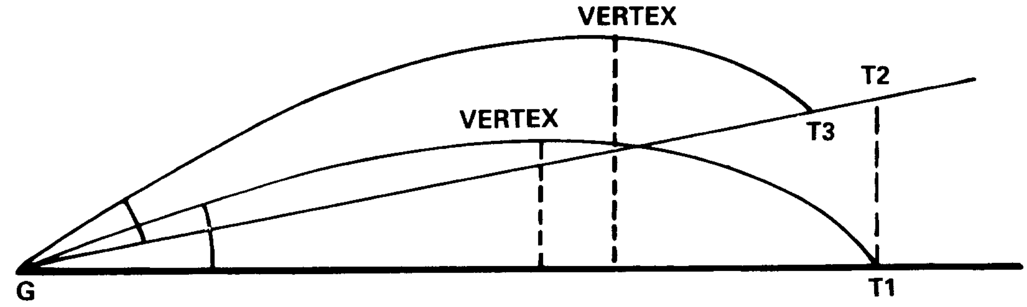


Figure 6-1-4 Non-rigidity of the Trajectory (Low Angle) (Elevation View)

c. **Density**. The drag of a given projectile is proportional to the density of the air through which it passes. In the higher trajectory, the projectile passes through air of lower density than in the lower trajectory, therefore, its range is increased.

11. Generally, the effects of slant range and the horizontal component of velocity are together greater than the effect of density, ie the projectile range is short for a positive A/S and over for a negative A/S.

12. In high angle fire, an increase in the A/P decreases range and a decrease in the A/P increases range, therefore, for a positive A/S, the A/P must be reduced (see paragraph 7). In high angle fire, the correction to elevation required because of the difference in altitude between the gun and the target is applied as complementary angle of sight when using the graphical site table and complementary range or **complementary angle of sight** when using tubular FTs. It can be seen from Figure 6-1-5 that if the low angle convention of adding a positive A/S to an A/E to obtain QE were applied at high angle fire, the trajectory would be pulled short of the target.

13. **Change in Muzzle Velocity**. As MV increases for a given A/P and C_o, the range, TOF and maximum ordinate all increase. This statement is true for both low and high angle fire (see Figures 6-1-7 and 6-1-8).

14. **Change in Ballistic Coefficient**. As the C_o increases for a given A/P and MV, the range, TOF and maximum ordinate all increase for both low and high angle fire. Figures 6-1-7 and 6-1-8 apply with MV replaced by C_o. It must be noted that an increase in the value of the C_o can be caused, for a given shaped projectile, by any of the following changes:

a. increase in weight of projectile;

b. increase in ballistic air temperature; and

c. decrease in ballistic density (or barometric pressure).

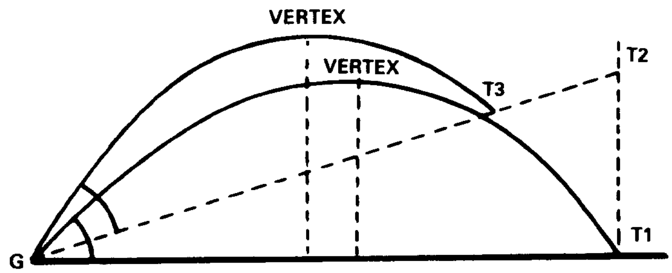


Figure 6-1-5 Non-rigidity of the Trajectory (High Angle)

Component of Non-rigidity	Variations due to positive A/S on range to level point in terms of range	Corrections for Positive A/S		
		Range	Low Angle	High Angle
Slant range.	Short (−)	Add (+)	Elevation (+)	Depression (−)
Horizontal component of velocity.	Short (−)	Add (+)	Elevation (+)	Depression (−)
Density.	Over (+)	Drop (−)	Depression (−)	Elevation (+)
General overall effect. (See Note)	Short (−)	Add (+)	Elevation (+)	Depression (−)

NOTE

At low angle with high velocity guns, the density effect may outweigh the slant range and horizontal component of velocity effects, with the result that the non-rigidity corrections for a positive A/S may be negative.

Figure 6-1-6 Effects of the Components of Non-rigidity

15. In the case of subparagraph 14a, two opposing factors affect the trajectory of a projectile of non-standard weight. A heavier projectile is more efficient in overcoming air resistance, however, because it is more difficult to push through the bore. As a result of this the MV is normally lower. An increase in projectile efficiency increases range, but a decrease in MV decreases range.

16. In FTs, corrections for these two opposing factors are combined into a single correction. The change in MV predominates at the shorter TOF, therefore, for a heavier than standard projectile, the correction is plus at the shorter TOF and minus at the longer TOF. This change can be observed in the 105 mm FTs, charge seven, at a range of 8 300 metres.

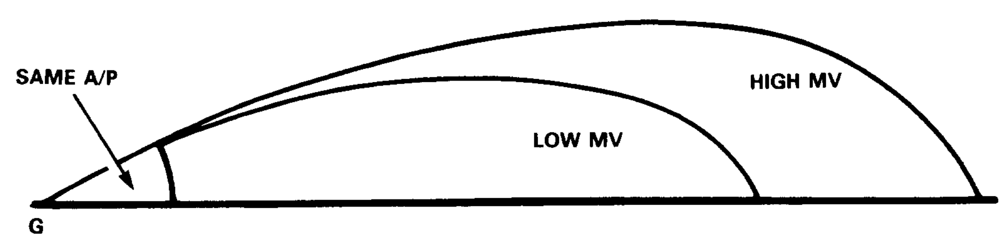


Figure 6-1-7 Variation Due to Change in Muzzle Velocity (Low Angle) (Elevation View)

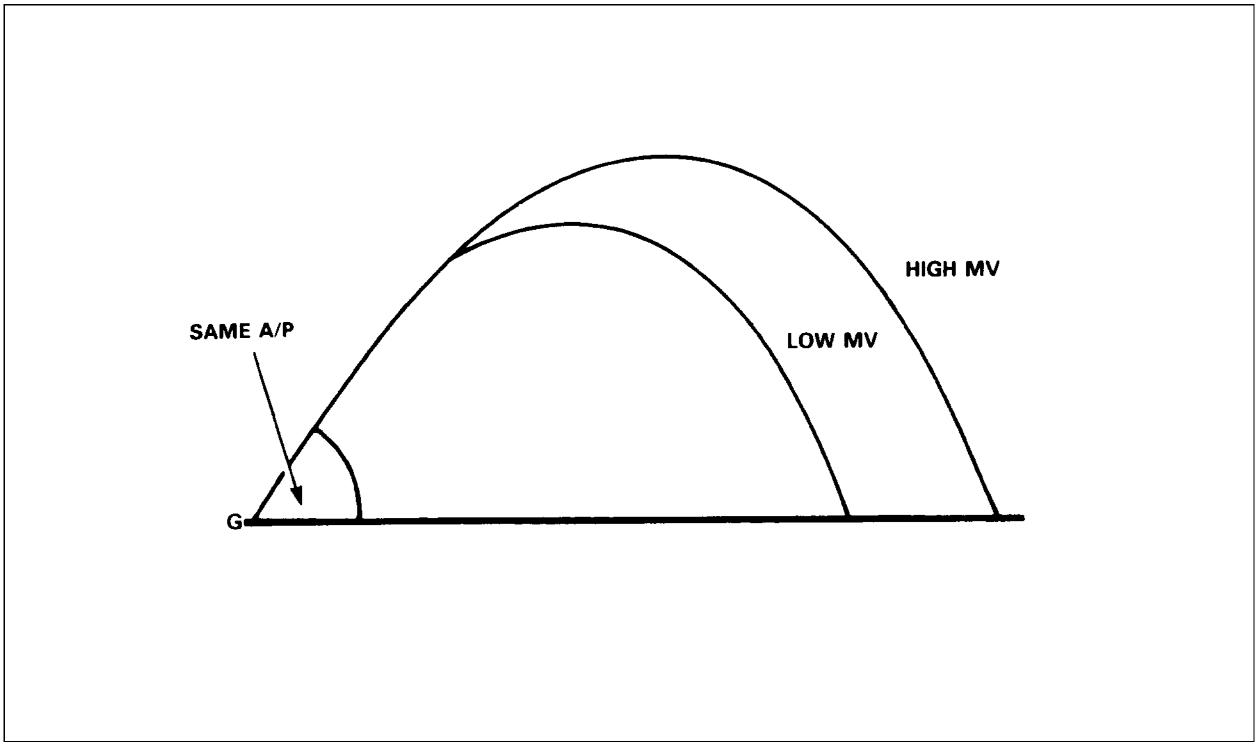


Figure 6-1-8   Variation Due to Change in Muzzle Velocity (High Angle) (Elevation View)

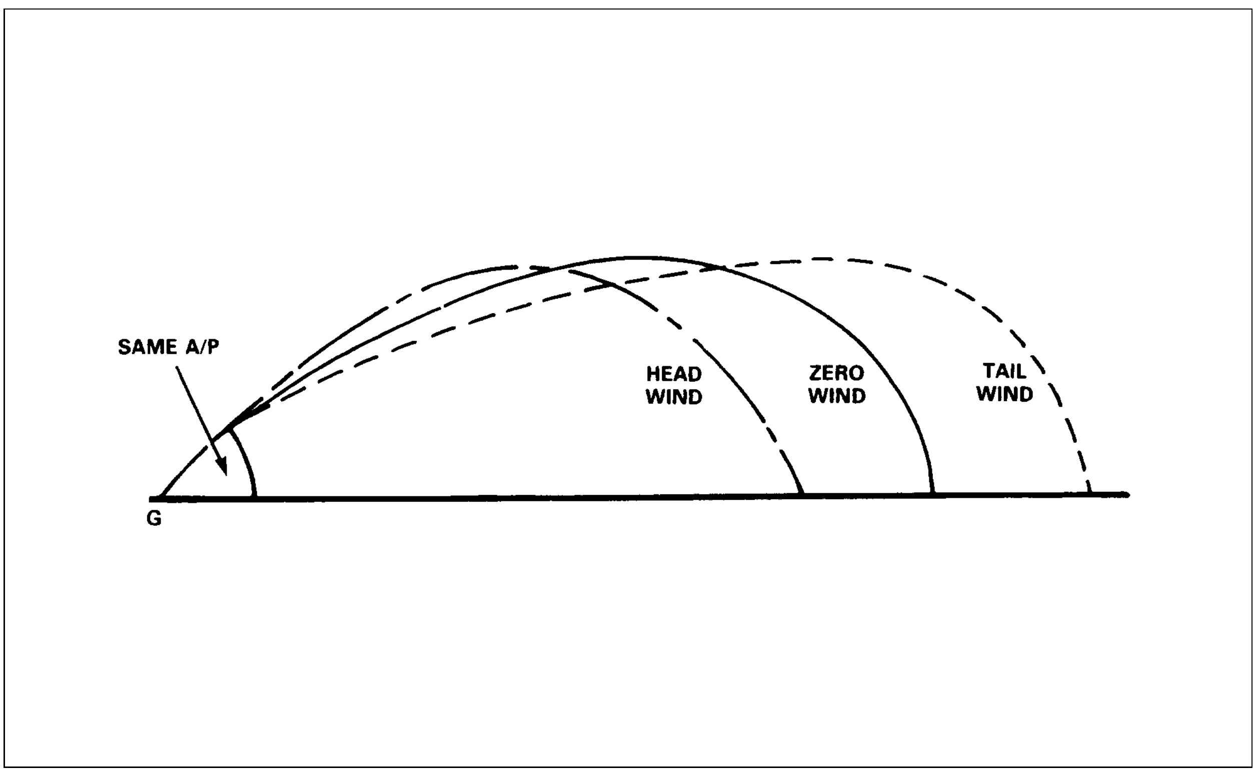


Figure 6-1-9   Variation Due to Change in Wind (Low Angle) (Elevation View)

17. **Wind**. A projectile ranges shorter when under the influence of a head wind than when no wind is present. The stronger the head wind the shorter the range will be; conversely, a tail wind increases range. TOF and vertex height are affected very little. A tail wind only slightly increases TOF and vertex height (see Figures 6-1-9 and 6-1-10).

VARIATIONS IN BEARING

18. **Change in A/P**. Angular deviation due to drift increases when A/P increases (for low and high angle fire).

19. **Change in A/S**. For a given A/P drift is practically independent of A/S. The two trajectories shown in Figure 6-1-4 have practically the same drift at points T1 and T3. Since drift is a function of TOF, and since an alteration in A/S results in a small variation in TOF, there will be a small corresponding variation in drift.

20. **Different Projectiles**. Projectiles of different shapes may not drift the same amount when fired under identical conditions.

21. **Change in Wind**. A cross-wind blowing from the right of the bearing of fire causes a variation to the left; the stronger the cross-wind the greater the variation. A cross-wind blowing from the left causes a variation to the right.

STANDARD AND NON-STANDARD CONDITIONS

22. Certain atmospheric, positive and material conditions are accepted as standard. These conditions are normally listed in the FTs. The conditions for standard are determined as a result of experimental firings, with the exception of charge temperature which is arbitrarily selected.

23. Any conditions other than those listed are called **non-standard** and these variations from standard, if not corrected in computing firing data, will cause the projectile to impact or burst at some point other than that desired.

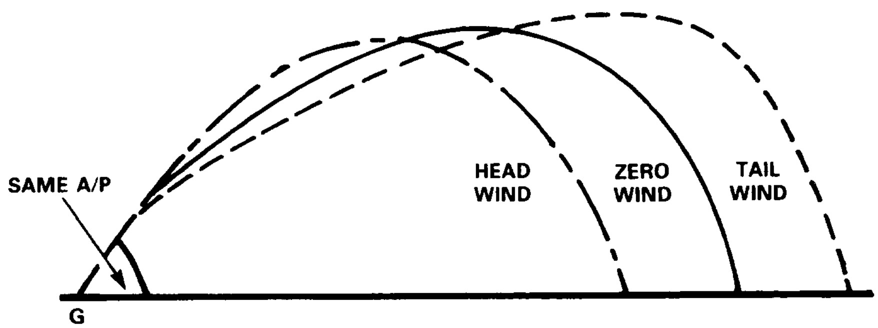


Figure 6-1-10 Variation Due to Change in Wind (High Angle) (Elevation View)

24. **Non-Linearity of Variations**. If for example, under certain conditions a decrease in a standard condition of 5 per cent gives a variation in range of + 70 metres, it would probably be true to say that a decrease of 10 per cent would give a variation of twice as much, ie + 140 metres. In this situation we would say that the variation was linear. This is seldom the case with large variations as they are not linear. This phenomenon of non-linearity occurs with most variations when they are large.

25. **Combination of Variations**. When two or more conditions are non-standard, it is usually assumed that the total variation is equal to the of the separate variations.

CROSS-TERM EFFECTS

26. The method of combining variations is based on the assumption that all other variations are standard and have no effect on the variation being considered. When variations are small, this assumption does not introduce errors of any appreciable magnitude, but when variations are larger, errors due to the cross-term effects of combination of variations arise. The effect of one variation on the effect of another variation is known as the interacting, or cross-term effect.

SECTION 2

CORRECTIONS

DEFINITION

1. A correction is the alteration required to counteract a variation. It is not numerically equal to the variation with the sign reversed.

CORRECTIONS TO ELEVATION OR RANGE

2. Elevation corrections are often applied as range corrections. These range corrections, applied to compensate for the prevailing non-standard conditions, will cause the projectile to hit the target.

DESCRIPTION OF RANGE CORRECTIONS

3. Range corrections are required to counteract the effect of non-standard conditions that will cause the projectile to range plus or minus of the required point. They consist of corrections for:

   a. range correction of the moment (C of M),

   b. non-standard projectile,

   c. non-rigidity of the trajectory, and

   d. MV.

4. **Range Correction of the Moment**. This consists of corrections for:

   a. range wind component,

   b. ballistic air temperature,

   c. ballistic air density,

   d. rotation of the earth, and

   e. barometric pressure with some equipments.

5. **Non-Standard Projectile Weight**. This consists of corrections for non-standard weights (type, fuze) of the projectile.

6. **Non-Rigidity of the Trajectory**. This consists of corrections for non-rigidity of the trajectory.

7. **MV Correction**. This consists of corrections for:

   a. non-standard MV, and

   b. charge temperature.

SECTION 3

DISTINCTION BETWEEN RANGE VARIATIONS AND RANGE CORRECTIONS

DIFFERENCE IN SIGN

1. If the range achieved is decreased because a certain condition is non-standard, the range variation is negative. Accordingly, the range correction Is positive or ADD and the elevation must be increased in low angle fire. Similarly a positive variation requires a DROP correction. The reverse is true in high angle fire.

DIFFERENCE IN SIZE

2. At a given range, the correction to counteract a variation is not numerically equal to that variation with its sign reversed. The relationship between variations and corrections at a given range can be expressed as:

$$\text{Corrections} = \frac{\text{Standard Range x Variations}}{\text{Standard Range + Variations}}$$

Standard Range is the range opposite a given elevation in the FTS.

Example:

$$\text{Correction} = \frac{\text{10 000 metres}}{\text{10 000 metres - 500 metres}} \text{ x 500 metres}$$

Correction = 1.05 x 500 metres = +525 metres.

3. Where the variation was - 500 metres at 10 000 metres, the correction required is + 525 metres at 10 000 metres. Graphically, this example is portrayed in Figure 6-3-1, where:

a. R1 equals standard range (10 000 metres).

b. R2 equals range attained due to variation (9 500 metres).

c. R3 equals corrected range (10 525 metres) to attain R1.

4. Consider what happens when all conditions are standard except there is a head wind (see Figure 6-3-1):

a. It is required to hit a target T_1 at range R_1 at low angle. Under standard conditions, A/P is A_1 and the projectile will follow trajectory No. 1 hitting T_1.

b. Because of a head wind, if the projectile were fired at an A/P of A_1, it would adopt trajectory 1A and hit T_2 at range R_2. The difference V, between R_1 and R_2 variation at range R_1.

c. In order to hit target T_1 in the presence of a head wind, an A/P of A_2 greater than A_1 must be applied. Under standard conditions, this A/P would lead to trajectory No. 2 and achieve T_3 at range R_3.

d. The correction C is opposite in sign not in value to the variation V.

5. The range variation V at the Standard Range R_1 and A/P of A_1 is the difference between the range R_1 which would have been achieved under standard conditions and the range R_2 actually achieved when the conditions were non-standard. It always refers to the Standard Range.

6. The range correction C at the range achieved under non-standard conditions R_1 and A/P of A_2 is the difference between the range R_1 actually achieved under non-standard conditions and the range R_3 which would have been achieved under standard conditions. It always refers to the range actually achieved when conditions are non-standard.

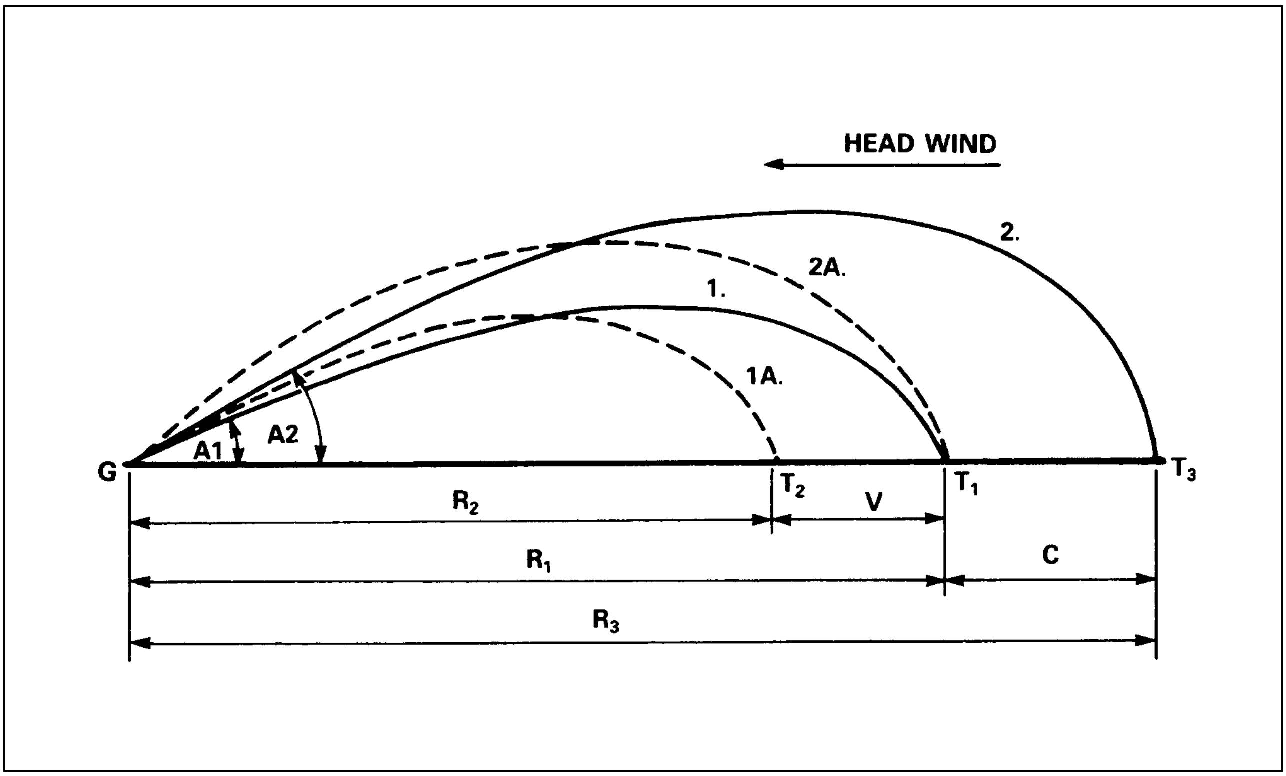


Figure 6-3-1 Definition of Variations and Corrections (Elevation View)

7. There is a definite relation between the size of variations and corrections (see Figure 6-3-2). Under standard conditions with an A/P of A_1, the projectile will hit T_1 at range R_1. With an A/P of A_2, the projectile will hit T_2 at range R_2.

8. Suppose that there is a head wind such that with an A/P of A_2 the projectile follows trajectory 3, ranging and hitting T_1 at range R_1:

a. From the statement in Section 3, paragraph 5, the range variation **at the standard range R_2** is the difference between the range that would have been achieved under standard conditions R_2 and the range actually achieved R_1, ie Range variation at $R_2 = R_1 - R_2 = -d$.

b. From the statement in Section 3, paragraph 6, the range correction **at the range actually achieved R_1** is the difference between the range actually achieved under non-standard conditions, R_1 and the range that would have been achieved under standard conditions R_2, ie Range correction at $R_1 = R_2 - R_1 = +d$.

9. These examples illustrate that the correction at a given range R_1 is equal numerically to the variation at a range R_2. This range R_2 is equal to the given range R_1 + d, the variation at R_2.

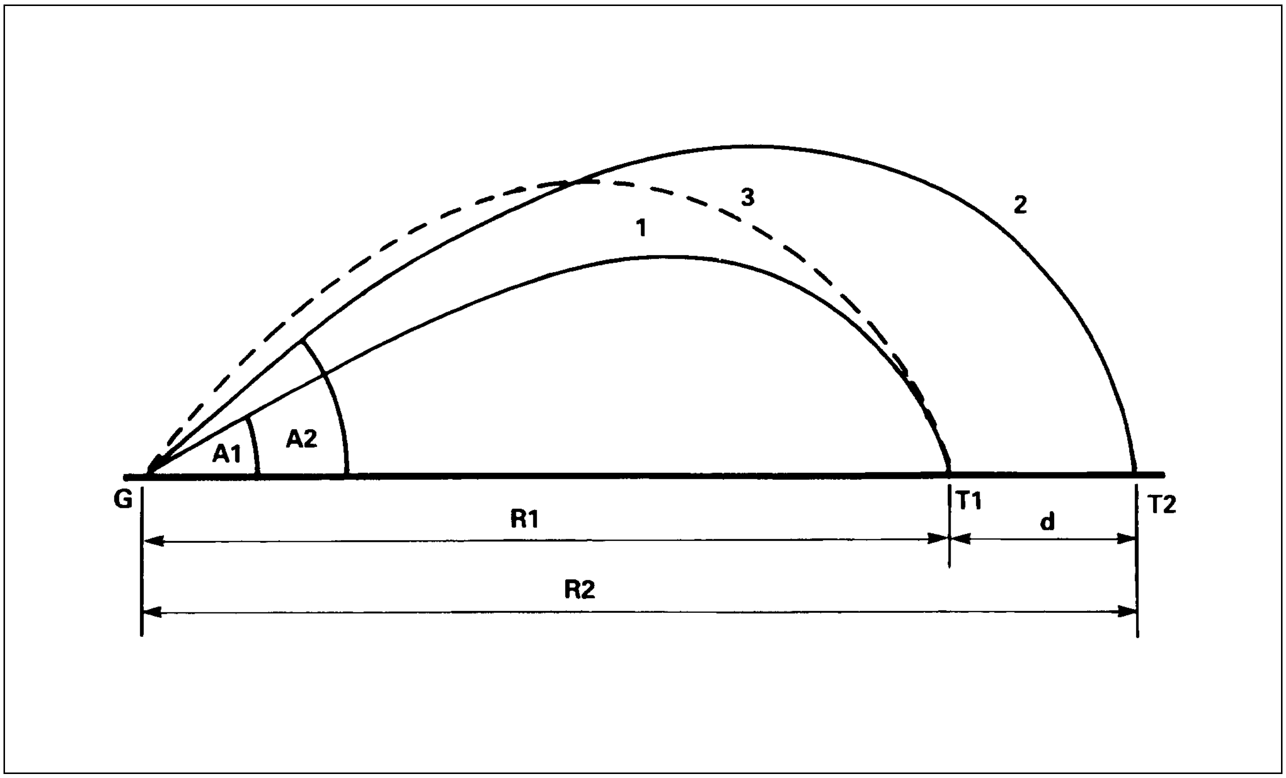


Figure 6-3-2 Relationship Between Variations and Corrections (Elevation View)

SECTION 4

DETERMINATION OF CORRECTIONS

GENERAL

1. The information contained in this section is applicable to the process of prediction when using tabular FTs. When Graphical Firing Tables (GFTs) are being used, corrections are determined and applied at the setting-up range for the applicable equipment and charge. When data is produced by computers, the corrections are automatically determined and applied to the data by the computer program.

DETERMINATION OF RANGE CORRECTION OF THE MOMENT

2. The range C of M is calculated from the unit corrections given in the FT.

3. C of M is required at map range. The range to which a variation applies is not map range but is the elevation required to hit the target under the non-standard condition. FTsing variations, this elevation cannot be determined in advance except by a process of successive approximation.

4. A better value of the correction could be ascertained by applying the correction given against the map range to find a new elevation and taking the correction against this new elevation as the true correction. In practice, it is not feasible to carry out such successive approximation.

5. **Appropriate Met Conditions**. The equivalent constant wind and ballistic air temperature given in the met message are usually different for different vertex heights (TOF). It is, therefore, necessary to use the met conditions appropriate to the vertex height actually achieved by the projectile. This has three aspects discussed in the next three paragraphs.

6. **The Effect of the Correction on Vertex Height**. The met message and C of M tables are calculated in relation to standard vertex heights (TOF). Because of the non-standard condition, the vertex height actually achieved by the projectile will be different. This introduces a small error that is ignored.

7. **Effect of Variation in MV on Vertex Height**. The ranges corresponding to the TOF given in the FTs are based on guns of standard MV. In order to hit a given target with a gun of low MV, at low angle fire, the barrel must be elevated. Therefore, at a given range, the vertex height for a gun of low MV is higher than that for a gun of high MV (see Figure 6-4-1). This difference in vertex height is due to non-standard MV and the correction is automatically applied to the data by the computer.

8. **Met Time of Flight**. The normal relation between vertex height and TOF is not true for large angles of sight. Figure 6-4-2 shows two trajectories under standard met conditions that range to C and A respectively, where C is at zero A/S and A is at a large A/S. Both are at range R1. The TOF to A and C are practically the same, but the vertex heights differ considerably. The

TOF that corresponds to the vertex height of trajectory 2 is the TOF to graze at B. This is the met TOF.

NON-STANDARD PROJECTILE CORRECTION

9. Non-standard projectile correction is read from the FT against map range. The data given are in the form of true corrections.

10. In some cases, such as illuminating, special tables are provided giving false ranges instead of non-standard projectile corrections.

ROTATION CORRECTION

11. The correction for rotation is read from the FT range against the bearing of the target with a factor for latitude.

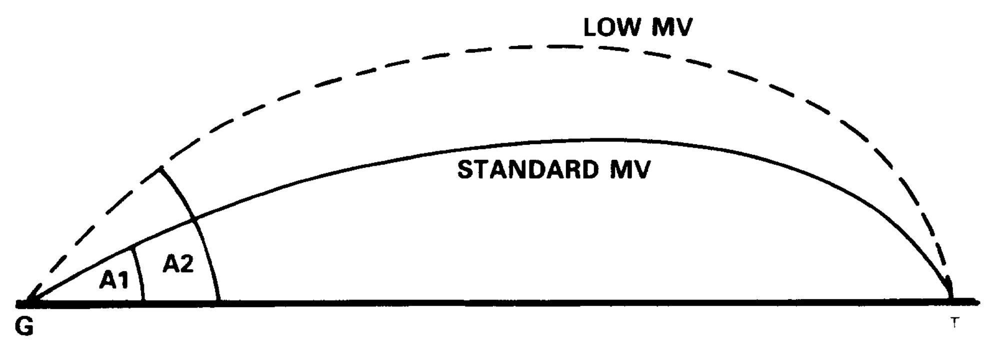


Figure 6-4-1 Dependence of Vertex Height on Muzzle Velocity for a Range (Elevation View)

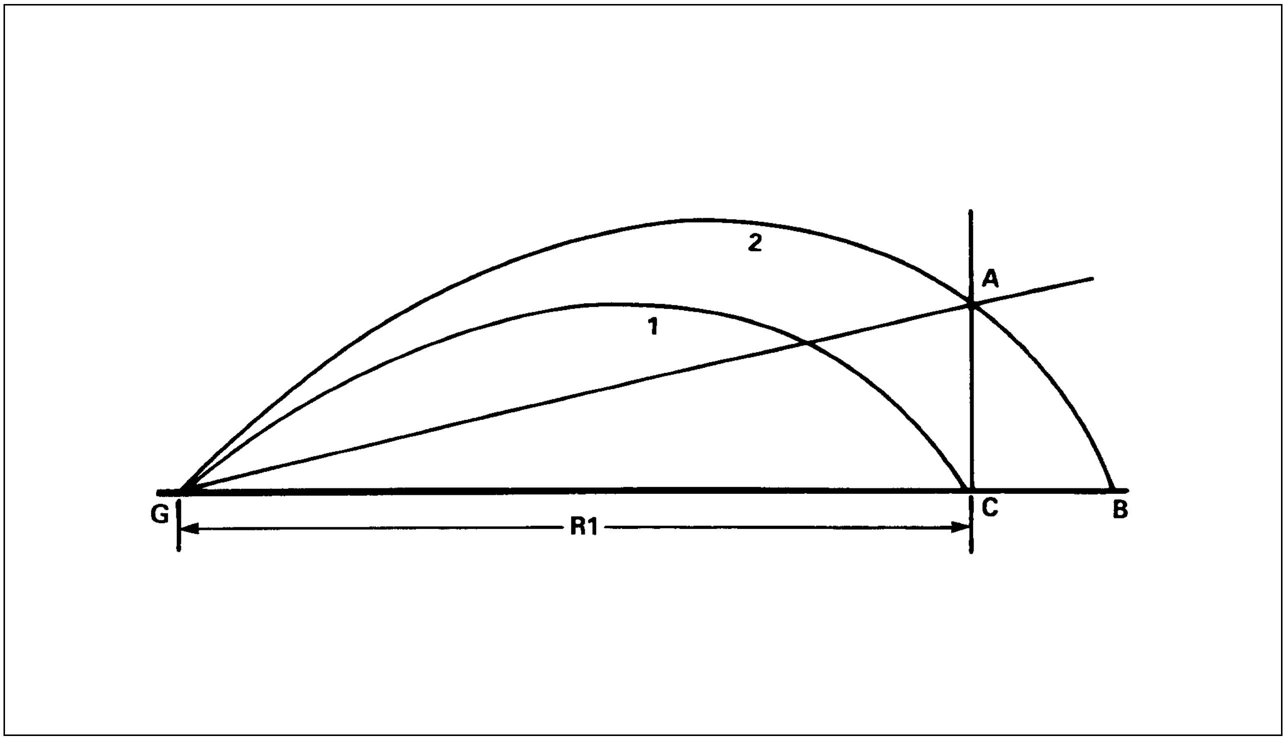


Figure 6-4-2 Dependence of Vertex Height on Angle of Sight (Elevation View)

NON-RIGIDITY CORRECTION

12. The correction for non-rigidity is read from the FT against he map range and the difference in altitude of target and gun.

MV CORRECTION

13. The range applied to a calibrating sight is the predicted range and non-standard MV is automatically corrected by for the sight. If there is no such sight, an MV correction must be included in the elevation ordered to the gun. These corrections are given in the FTs as true corrections and are tabulated against predicted ranges. The A/E applied to a gun is made up of predicted range plus MV correction for the latter range.

DESCRIPTION OF BEARING CORRECTIONS

14. Bearing corrections can be divided into three components:

a. bearing C of M,

b. drift correction, and

c. rotation of the earth.

15. **Bearing Correction of the Moment**. This consists of corrections that are usually common to all guns of a battery and that are accurate for a definite period of time. This applies to corrections to counteract variations associated with the cross component of the equivalent constant wind.

16. **Drift Correction**. This consists of a correction, normally common to all guns of a battery, to counteract the drift of the projectile. This correction is determined at practical range because the drift varies with the trajectory and the TOF.

17. **Rotation Correction**. Rotation corrections are tabulated in the FTs, range against bearing of target at the appropriate latitude.

18. **Lack of Level of Trunnions**. All sights are reciprocating, ie they have a cross-levelling gear which ensures that the lack of level of trunnions does not produce an error in bearing.

BEARING VARIATIONS AND BEARING CORRECTIONS

19. If a variation due to non-standard condition is to the right of the bearing of fire, then the correction required is taken as the same angle in the other sense, ie left. Similarly, a variation to the left requires an equal correction to the right.

20. **Tabulation of Bearing Correction of the Moment Corrections**. These are given in FTs. They are calculated for the predicted range and tabulated against map range. They are applied to map bearing.

21. **Predicted Bearing**. Predicted bearing is map bearing plus corrections for drift, met conditions and rotation of the earth.

22. The final bearing applied to the gun is the predicted bearing with any additional drift correction required for the projectile in use.

DESCRIPTION OF FUZE SETTING CORRECTIONS

23. Fuze settings are taken from the FTs at predicted range. These settings are equivalent to the TOF to graze at that predicted range under standard conditions. When conditions are non-standard, the projectile will not follow the standard trajectory and will have a different TOF. Thus, with all time fuzes, variations that alter TOF require fuze setting corrections. The variations include:

a. MV,

b. charge temperature,

c. barometric pressure,

d. air density,

e. ballistic air temperature, and

f. A/S.

MV VARIATIONS

24. Fuze setting corrections are applied at predicted range before the application of MV correction. There is, therefore, a difference between the A/P at which the fuze setting was predicted and the A/P at which the gun fired. There are two components in the correction for variations in MV:

a. variation in TOF due to variation in MV; and

b. variation in TOF due to alteration of the A/P by the application of MV correction.

25. **Variation in TOF due to Variation in MV**. The fuze setting extracted from the FT at predicted range applies to the standard trajectory for that A/P. Because of an increase in MV, the projectile will range farther and the TOF will be increased. Thus, for MV taken by itself, an increase in MV requires a lengthening of the fuze setting.

26. **Variation in TOF due to Alteration of A/P**. To counteract a gain in MV in low angle fire, the barrel must be depressed from the A/P equivalent to the predicted range. The TOF will thus be reduced and the fuze settings must be shortened. Conversely, a decrease in MV requires an increase in A/P and, therefore, a lengthening of fuze setting.

27. It follows that the two components in the MV correction are in opposite directions, however, the change of the A/P component is much greater in size than that of the MV variation itself. Therefore, the overall fuze setting correction for an increase in MV is to shorten the fuze setting.

CORRECTION OF THE MOMENT

28. **Charge Temperature**. Variations in charge temperature affect the TOF by altering MV. As this effect has been taken into account in arriving at the predicted range, there is no A/P component and the correction is solely that of fuze setting.

29. **Barometric Pressure and Air Density**. A fall in barometric pressure leads to a decrease in density. The projectile will range further; the TOF will be greater and the fuze will require lengthening.

30. **Ballistic Air Temperature**. A rise in ballistic air temperature leads to a decrease in density. The projectile will range further; TOF will be greater and the fuze will require lengthening.

ANGLE OF SIGHT

31. The effect of A/S on TOF is not great for small angles of sight, however, for large angles of sight a correction is necessary. Generally, a positive A/S increases TOF and requires a lengthening of the fuze setting. Conversely, a negative A/S requires a shortening of the fuze setting.

32. In addition, the FTs include a table of corrections to fuze setting required to raise the HOB along the trajectory. The correction is calculated from the remaining velocity and angle of fall.

MECHANICAL FUZES

33. In addition to variations in TOF, variations in running time necessitate further corrections to fuze settings. With certain mechanical fuzes, variations in MV affect the running time by altering the rate of spin. This additional source of variation is taken into account in the tables of corrections given in the FTs.

CORRECTIONS IN HIGH ANGLE FIRE

34. **Range Corrections**. Map range is corrected for C of M, non-rigidity, MV and non-standard projectile in the same way as in low angle fire.

35. **Muzzle Velocity**. The corrections for variations in MV are applied to predicted range in the form of range.

36. **Bearing Corrections**. These are determined as described in Section 4, paragraphs 13 to 23.

REDUCTION OF DATA

37. It is often necessary to produce the grid reference of a position from the fired data at which it was engaged. The process is known as reduction and is the procedure by which all conditions are reduced, as far as possible, to FT standard.

38. **Range**. Consider the process of prediction for range at low angle fire. The corrections that are applied to the data are for:

a. met,

b. non-standard projectile,

c. non-rigidity of the trajectory,

d. MV differences, and

e. rotation of the earth.

39. These corrections are applied either by calculation when using tabular FTs, calculated from the data contained in the FTs and applied to the GFT as a total correction at the sitting up ranges or by computer program when field computers are used.

40. In reduction, ideally, the corrections applied for prediction are removed. In fact, this cannot happen as the corrections would be calculated at map range and, therefore, would be different from those calculated for reduction.

41. Field computers solve the problem by continuously updating the target grid and, therefore, in effect, updating the available map data at which corrections are calculated for prediction or reduction.

42. The manual method of calculation currently uses the GFTs. It is accepted that the corrections applied during prediction are the same as those required for reduction (same value with their sign reversed). Therefore, the map data is said to have changed only by the amount of any adjustment that may have taken place.

43. It must be appreciated that whatever the means of calculation, the reduced range produced will still contain other errors inherent in prediction.

44. **Bearing**. The process of reduction for bearing is comparatively simple in that the same data is used for reduction as for prediction. When the GFT is used for calculating the correction for prediction, the principle explained in paragraph 39 is applied for reduction.

CHAPTER 7

ACCURACY AND CONSISTENCY OF ARTILLERY FIRE

SECTION 1

INTRODUCTION

DEFINITIONS

1. **Accuracy**. Accuracy is the measure of the precision with which the MPI of a group of rounds can be delivered at the target from occasion to occasion.

2. **Consistency**. The consistency of a gun is a measure of the dispersion of a single group of rounds about the MPI at a given elevation. Consistency is mainly governed by variations in the gun itself and is measured, not about the target, but about the MPI.

3. **Comparison of Accuracy and Consistency**. If, on every occasion, a weapon system delivered all rounds on the target at which it was aimed, accuracy and consistency would be perfect. If the MPI was always on the target but there was a big dispersion of rounds about the MPI, accuracy would be perfect but consistency would be poor. If there was a small dispersion of rounds about the MPI but the MPI was far from the target, consistency would be good but accuracy would be poor.

4. Accuracy and consistency are important characteristics of any weapon system. Gunnery procedures often require a consideration of accuracy and consistency at both the observation post and at the guns. This chapter will first establish a working knowledge of statistics and then apply this knowledge to the gunnery problem.

SECTION 2

STATISTICS FOR THE GUNNER

INTRODUCTION

1. Probability and statistics have been described as "the fundamental languages of any human activity which can be expressed in numbers". There is no doubt that numbers are common currency in gunnery and, therefore, some knowledge of probability and statistics is required to understand the background of gunnery procedures.

2. Statistics can form a lifetime study of considerable depth. In this section only those elements that are of background value to an understanding of gunnery will be presented. The three aspects that will be considered are:

a. measures of central tendency,

b. measures of dispersion, and

c. probability.

MEASURES OF CENTRAL TENDENCY

3. **General**. The Measures of Central Tendency are defined as the average or typical value of a group of values. These are:

a. mean,

b. mode, and

c. median.

4. **Mean**. The mean is defined as the formula:

$$\text{Mean} = \frac{\text{sum of all values}}{\text{number of values}}$$

The mean is the most common measure of central tendency and is also known as the arithmetic average.

5. **Mode**. The mode is defined as the most frequent value occurring in a set of values.

6. **Median**. The median is defined as the mid-point value in a set of values arranged from the lowest to the highest. It can be seen that there will be as many values less than the median as there are greater.

7. The following is an example of a typical problem and solution:

a. A group of rounds was fired and the individual rounds were measured to the nearest 10 metres along the line GT by the OP officer in terms of achieved range as shown in Figure 7-2-1.

b. The mode, median and mean of this group of rounds is required -

(1) The mode can be found by simple inspection as the most frequently occurring value. This was 9 390 metres. More rounds fell at this range than at any other range.

(2) The median has as many values below it as above it. Again by inspection, 43 rounds fell beyond 9 380 metres and 43 rounds fell short of 9 380 metres. Therefore, 9 380 is the median.

Range (m)	Number of Rds	Range (m)	Number of Rds
9 310	2	9 400	8
9 320	3	9 410	7
9 330	4	9 420	6
9 340	8	9 430	4
9 350	8	9 440	3
9 360	9	9 450	2
9 370	9	9 460	0
9 380	10	9 470	1
9 390	11	9 480	1

Figure 7-2-1 Fall of Shot Data

(3) The mean is found by taking the sum of the values and dividing by the number of values.

This is: $\frac{9\,310 \times 2 + 9\,320 \times 3 + 9\,330 \times 4 + \ldots}{96}$

Mean = 9 383.4

MEASURES OF DISPERSION

8. **General**. The Measures of Dispersion is defined as the spread of a group of values about the spread's mean. These are:

a. mean deviation; and

b. PE.

9. **Mean Deviation**. The mean deviation is the sum of differences from the mean divided by the number of values. The differences are always positive values.

10. **Probable Error**. PE is defined as the error that is exceeded as often as it is not exceeded. PE may be calculated using the formula:

$$PE = 0.845 \times \text{Mean Deviation}$$

11. **Correction for Sample Size**. When dealing with a small number of values, the value of dispersion must be corrected by a factor. The correction factor is obtained by the formula:

$$\text{Correction Factor} = \sqrt{\frac{N}{N-1}}, \ N = \text{number of values}$$

12. **Sample Calculation**. Figure 7-2-2 gives the fall of shot data obtained in testing a new gun. It is desired to determine the PE in range for this gun:

Round	Distance from Reference Point in Metres		Distance of Round from MPI (deviations)
	Plus Rounds	Minus Rounds	
(1)	(2)	(3)	(4)
1	+ 200		119.6
2	+ 150		69.6
3		− 3	83.4
4	+ 72		8.4
5		− 17	97.4

Figure 7-2-2 Calculation of Probable Error for Range

a. **Compute MPI** -

$$MPI = \frac{\text{Sum of plus distances - Sum of minus distances}}{\text{Number of Rounds}}$$

$$MPI = \frac{422 - 20}{5}$$

MPI = + 80.4 metres

b. **Complete column 4 (Figure 7-2-2)**. Note that these are all deviations from the mean (distance from MPI to point of impact) and are all positive values.

c. **Compute the mean deviation (MD) -**

$$MD = \frac{\text{Sum of deviations}}{\text{Number of values}}$$

$$\frac{378.4}{5} = \text{MD of } 75.7 \text{ m}$$

d. **Compute PE -**

PE = 0.845 x MD

PE = 0.845 x 75.7

PE = 64 metres

e. **Correct for Sample Size -**

$$\text{Correction Factor} = \sqrt{\frac{N}{N-1}} \quad N = \text{number of values}$$

$$= \sqrt{5/4}$$

$$= 1.118$$

Therefore, corrected PE = 1.118 x 64 = 71.5 metres

COMBINATION OF DISPERSIONS

13. When there is more than one independent source of dispersion operating at one and the same time, the overall PE is less than the sum of the component Pes because the variations do not necessarily all have the same magnitude or act in the same direction at the same time.

14. The method of combination is known as the root sum of squares method. The procedure is to add the squares of component PEs and take the square root of this sum. This can be expressed by a formula as:

$$\text{PE total} = \sqrt{\text{PE1}^2 + \text{PE2}^2 + \ldots}$$

THE NORMAL DISTRIBUTION CURVE

15. **General**. Re-occurring events will obey the Law of Random Distribution. Figure 7-2-3 shows the ranges achieved by the 105 mm Howitzer firing charge five. Observers to a flank estimated the range to impact would occur between poles laid out at 25 m intervals from a reference point.

Range Interval Metres	5 375 to 5 400	5 400 to 5 425	5 425 to 5 450	5 450 to 5 475	5 475 to 5 500	5 500 to 5 525	5 525 to 5 550	**Total**
Number of Rounds	1	11	25	36	30	14	3	120

Figure 7-2-3 Dispersion of Rounds

16. **The Histogram**. The best way to represent the data from Figure 7-2-3 is by a histogram, in which the number of rounds in each interval is plotted against the range (see Figure 7-2-4).

17. If the interval were decreased from 25 to 5 metres and more rounds fired, the overall shape would remain the same but the histogram would become smoother (see Figure 7-2-5).

18. The smooth curve derived from a histogram is known as a frequency curve and represents the distribution of rounds at various ranges that could be expected in an unlimited extension of the trial. The curve can be used to determine the ratio of the number of rounds failing in any range bracket to the total number of rounds fired.

19. In Figure 7-2-6 the number of rounds falling between 5 400 and 5 450 metres can be predicted by expressing the area under the curve between those ranges to the total area under the curve. Visual inspection shows that the area under the curve for those ranges is about 35 per cent of the total area. Therefore, 35 per cent of all rounds fired can be expected to fall inside that range bracket.

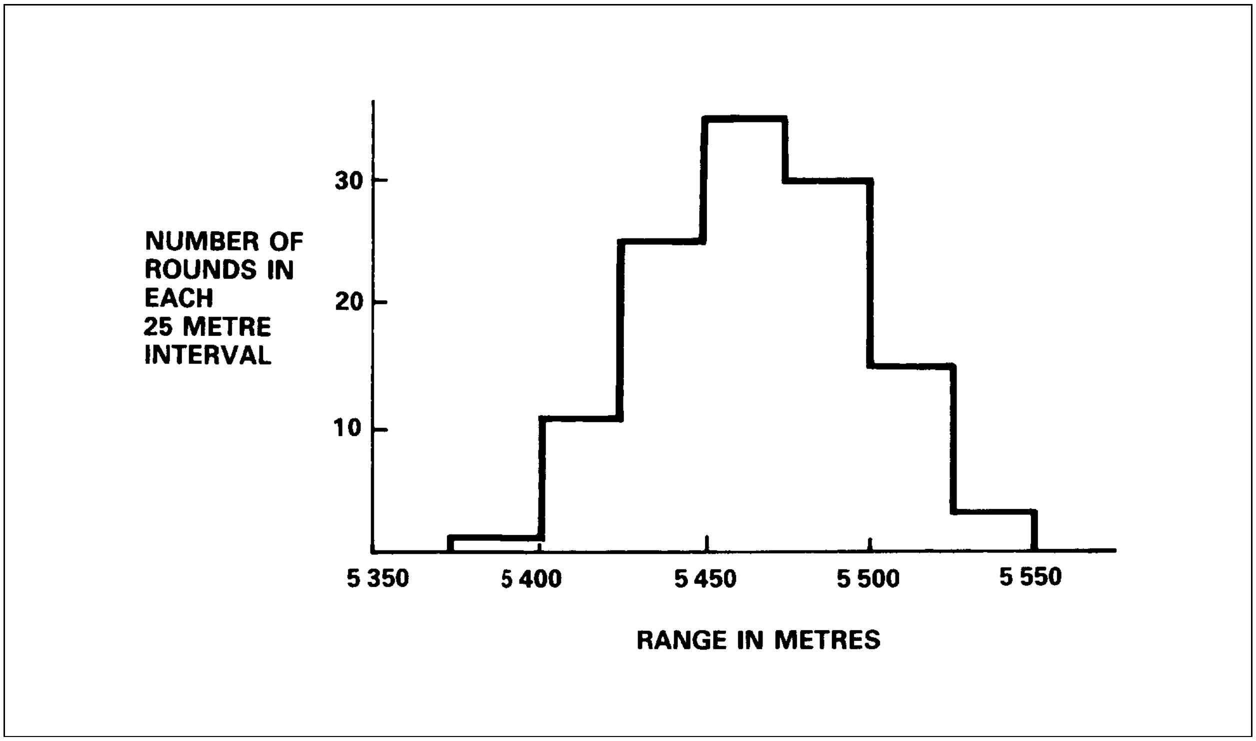


Figure 7-2-4 Histogram of Figure 7-2-3

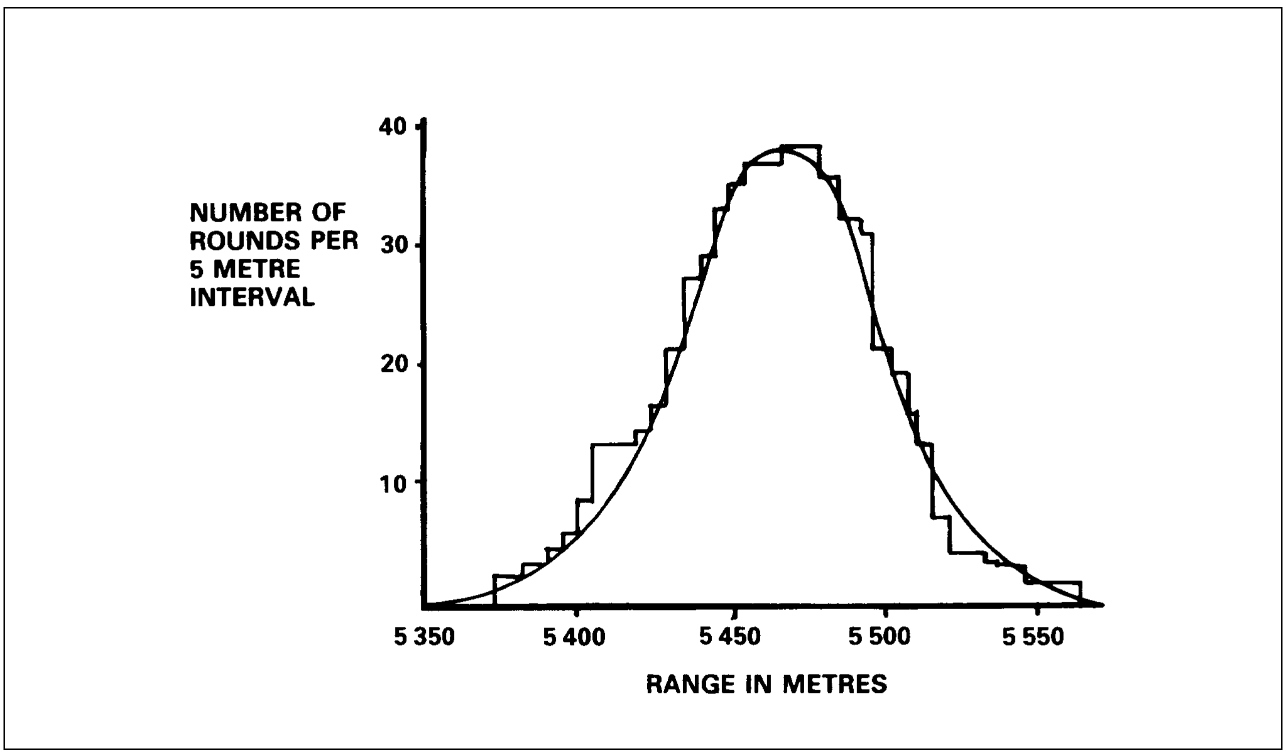


Figure 7-2-5 Histogram with Increased Number of Rounds and Decreased Interval of Measurement

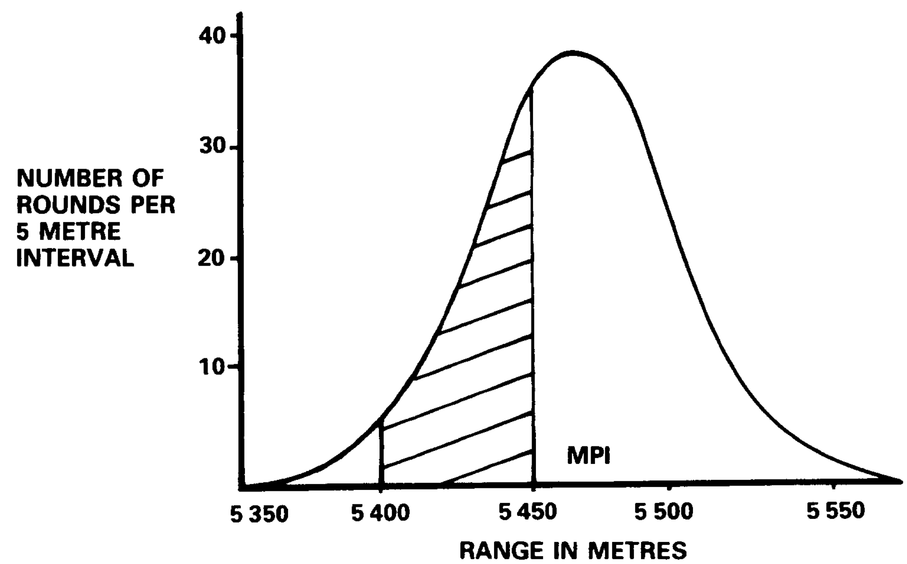


Figure 7-2-6 Determination of Percentage of Rounds Failing in a Bracket from the Frequency Curve

SECTION 3

DISPERSION AND PROBABILITY

GENERAL

1. If a number of rounds of the same calibre and same lot of ammunition are fired from the same weapon with the same settings in QE and bearing, the rounds will not all fall at a single point but will be scattered in a pattern of bursts. In discussions of artillery fire, the natural phenomenon of change is called dispersion. The array of the bursts on the ground is the dispersion pattern (see Figure 7-3-1).

2. The point of impact of the projectiles will be scattered both laterally (bearing) and in depth (range). Dispersion is the result of minor variations of many elements from round to round and must not be confused with variations in point of impact caused by mistakes or constant errors. Mistakes can be eliminated and constant errors compensated for. Those inherent errors that are beyond control and cause dispersion are caused in part by the following:

a. **Conditions in the bore**. MV is affected by: minor variations in weight, moisture content, and temperature of the propelling charge; variations in the arrangement of the powder grains; differences in the ignition of the charge; differences in the weight of the projectile and in the form of the rotating bands; variations in ramming; and variations in the temperature of the bore from round to round. Variations in the bourrelet and rotating band may cause inaccurate centring of the projectile and, hence, inaccurate flight.

b. **Conditions in the Carriage**. Bearing and elevation are affected by play (looseness) in the mechanisms of the carriage, physical limitations on precision in setting scales and non-uniform reaction to firing stresses.

c. **Conditions During Flight**. Air resistance is affected by differences in weight, velocity and the form of the projectile and by changes in wind, density and temperature of the air from round to round.

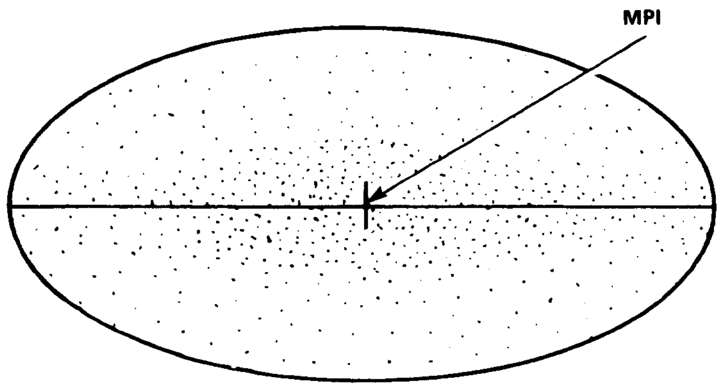


Figure 7-3-1 Dispersion

MEAN POINT OF IMPACT

3. For any large number of rounds fired, it is possible to draw a diagram showing a line perpendicular to the line of fire that will divide the points of impact into two equal groups. Half of the rounds considered will be inside the line, or over when considered from the weapon. For this same group of rounds there will also be a line parallel to the line of fire that will divide the rounds equally. Half of the rounds will fall to the right of the line; half will fall to the left of the line (see Figure 7-3-2). The first line, perpendicular to the line of fire, represents the mean range. The second line, parallel to the line of fire, represents the mean bearing. The intersection of the two lines is the MPI.

PROBABLE ERROR

4. Consider for a moment only the rounds that have fallen over (or short) of the MPI. There is some point along the line of fire, beyond the MPI, at which a second line perpendicular to the line of fire can be drawn that will divide the overs into two equal parts (see line A, Figure 7-3-3).

5. All of the rounds beyond the MPI manifest an error in range, ie they are all overs. Some of the rounds falling over are more in error than others. If the distance from the MPI to line A is a measure of error, it is clear that half of the rounds over have a greater error and half of the rounds over have a lesser error. The distance from the MPI to line A, thus, becomes a convenient unit of measure. This distance is called the PE. The most concise definition of a PE is, it is the error that is exceeded as often as it is not exceeded.

DISPERSION PATTERN

6. The distribution of rounds in a normal burst pattern will be the same number of rounds short of the MPI as the number of rounds over the MPI. The PE will be the same in both cases.

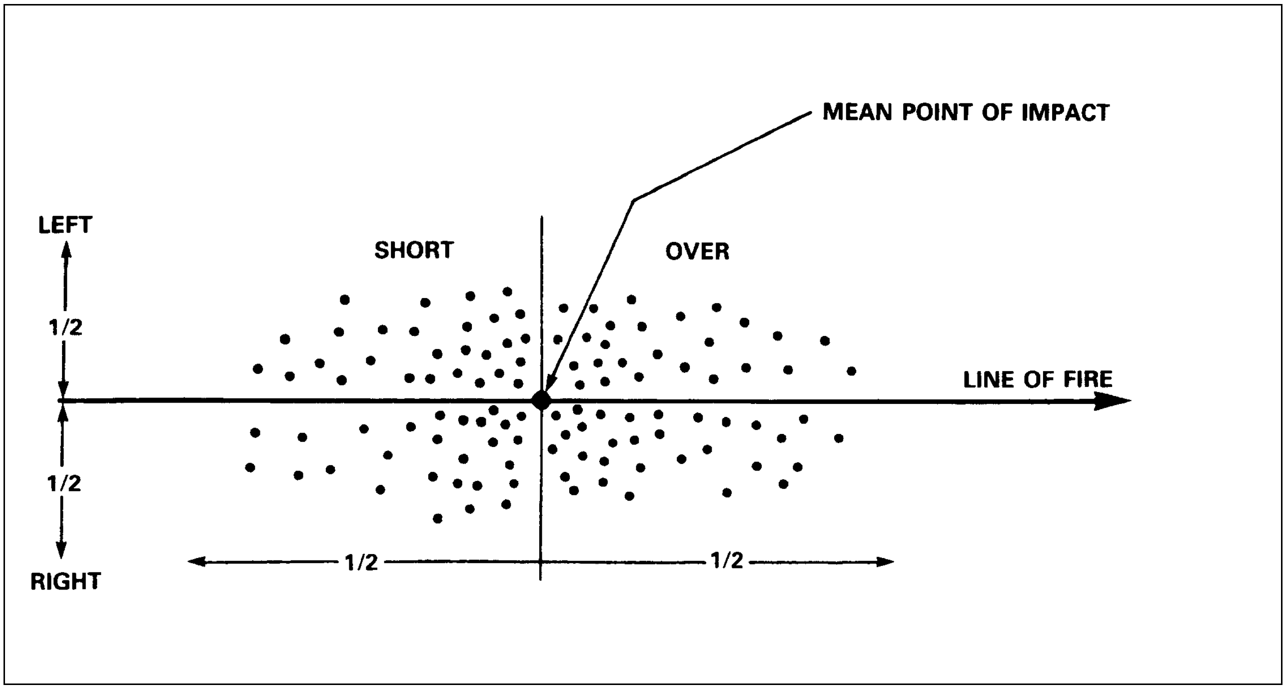


Figure 7-3-2 Mean Point of Impact

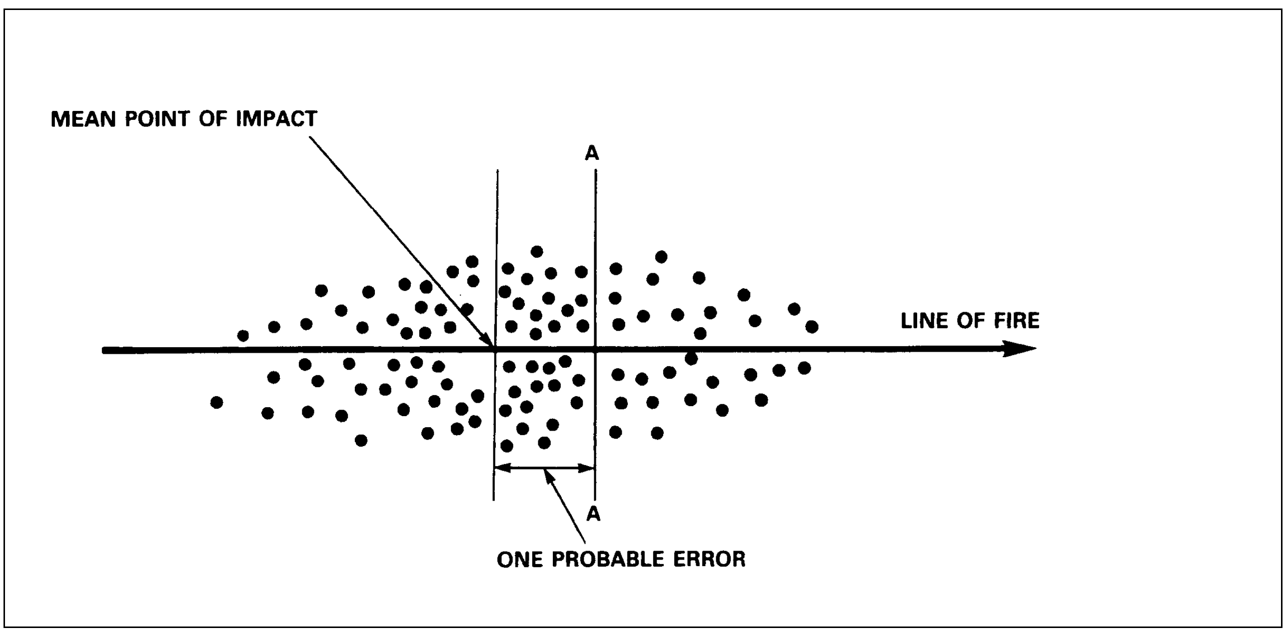


Figure 7-3-3 Range Probable Error

7. It is a mathematical fact that for any normal distribution (such as artillery fire) a distance of four PEs on either side of the MPI will include virtually all of the rounds in the pattern. This is not precisely true, since a very small fraction of the rounds (approximately seven out of 1 000) will fall outside four Pes on either side of the MPI but it is true for all practical purposes.

8. The total pattern of a large number of bursts is roughly elliptical (see Figure 7-3-3). However, using the fact that four PEs on either side of the MPI (in range and in bearing) will encompass virtually all rounds, a rectangle normally is drawn to include the full distribution of the rounds. This rectangle is the 100 per cent rectangle shown in Figure 7-3-4.

DISPERSION SCALE

9. If PE is used as the unit of measurement to divide the dispersion rectangle evenly into eight zones in range, the percentage of rounds falling in each zone will be as indicated in Figure 7-3-4. By definition of PE, the 50 per cent of rounds nearest the mean range line (line through the MPI) fall within one PE. The other percentages have been found to be true by experiment.

10. What is true in range also will be true in bearing. If range and bearing dispersion zones are both considered, a set of small rectangles is created. The per cent of the rounds falling in each rectangle is shown in Figure 7-3-5.

NORMAL PROBABILITY CURVE

11. The dispersion of artillery rounds follows the laws of probability and normal distribution. The pattern of bursts on the ground can be graphed with a normal probability curve, a common method of representing the probability of the occurrence of an error of any given magnitude in a series of samples.

12. Distances of points on the horizontal (base) line (Figure 7-3-6) measured to the right and left of the centre represent errors in excess (over) or in deficiency (short). The area under the curve represents the probability of the occurrence of an error within the magnitudes represented by the ends of the base line segment considered. In Figure 7-3-6 the shaded area represents the number of rounds falling over and within one PE of the MPI, which is 25 per cent.

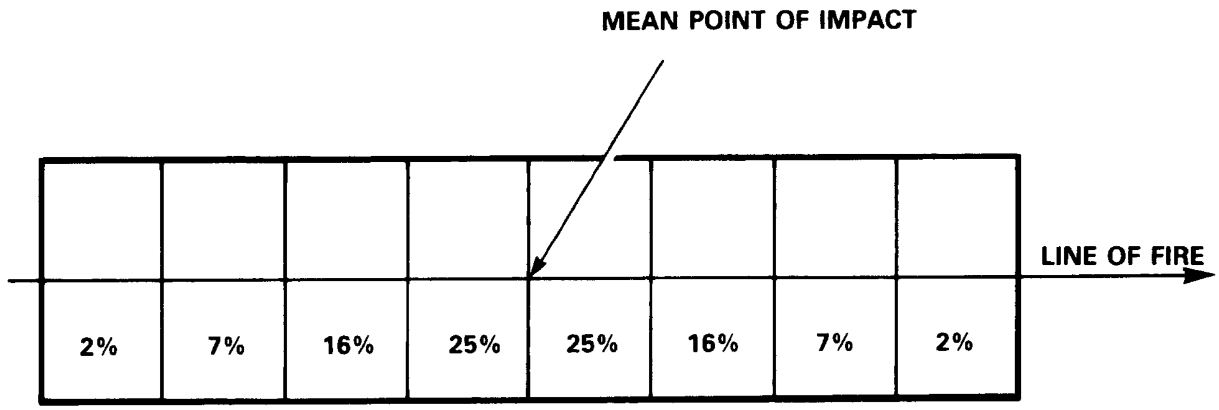
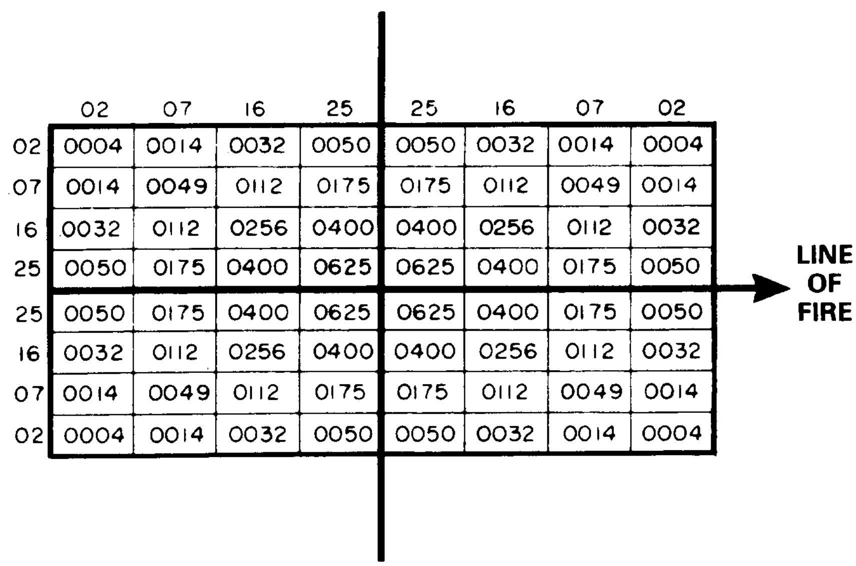


Figure 7-3-4   The 100 Per cent Rectangle



	02	07	16	25	25	16	07	02
02	0004	0014	0032	0050	0050	0032	0014	0004
07	0014	0049	0112	0175	0175	0112	0049	0014
16	0032	0112	0256	0400	0400	0256	0112	0032
25	0050	0175	0400	0625	0625	0400	0175	0050
25	0050	0175	0400	0625	0625	0400	0175	0050
16	0032	0112	0256	0400	0400	0256	0112	0032
07	0014	0049	0112	0175	0175	0112	0049	0014
02	0004	0014	0032	0050	0050	0032	0014	0004

Figure 7-3-5   Dispersion Rectangle

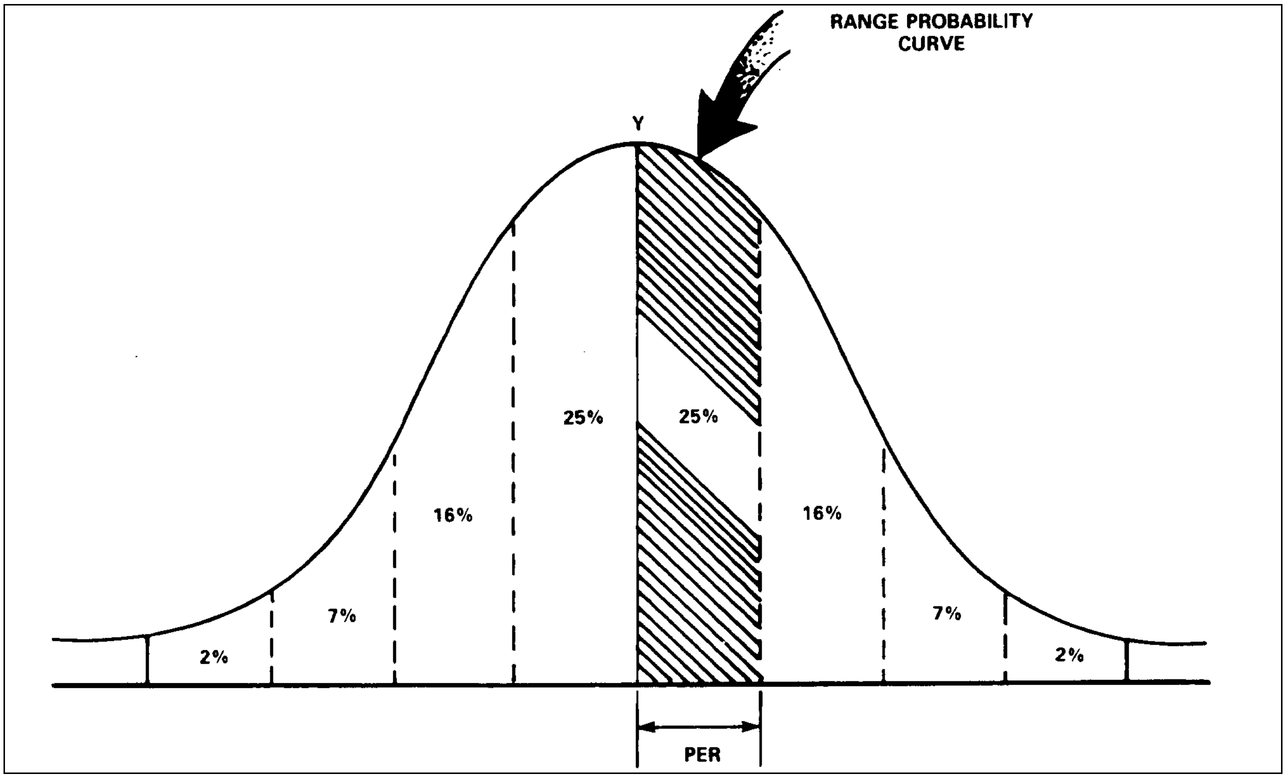


Figure 7-3-6 Areas Under the Normal Probability Curve

13. The curve (Figure 7-3-6) expresses the following facts:

a. In a large number of samples, errors in excess and errors in deficiency are equally frequent (probable) as shown by the symmetry of the curve.

b. The errors are not uniformly distributed. The smaller errors occur more frequently than the larger errors, as shown by the greater height of the curve in the middle.

RANGE PROBABLE ERROR

14. The approximate value of the probable error in range (PE_d is shown in Table G of the FTs and can be taken as an index of the precision of the gun. For example, for a 155 mm Howitzer M109A2/A3 firing charge 7 at a range of 8 000 metres, one PE_r is 23 metres. FT values for PEs are based on the firing of specific ammunition under controlled conditions. The actual round-to-round PE experienced in the field will normally be larger.

FORK

15. Fork is the term used to express the change in elevation in mils necessary to move the MPI four PEs. The value of the fork is given in Table F of the FTs. For example, for a 155 mm Howitzer M109A2/A3 firing charge 5 Green Bag at a range of 6 000 metres, the fork is 4 mils.

DEFLECTION PROBABLE ERROR

16. The value of the probable error in deflection (PE_d) is given in Table G of the FTs. For guns, the PE_d is considerably smaller than the PE_r. For example, for a 155 mm Howitzer M109A2/A3 firing charge 5 Green Bag at a range of 5 000 metres, the PE_d is 4 metres. In other words, 50 per cent of the rounds fired will fall within 4 metres, 82 per cent will fall within 8 metres and 96 per cent will fall within 12 metres of the mean deflection.

VERTICAL PROBABLE ERROR

17. The PE_r given in the FTs is based on firing on a horizontal plane. If the target is a vertical surface (or even a steep incline) the PE_r will be different. If the target is truly vertical, the PE against the target surface is equal to the PE_r divided by the cotangent of the angle of fall (see Figure 7-3-7). Precise computation of the size of the PE against a vertical or steep surface is seldom made. It is suffice to recognize that the vertical dispersion is a function of the range dispersion, the angle of fall and the angle of the target surface with respect to the horizontal. Except in high angle fire, the vertical probable error (PE_h) will normally be smaller than the PE_r.

AIRBURST PROBABLE ERROR

18. **Time to Burst Probable Error**. The value of probable error in time to burst (PE_{tb}) is shown in Table G of the FTs and can be taken as the weighted average (root mean square) of the precision of the timing mechanism of the fuze and the actual TOF of the projectile. For example, for a 155 mm Howitzer M109A2/A3 firing charge 5 Green Bag at a range of 5 000 metres, the PE_{tb} is 0.11 seconds for the M564 fuze. As in any other normal dispersion pattern, 50 per cent of the projectiles fired with fuze M564 will burst within ± 0.11 seconds, 82 per cent within ± 0.22 seconds and 96 per cent within ± 0.33 seconds of the mean time.

19. **Height of Burst Probable Error**. When the projectile is fuzed to burst in the air, the probable error in HOB (PE_{hb}) is the vertical component of one PE_{tb}. Thus the PE_{hb} reflects the combined effects of dispersion caused by variations in the functioning of fuzes and of dispersion due to other factors discussed earlier. Except for some complexity introduced by the two dispersion phenomena interacting, HOB dispersion follows the same laws of distribution as those discussed under range dispersion. Values of the PE_{hb} for a particular time fuze are given in Table G of the FTs. PE_{hb} for variable time (VT) and CVT fuzes cannot be predicted because the HOB varies with the angle of fall of the projectile and the type of terrain over which the projectile is passing. The PE_{hb} for VT and CVT fuzes can be estimated by observing and analyzing results obtained from firing on a given terrain.

20. **Range to Burst Probable Error**. When the projectile is fuzed to burst in the air, the total PE_r to burst is the horizontal component of one PE_{tb}.

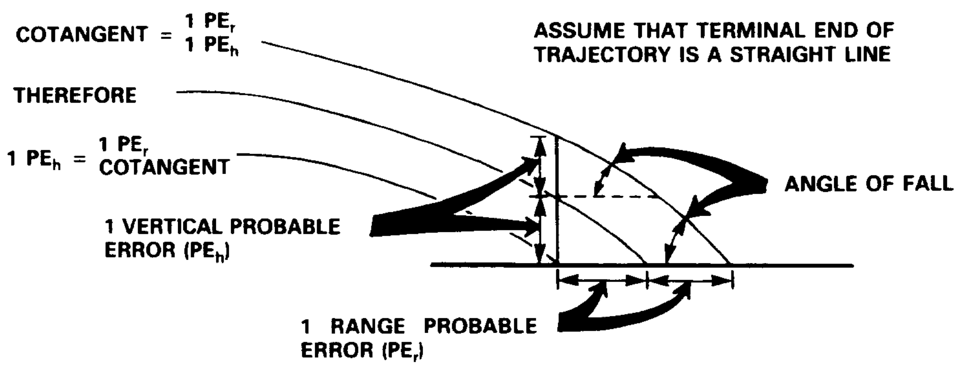


Figure 7-3-7 Vertical Dispersion

APPLICATION OF PROBABLE ERRORS

21. Normal distribution is expressed in terms of (PEs), because the distribution of bursts about the mean is the same, regardless of the magnitude of the PE. FTs (Table G) list probable errors for range, deflection, HOB, time to burst and range to burst at each listed range. It is possible to express a given distance in terms of PEs and solve problems by using the dispersion scale of probability tables.

22. To compute the probability of a round landing within an error of a certain magnitude, reduce the specified error to equivalent PEs in one direction along the dispersion scale and multiply the sum by two. For example, a 155 mm Howitzer M109A2/A3 has fired a number of rounds at charge 7 and the MPI has been determined to be at 12 000 metres. The probability that the next round fired will fall within 60 metres of the MPI is:

Solution:

PE_r at 12 000 metres (charge 7) = 30 metres.

Equivalent of rounds falling within 2 PEs (60/30) = 2

Per cent of rounds failing within 2 PE = 2 (25 per cent + 16 per cent) = 82 per cent (see Figure 7-3-4).

PROBABILITY TABLES

23. The computation of probability is simplified by the use of a probability table (see Figure 7-3-8). The entire area under the normal probability curve is a unit, or 100 per cent. The ratio of any particular portion of the area to the total area represents the probability that the burst in question will occur within the interval over which the particular area stands. For example, consider that portion of the total area that stands over the interval from the mean to a distance of one PE on one side of the mean. This is 25 per cent of the total area under the curve. Numbers in the body of the table are areas under the normal probability curve. The arguments are distances expressed in PEs. In the first vertical column are distances expressed in PEs to the nearest tenth; horizontally across the top of the table is the breakdown in hundredths of PEs.

24. Entry into the table is similar to entry into a table of logarithms. The total area under the probability curve is taken as one. Note that the maximum area defined in the body of the table is 0.5000, or 50 per cent, or one-half. Therefore, the numbers in the body of the table actually give the probability that the event in question will occur within various PEs from the mean and on one side only of the mean. Interpolation in the tables is an unnecessary refinement. A complete set of probabilities for one side of the mean is shown in Figure 7-3-8.

25. PEs can be solved by the use of the probability table as follows:

Equivalent PEs 2.0
Value from Figure 7-3-8 .... 0.4113
Probability (0.4113 x 2) .... 82.26 per cent

26. The answer differs slightly from that obtained by using the dispersion scale because probability tables are to an accuracy of four decimal places and are entered with PE expressed to the hundredth, whereas the dispersion scale is to an accuracy of only two decimal places and is entered with whole PEs. Probability tables provide the more accurate answer.

27. In some problems, the probability is required for only one side of the mean in which case the multiplication by two is omitted. For example, to determine the probability that a burst will be closer to the ground than 100 metres when the mean HOB is 350 metres above the ground and the PE_{hb} is 75 metres, the following procedures are used:

a. The specified error (metres) = 350 - 100 = 250.

b. 250 metres below the mean is 100 metres above ground.

c. Error in PE_{hb} = 250 - 75 = 3.33.

t	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0027	0.0057	0.0081	0.0108	0.0135	0.0162	0.0189	0.0216	0.0243
0.1	0.0269	0.0296	0.0323	0.0350	0.0377	0.0404	0.0431	0.0457	0.0484	0.0511
0.2	0.0538	0.0565	0.0591	0.0618	0.0645	0.0672	0.0699	0.0725	0.0752	0.0778
0.3	0.0804	0.0830	0.0856	0.0882	0.0908	0.0934	0.0960	0.0986	0.1012	0.1038
0.4	0.1064	0.1089	0.1115	0.1140	0.1166	0.1191	0.1217	0.1242	0.1268	0.1293
0.5	0.1319	0.1344	0.1370	0.1395	0.1421	0.1446	0.1472	0.1497	0.1522	0.1547
0.6	0.1572	0.1597	0.1622	0.1647	0.1671	0.1695	0.1719	0.1743	0.1767	0.1791
0.7	0.1815	0.1839	0.1863	0.1887	0.1911	0.1935	0.1959	0.1983	0.2007	0.2031
0.8	0.2054	0.2077	0.2100	0.2123	0.2146	0.2169	0.2192	0.2214	0.2236	0.2258
0.9	0.2280	0.2302	0.2324	0.2346	0.2368	0.2390	0.2412	0.2434	0.2456	0.2478
1.0	0.2500	0.2521	0.2542	0.2563	0.2584	0.2605	0.2626	0.2647	0.2668	0.2689
1.1	0.2709	0.2730	0.2750	0.2770	0.2790	0.2810	0.2830	0.2850	0.2869	0.2889
1.2	0.2908	0.2927	0.2946	0.2965	0.2984	0.3003	0.3022	0.3041	0.3060	0.3078
1.3	0.3097	0.3115	0.3133	0.3151	0.3169	0.3187	0.3205	0.3223	0.3240	0.3258
1.4	0.3275	0.3292	0.3309	0.3326	0.3343	0.3360	0.3377	0.3393	0.3410	0.3426
1.5	0.3442	0.3458	0.3474	0.3490	03506	0.3521	0.3537	0.3552	0.3567	0.3582
1.6	0.3597	0.3612	0.3627	0.3642	0.3657	0.3671	0.3686	0.3700	0.3714	0.3728
1.7	0.3742	0.3756	0.3770	0.3784	0.3798	0.3811	0.3825	0.3838	0.3851	0.3864
1.8	0.3877	0.3890	0.3903	0.3915	0.3928	0.3940	0.3952	0.3964	0.3976	0.3988
1.9	0.4000	0.4012	0.4024	0.4035	0.4047	0.4058	0.4069	0.4080	0.4091	0.4102
2.0	0.4113	0.4124	0.4135	0.4146	0.4156	0.4167	0.4177	0.4187	0.4197	0.4207
2.1	0.4217	0.4227	0.4237	0.4246	0.4256	0.4265	0.4274	0.4283	0.4292	0.4301
2.2	0.4310	0.4319	0.4328	0.4336	0.4345	0.4353	0.4361	0.4369	0.4373	0.4385
2.3	0.4393	0.4401	0.4409	0.4417	0.4425	0.4433	0.4441	0.4448	0.4456	0.4463
2.4	0.4470	0.4477	0.4484	0.4491	0.4498	0.4505	0.4512	0.4519	0.4526	0.4533
2.5	0.4540	0.4547	0.4553	0.4560	0.4566	0.4572	0.4578	0.4584	0.4590	0.4596
2.6	0.4602	0.4608	0.4614	0.4620	0.4625	0.4630	0.4636	0.4641	0.4646	0.4651
2.7	0.4657	0.4662	0.4667	0.4672	0.4677	0.4682	0.4687	0.4692	0.4697	0.4701
2.8	0.4705	0.4710	0.4714	0.4718	0.4722	0.4727	0.4731	0.4735	0.4739	0.4743
2.9	0.4748	0.4752	0.4756	0.4760	0.4764	0.4768	0.4772	0.4776	0.4780	0.4783
3.0	0.4787	0.4790	0.4793	0.4796	0.4800	0.4803	0.4806	0.4809	0.4812	0.4815
3.1	0.4818	0.4821	0.4824	0.4827	0.4830	0.4833	0.4836	0.4839	0.4842	0.4845
3.2	0.4848	0.4851	0.4853	0.4855	0.4857	0.4859	0.4862	0.4864	0.4866	0.4868
3.3	0.4870	0.4873	0.4875	0.4877	0.4879	0.4881	0.4883	0.4885	0.4886	0.4888
3.4	0.4890	0.4892	0.4893	0.4895	0.4897	0.4899	0.4901	0.4902	0.4904	0.4906
3.5	0.4908	0.4909	0.4911	0.4913	0.4915	0.4916	0.4917	0.4919	0.4921	0.4922
3.6	0.4923	0.4924	0.4926	0.4927	0.4928	0.4929	0.4931	0.4933	0.4934	0.4935
3.7	0.4936	0.4938	0.4939	0.4940	0.4941	0.4942	0.4944	0.4945	0.4946	04947
3.8	0.4948	0.4949	0.4950	0.4951	0.4952	0.4953	0.4953	0.4954	0.4955	0.4956
3.9	0.4957	0.4958	0.4959	0.4960	0.4960	0.4961	0.4962	0.4963	0.4964	0.4965
4.0	0.4965	0.4966	0.4967	0.4967	0.4968	0.4969	0.4969	0.4970	0.4971	0.4972
4.1	0.4972	0.4973	0.4973	0.4974	0.4974	0.4975	0.4975	0.4976	0.4976	0.4977
4.2	0.4978	0.4978	0.4979	0.4979	0.4980	0.4980	0.4980	0.4981	0.4981	0.4981
4.3	0.4982	0.4982	0.4982	0.4983	0.4983	0.4983	0.4983	0.4984	0.4984	0.4985
4.4	0.4985	0.4985	0.4986	0.4986	0.4986	0.4987	0.4987	0.4987	0.4988	0.4988
4.5	0.4988	0.4989	0.4989	0.4989	0.4989	0.4990	0.4990	0.4990	0.4990	0.4991
4.6	0.4991	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4992	0.4992
4.7	0.4993	0.4993	0.4993	0.4993	0.4993	0.4993	0.4994	0.4994	0.4994	0.4994
4.8	0.4994	0.4994	0.4994	0.4995	0.4995	0.4995	0.4995	0.4995	0.4995	0.4995
4.9	0.4995	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996
5.0	0.4996	0.4996	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997
5.1	0.4997	0.4997	0.4997	0.4997	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998
5.2	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998
5.3	0.4998	0.4998	0.4998	0.4998	0.4998	0.4998	0.4999	0.4999	0.4999	0.4999
5.4	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999
5.5	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999
5.6	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999
5.7	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999	0.4999
5.8	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
5.9	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000

Figure 7-3-8 Normal Probability Table, Areas of the Normal Probability Curve (t is expressed in probable errors)

d. From probability Figure 7-3-8, 3.33 corresponds to 0.4877, which is the probability that the burst will be between the mean and 100 metres above the ground. Since the total probability for a burst being below the mean is 0.5000, then the probability of a burst being less than 100 metres above the ground, that is, more than 250 metres below the mean, is 0.5000 - 0.4877 = 1.23 per cent.

28. By extension, the probability that the burst will occur at either less than 100 metres above the ground (250 below the mean) or more than 600 metres above the ground (250 above the mean) is 1.23 per cent + 1.23 per cent = 2.46 per cent. Any combination of limiting height above the ground can be similarly solved. The maximum and minimum limits specified need not reduce the same error from the mean as in the foregoing example. Each is solved independently and the possibilities are added.

29. It is emphasized that the probability tables give the probability of not exceeding a certain error or, by subtraction, the probability of making an error equal to or less than a specified error. The probability tables cannot give the probability of making a particular error. Though there is little application for the computation in artillery, from the computation already discussed, it would be relatively simple to determine the probability of making an error greater than 1 00 metres and less than 100 metres.

30. The major reason for the difference in figures derived from the dispersion scale and those from the probability table is that linear interpolation is used with the dispersion scale when the conversion of a distance to PEs results in a fractional value. The assumption that the distribution of bursts is uniform within the limits of one error is false.

MOST PROBABLE POSITION OF THE MEAN POINT OF IMPACT

31. Thus far, only the probability of an outcome of a future event has been considered. This is not always the problem. For example, the observer's spottings in the fire for effect phase of a fire mission are the outcome of the rounds fired, but they do not in themselves define the relative locations of the MPI and target that yielded these spottings. The problem is to find the most probable relative locations.

32. There are simple methods of determining the most probable location of the target with respect to the MPI. These methods are based on, first, the fact that the definite range spottings used are of two outcomes only - either over or short; and second, the assumption being that the small number of rounds observed follows normal distribution exactly. For example, if five shorts and one over are obtained, five-sixths, or 83.33 per cent of the rounds fell short of the target. According to the dispersion scale, the target must be 1.52 PEs beyond the MPI (one PE +8.33 PE/16, or 1.52 PE beyond the MPI). By definition, 50 per cent 1.52 PE is beyond the MPI. By definitions 50 per cent of the rounds fell short of the MPI, therefore, 33.33 (83.33 - 50.00) per cent of the rounds fell between the MPI and the target. In the probability tables, 0.3333 represents 1.43 PEs to the nearest hundredth, which is a more accurate estimate of the distance of the target from the MPI. FTse of the preponderance formula described in Section 2 indicates the target to be 1.33 PE is beyond the MPI:

$$\frac{(5 \text{ shorts} - 1 \text{ over})}{2 \times 6} \times \text{fork} = 1/3 \text{ PE.}$$

33. Probability tables provide the most accurate answer. The preponderance formula is used, however, because of its simplicity and because the small number of rounds considered (six) does not warrant striving for the extra theoretical precision of the probability table.

SINGLE SHOT HIT PROBABILITY AND ASSURANCE

34. Single shot hit probability (SSHP) is the probability of hitting a target or area of finite dimensions with any one round.

35. The probability of a round hitting in any one of the areas bounded by one PE_r and one PE_d is the product of the probability of not exceeding that deflection error. This basic principle is applied in computing the SSHP. Before the probability tables can be used, the specific error must be reduced to equivalent PEs.

36. Computation of SSHP is based on the assumption that the MPI is adjusted to the exact centre of the target or area. This means, for example, that the limit of error is 20 metres if the target is 40 metres deep (see Figure 7-3-9). The same principle is true for deflection. Therefore, in order to reduce target dimensions to equivalent Figure 7-3-9 Single Shot Hit Probability PEs, it is first necessary to determine the limit of error for range, ie one-half that target dimension parallel to the GT line and for deflection, one-half that target dimension perpendicular to the GT line. Then, the limits of error are divided by the respective FT PEs for the weapon, charge and range being used. The quotient (t) is the limit of the error expressed in PEs and is the argument for entering the probability tables to determine the range probability and the deflection probability. The product of these two probabilities gives the probability of hitting a specific quarter of the four quarters of the target as shown by the shaded area in Figure 7-3-9.

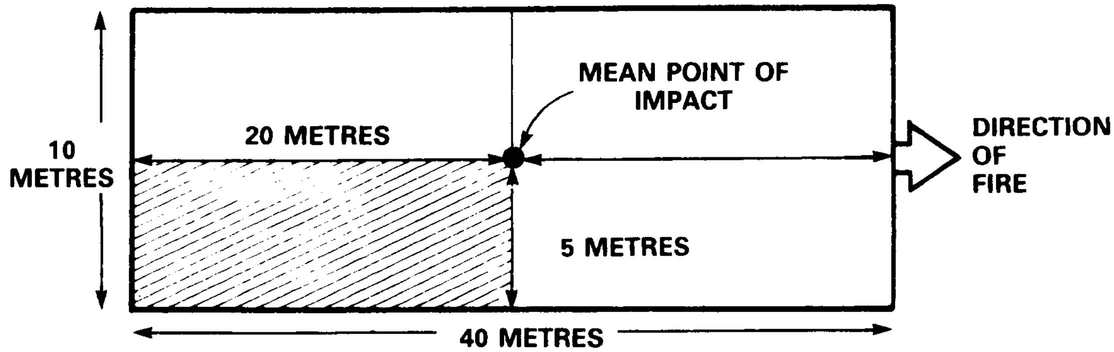


Figure 7-3-9 Single Shot Hit Probablility

37. Since a hit in any one of the four quarters constitutes success, the probability of getting a hit in any quarter must be multiplied by four. For example, the target is a bridge 10 metres by 40 metres with the long axis parallel to the bearing of fire. Range to target is 9 870 metres. The MPI is adjusted on the centre of the target by use of precision fire techniques. After the MPI is correctly adjusted on the centre of the target, the SSHP is computed as follows:

Given: a 155 mm Howitzer M109A2/A3 firing charge 7 at a range of 9 870 metres.

From the FT, determine PE_r and PE_d.

Enter Table G with range rounded to the nearest 100 metres (9 900). PE_r = 26 metres;

PE_d = 5 metres

$$\text{Range } t = \frac{1/2\ (40)}{26} = \frac{20}{26} = 0.77.$$

$$\text{Deflection } t = \frac{1/2\ (10)}{5} = \frac{5}{5} = 1.0.$$

From probability tables: Range t(0.77) = 0.1983;
Deflection t(1.00) = 0.2500.

SSHP = 4(0.1983) (0.2500) = 19.83 per cent.

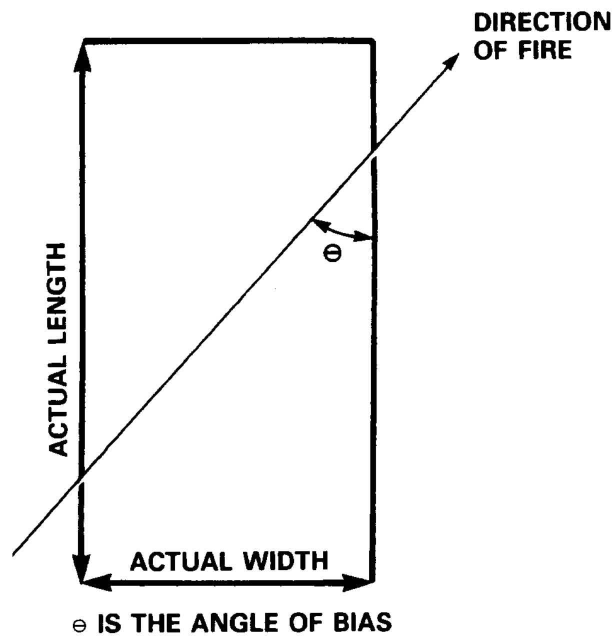


Figure 7-3-10 Bias Target

SINGLE SHOT HIT PROBABILITY FOR BIAS TARGETS

38. A target is said to be biased when its specified dimensions are neither parallel nor at right angles to the direction of fire. The only change in procedure required is that the specified dimensions of the target must first be converted to an effective depth and width that fits the dispersion pattern with respect to the line GT. Once the effective depth and width are known, the SSHP is computed as it was previously. Figure 7-3-10 illustrates a bias target.

39. The following tabulation can be used to approximate the effective dimensions. Greater accuracy is not warranted in view of the approximate dimensions of the target itself and the approximation of the angle of bias. The angle of bias is the smallest angle measured between the long axis of the target and the direction of fire.

Angle of bias between	Effective depth	Effective width
0 and 400 mils	Actual length	Actual width
401 and 650 mils	2 x actual width	0.5 x actual length
651 and 950 mils	1.41 x actual width	0.71 x actual length
951 and 1 200 mils	1.15 x actual width	0.87 x actual length
1 201 and 1 600 mils	Actual width	Actual length

40. For example, the target is a bridge 8 metres by 40 metres with the long axis at an 800 mil angle to the direction of fire. The range is 11 040 metres. After the MPI has been adjusted to the centre of the target, the SSHP for a 155 mm Howitzer M109A2/A3 firing charge 7 is computed as follows:

Effective depth = 1.41 (from paragraph 39 previously) × 8 metres = 11.28 (use 11).

PE_r = 28 metres

$$\text{Range } t = \frac{1/2\ (11)}{28} = \frac{11}{56} = 0.2.$$

Effective width = 0.71 (from paragraph 39 previously) × 40 metres = 28.40 (use 28).

PE_d = 6 metres

$$\text{Deflection } t = \frac{1/2\ (28)}{6} = 2.33.$$

From probability tables: Range t (0.2) = 0.0538;
Deflection t(2.33) = 0.4417.

SSHP = 4(0.0538) (0.4417) = 0.0950 or 9.50 per cent

CONVERSION OF A CIRCULAR TARGET TO AN EQUIVALENT SQUARE

41. Many targets are described as circular. In order to compute SSHP for a circular target, it is necessary to convert the target to a square of the same area. This conversion is necessary because the dispersion pattern of guns is elliptical and can be reasonably defined by a rectangle.

42. A circular shape is converted to a square shape by multiplying the radius of the circle by 1.7725 (1.7725 is the square root of pi). The product is the length of the side of a square that has an area equal to the area of the original circle.

ASSURANCE AND ASSURANCE GRAPHS

43. Assurance is a broad term associated with the probability of hitting a target with any given number of rounds, assuming a constant SSHP.

44. The assurance formulae for at least one hit, two hits, three hits, etc may be graphed as shown in Figures 7-3-11 through 7-3-13. The only computation necessary is that for the SSHP. Once that is known, the graph provides a rapid determination of either the assurance obtainable from firing a specified number of rounds (N) or the number of rounds required for a desired assurance.

Assurance formula: Assurance = 1 - (1 - SSHp)^5

45. The number of rounds is indicated along the bottom of the graph, the SSHP is indicated on either side of the graph and the assurance is indicated by the curves drawn within the graph. When the assurance graph is used, the intersection of the two known elements is found and then the desired element is read opposite this intersection. Interpolation between numbered graduations is permissible.

46. For example, determine the assurance of getting at least one hit when 20 rounds are fired with a SSHP of 0.045. (Answer: 0.60, Figure 7-3-11). Determine the number of rounds required for at least two hits when the SSHP is 0.08 and the desired assurance is 0.70. (Answer: 30 rounds, Figure 7-3-12).

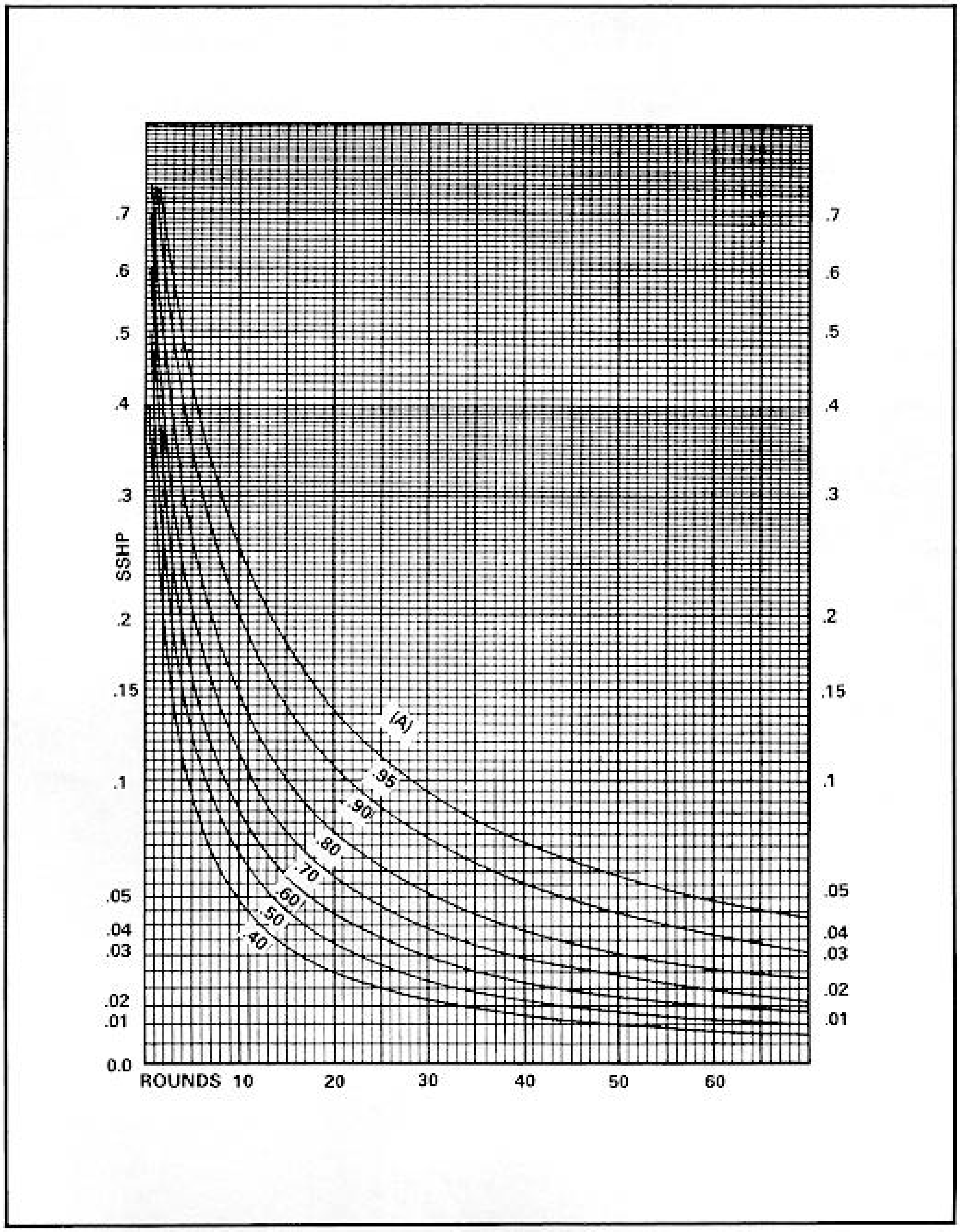


Figure 7-3-11 Assurance of at Least One Hit for "N" Rounds when Single Shot Hit Probability is Known

47. Although it is impossible to be certain of the number of rounds needed to hit or destroy a target, use of the graphs will provide an approximation. Probability (assurance) is a substitute for fact and, until the fact is actually known, probability provides the best guide as to what to expect. Unfortunately, the SSHP and assurance levels are usually less than the ones derived from the method in paragraphs 43 through 45 previously, because the MPI usually is not at the centre of the target as assumed. For example, an apparent MPI located by the mean of 12 rounds is more accurate than one located by the mean of only 6 rounds. An estimate of the PE of the MPI as a function of the number of rounds from which it was determined can be found by multiplying the FT PE by the following appropriate factor.

Number of Rounds	**Factor**	**Number of Rounds**	**Factor**
2...................	0.7.................	12.................	0.3................
4...................	0.5.................	14.................	0.3................
6...................	0.4.................	16.................	0.3................
8...................	0.4.................	18.................	0.2................
10..................	0.3.................	20.................	0.2................

48. In the example shown in paragraph 37 for the 155 mm Howitzer M109A2/A3, if the adjusted data of the MPI were based on 6 rounds, then the PE_r of the MPI at that range would be 10 metres (0.40 x 26 = 10.40). This has the effect in SSHP computations of an apparent increase in the weapon PE. The magnitude of the apparent weapon PE is approximately equal to the square root of the sum of the squares of the weapon PE and the MPI PE or, in this case, ? $26^2 + 10^2$, equals 28 metres to the nearest metres. Hence, 28 metres would be used in the place of 26 metres in the computation of SSHP. If the target is to be engaged without adjustment, the apparent weapon PE is assumed to be twice the weapon PE. The PE_d can be found in a similar manner although the change normally will not be significant. The method outlined previously is valued for only one round in fire for effect. Thus, it is not to be used with the assurance graphs.

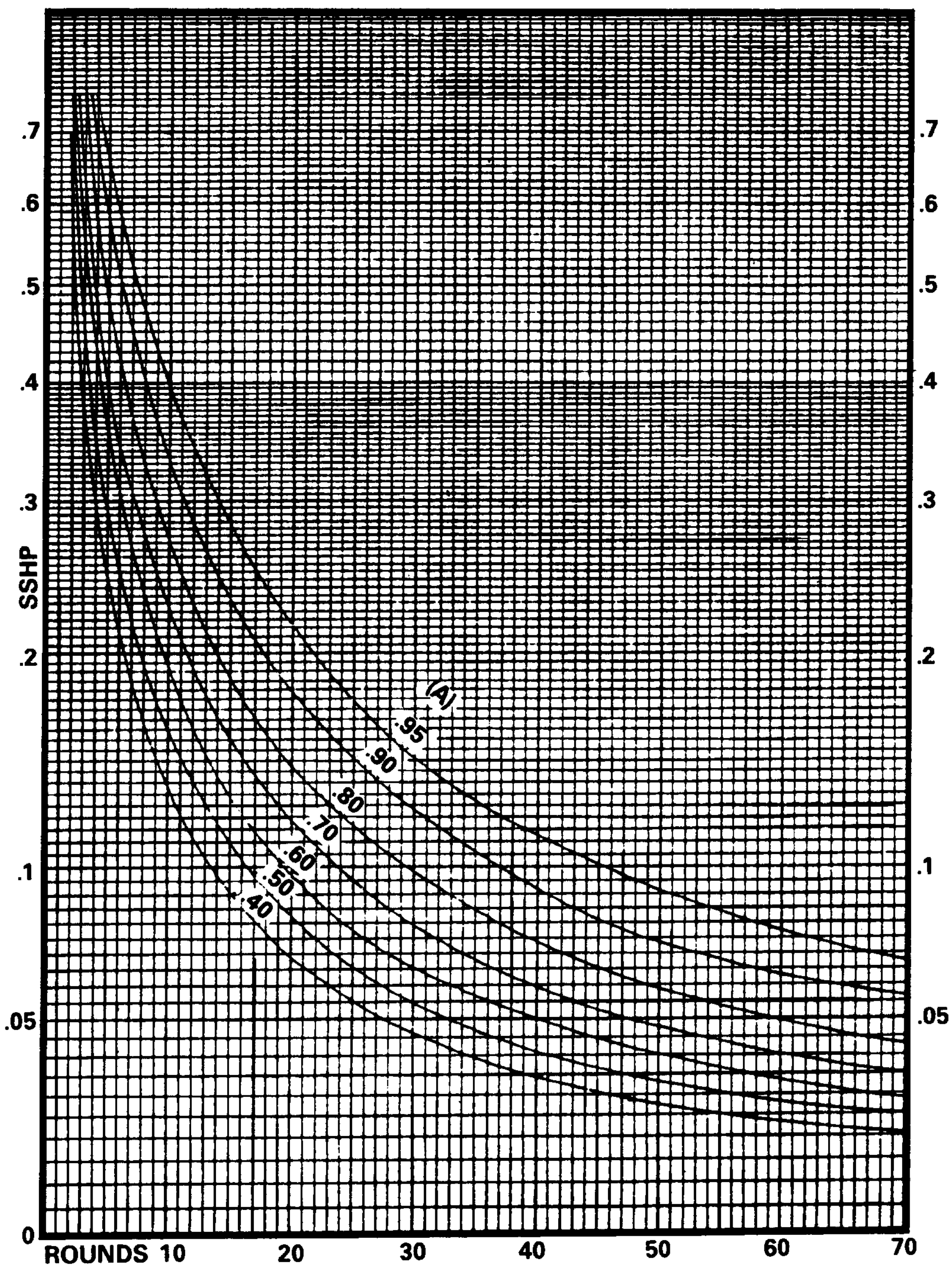


Figure 7-3-12 Assurance of at Least Two Hits for "N" Rounds when Single Shot Hit Probability is Known

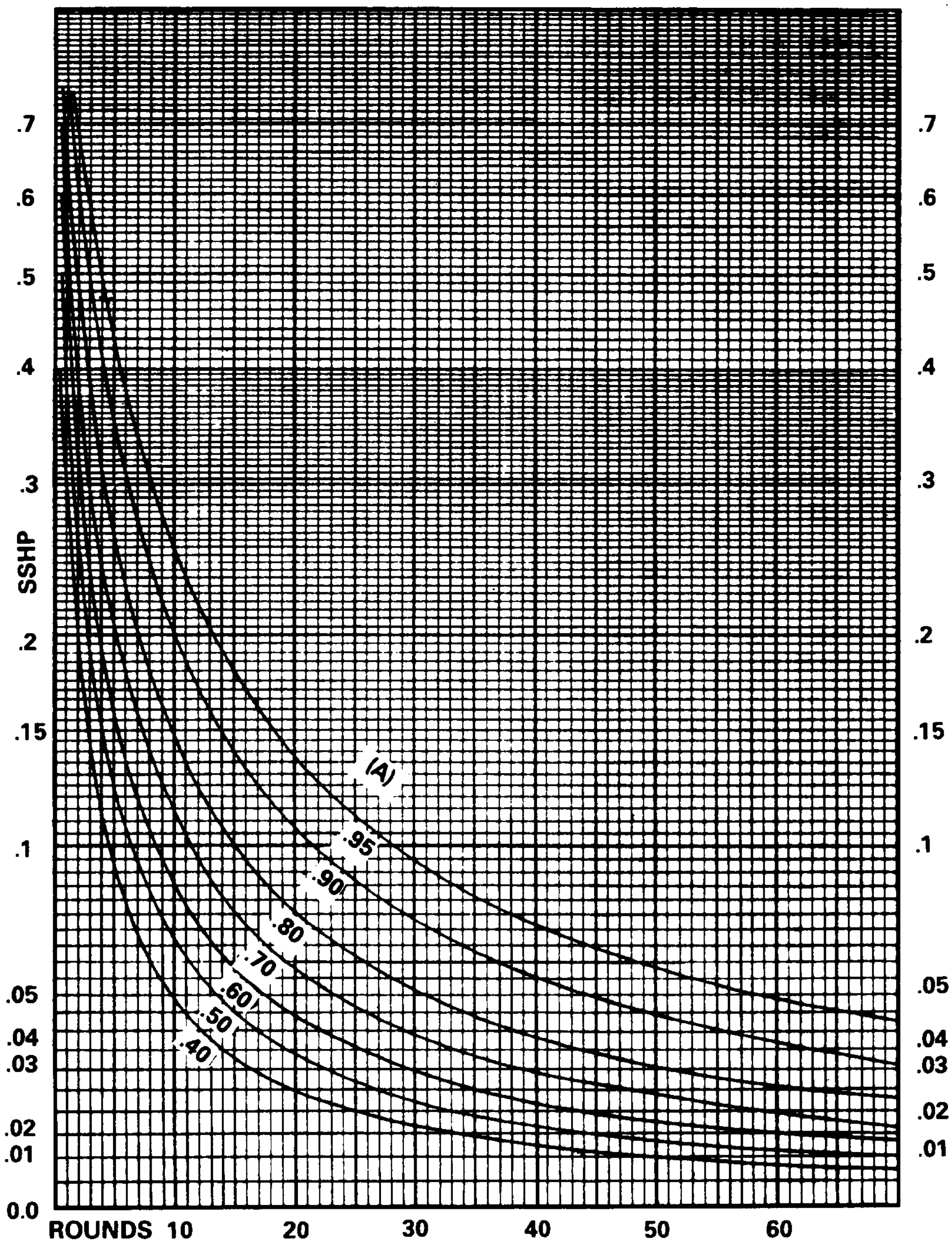


Figure 7-3-13 Assurance of at Least Three Hits for "N" Rounds when Single Shot Hit Probability is Known

CHAPTER 8

FIRE CONTROL DATA

SECTION 1

ESTABLISHING BALLISTIC DATA

GENERAL

1. For fire control purposes, ballistic information is required to be presented in various forms, such as computer gunnery tapes, FTs and GFTs. It is the user who decides what is required and, subject to any standardization agreements in what form it should be presented. This information is derived from basic data obtained from trials.

DETERMINATION OF BASIC BALLISTIC DATA

2. The behaviour of a projectile in flight is a complicated function of its size, shape, mass distribution and aerodynamic characteristics. The dominant aerodynamic parameter is drag, ie the force acting along the tangent to the trajectory which opposes motion. The Drag Law or Resistance Law is determined at an early stage by wind tunnel tests, firing in an indoor range using spark photography, or by comparison with previous designs. The drag law is used for the calculation of trajectories.

3. R and A firings of projectiles of the standard finally accepted for service take place under carefully controlled conditions at Proof Experimental Test Establishments, where a high standard of instrumentation is available. For each round fired, measurements are recorded of projectile weight, gun elevation, MV, TOF, range to impact or burst and deflection. Charge temperature is carefully controlled throughout the firing. Barrel wear and the met conditions prevailing at the time are also measured. Bias errors are removed as far as possible by firing on different occasions, using a number of guns and several elevations for each charge.

4. For each combination of gun, elevation, charge and occasion, an estimate is made of a fitting factor (equivalent to K_o) which, with the established drag law, gives the best match to the observed results. This fitting factor is necessary because of the effect of the projectile's yawing motion, which is not allowed for in the mathematical model currently used for trajectory calculation and because of errors in observations of drag and met conditions. This fitting factor is included in the C_o and is determined with respect to the range of the projectile.

PROCESSING OF BALLISTIC DATA

5. Analysis of R and A trials provides estimates of C_o deflection, TOF and the standard of these parameters. Statistical techniques are now used to express C_o and deflection as polynominal algebraic expressions of elevation that are used to compute all the data required for

computer tapes and FTs. Because C_o is derived with respect to range only, errors will occur in the TOF and it is necessary, therefore, to correct the estimated TOF to those observed in the trial.

NON-STANDARD AMMUNITION

6. For HE projectiles where accuracy of delivery is essential, the full procedure outlined previously is needed; for other ammunition such as the illuminating round which does not need such accuracy, the expense and delay of repeating this procedure would not be justified and, in any case field computers have insufficient capacity to store a separate drag law for each type of projectile. Instead, trials are fired to compare the non-standard projectile, round for round, with the HE projectile and, if necessary, a further correcting factor called the ballistic correction factor (13CF) is deduced, which is applied to C_o. A BCF may also be applied to the projectile in certain circumstances when using field computers, eg for projectiles manufactured in different countries.

PREPARATION OF COMPUTER TAPES AND FIRING TABLES

7. **Computer Gunnery Tapes**. Ballistic data are used to develop the program tape required for computers. This program also incorporates weapon limitations and relevant user requirements. Each program is checked for validity and accuracy against a large number of problems, many of which are randomly generated. Comparisons are also made between the solutions to a large number of problems solved by the field computer and by the more accurate computer used to produce the original data. When both the drills and the ballistic accuracy are satisfactory, the program design is **protected** and the tape copied for issue to the user. Computer tapes cannot be amended. Changes in the ballistic data or in the drills necessitate the issue of a new series of tapes, except that changes can be entered manually after programming.

8. **Firing Tables**. In order to produce FTs, trajectories are calculated for a number of angles of elevation at close intervals in the range of MVs likely to occur during the life of a gun. These trajectories are then used with a computer program that inverts the argument from elevation to range, as it is required by the FTs. Similar data is required for the production of the GFT. Other computer programs are used to calculate corrections such as those for non-standard met parameters or for earth's rotation. The output from these programs is then used with an editing program to produce a master tape that generates the required FT layout onto bromide paper. Printed headings are attached, details of lines, shading, etc, are completed by an illustrator and the result is reduced to a photographic negative that is used for the final printing. The process is mechanized as far as possible to reduce human error and reduce the checking that takes place before the tables are finally produced. Fts are produced to the NATO-agreed format.

SECTION 2

TABULAR FIRING TABLES

GENERAL

1. For simplicity and ease of computation, FTs are computed assuming certain so-called standard conditions. Not only are these standards physically impossible to attain, but include for convenience, many factors that have been discussed in Chapter 3. Standard conditions assume a gun located at sea level is firing at a target also at sea level. In addition, the firing is on a flat, non-rotating earth with only drag and gravity forces acting (no wind) and with a standard distribution of air density and temperature. The projectile has no dimensions and its mass is considered a particle located at the CG. Standard air temperature is 15 degrees C (50 degrees F) and standard propellant temperature is 21 degrees C (70 degrees F). The standard air temperature was selected because at sea level, the speed of sound is the standard 340 m/s (1 120 Ws) at 15 degrees C (50 degrees F). The 21 degrees C (70 degrees F) for standard propellant temperature was arbitrarily selected.

2. In past years, FT computations were done by dozens of mathematicians integrating the equations of motion for weeks to produce one table. High speed computers have simplified the task and also permit improvements in the calculations.

CONSTRUCTION OF THE FIRING TABLES

3. The following discussion on the construction of the FTs is designed to outline the important points. Some of the items are self-evident so that only a minimum of comment will be made on them.

4. **Table A**. Entry is with QE either known or inferred. QE best describes tile height of the trajectory (vertex) and, therefore, the segment of atmosphere through which the projectile will fly. The height of trajectory is determined by computer simulation using the equations of motion. There is no allowance given for the possibility that the met datum plane (MDP) may be at a different altitude than the gun except to correct air density and air temperature. Studies have shown that even in the unusual case where the MDP is a line number or more above or below the gun, there is a negligible error in the manual solution. There is, of course, no error in the field computer solution. The principal reason for not correcting for the difference in altitudes between MDP and gun is that winds tend to follow the contours of the earth. Table A also assumes that the target is at the level point. If there is a large vertical interval (positive or negative) the line number selected will not exactly describe the atmosphere through which the projectile flies. There is only a negligible error in this circumstance. Field computers do not have this problem as they consider the vertical interval and simulate the projectile flight through the correct portion of the atmosphere.

5. **Table B**. The line number is extracted as a function of range and vertical interval. A comparison of QE from Table A and a corresponding range and vertical interval converted to a QE will show that Tables A and B result in the same line number. The change in range for

complementary angle of sight is determined by running a computer simulation of the trajectory at each listed range and vertical interval. The difference in range between zero vertical interval and the listed vertical intervals is in the body of the table.

6. **Table C**. This table is a simple look-up of the wind vectors involved as a function of bearing of fire and direction of wind. In Figure 8-2-1, given a bearing of fire and direction of wind, the effect of the wind is determined by computing the sine and cosine values for a wind of 1 knot. Angle A is the chart direction of the wind (direction of wind minus bearing of fire). The values of range wind are cos a = X/1 knot wind and for cross-wind, sin a = Y/1 knot wind. Multiplying cross-wind and range wind components by the wind velocity provides the effect on the projectile for the wind at other than 1 knot. Because the hypotenuse of the triangle in Figure 8-2-1 is one, the square root of the sums of the squares of the cross-wind and range wind components is one.

7. **Table D**. Values in Table D are standard departures of air density and temperature as a function of height are then converted to a per cent of standard.

8. **Table E**. Muzzle Velocity Firings are usually conducted at 21.1 degrees C (70 degrees F standard), 51.7 degrees C (125 degrees F), 17.8 degrees C (0 degrees F) and - 40 degrees C (-40 degrees F). Propellants are pre-conditioned to these temperatures and fired with MVs measured by chronograph. A smooth graph is constructed and the values listed in the table are extracted.

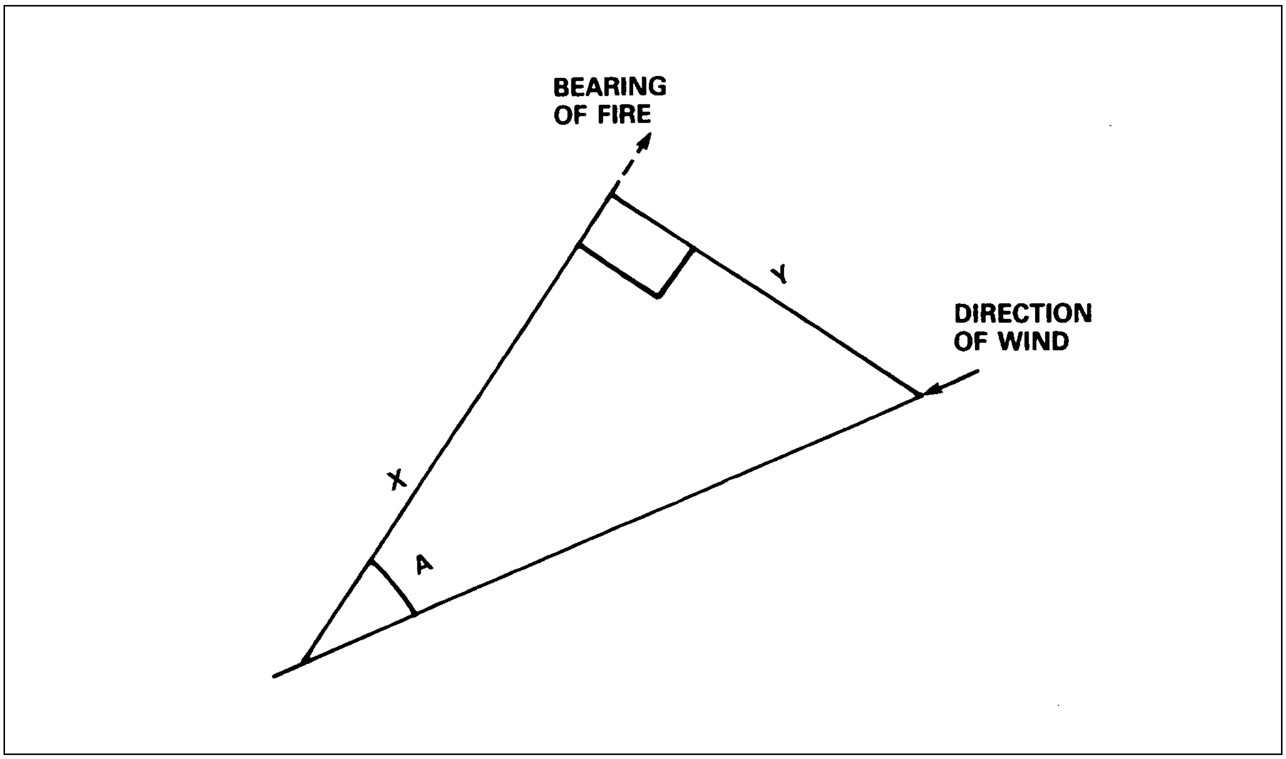


Figure 8-2-1 Determining Components of a 1 Knot Wind

9. **Table F**. The basic data tables are determined as follows:

a. **Ranges**. Ranges listed are on the surface of the earth and are described in the FTs as spherical ranges. This is really a misnomer because the corresponding elevations are those angles required to reach the listed ranges on a flat earth. In effect, for all practical purposes, the ranges can be considered as horizontal rather than spherical.

b. **Elevations**. Elevations listed are those required to reach the ranges in column one. Firings are usually conducted at elevations of 267, 445, 622 and 800 mils (15 degrees, 25 degrees, 35 degrees and 45 degrees) to provide coefficients for the basic equations of motion. Computer simulations fill in those elevations not actually fired. Elevations normally stop at around 1 170 mils (depending on weapon and charge) because at higher angles there is a high probability that the projectile will not track and thus land base first or on its side.

c. **Fuze Setting**. The fuze setting for a graze burst is obtained much like elevation. A limited number of highly instrumented firings at elevations of 800, 978 and 1 156 mils (45 degrees, 55 degrees and 65 degrees) provide a coeff icient for use in computer simulations.

d. **Time of Flight**. TOF is real time as differentiated from fuze settings.

e. **Drift**. Firings to determine drift corrections are usually conducted at elevations of 267, 445, 622, 800, 978 and 1 156 mils (15 degrees, 25 degrees, 35 degrees, 55 degrees and 65 degrees). A drift K for the difference between machine computer drift and observed drift is applied to all ranges.

f. **Bearing Corrections**. Bearing corrections for wind are obtained from computer simulations by programming 50 knot head and tail winds into the computer. Dividing by 50 provides data for a 1 knot wind.

g. **Columns 10 to 19**. These corrections are obtained in the same manner as are the (bearing) corrections for a 1 knot wind. Computer simulations are made with non-standard conditions of air density (± 10 per cent), air temperature (± 10 per cent), projectile weight (approximately ± 1 square), ballistic wind (± 50 knots) and MV (± 15 m/s). The factors listed are correct for each non-standard condition on the assumption that all other conditions are standard. This is never the case. The interaction effects introduce a small error into the manual solution. This cannot be avoided without complicating the manual procedure. Field computers greatly minimize this problem.

10. **Table G**. The supplementary tables are determined as follows:

a. **Probable Errors**. PEs are obtained from firing 10 round groups at key ranges and charges. PEs for ranges not fired are obtained by interpolation.

b. **Maximum Ordinates**. The maximum ordinates are computed in relation to a spherical earth rather than a flat one. At short ranges the difference between vertex above the arc as opposed to vertex above the horizontal is small, eg 8 metres at 10 000 metres. With longer ranges, the difference is 31 metres, and at 30 000, 71 metres.

c. **Complementary Sight**. Complementary sight factors are determined by computer simulations. Each listed range is fired (in the computer) at the level point and at ± 50 mils A/S. The difference between elevation required to achieve each range at the level point and each corresponding elevation plus A/S is the complementary sight for 50 mils. Dividing by 50 provides the complementary sight factor per mil. The values are valid for angles of sight up to and slightly beyond 50 mils but break down rapidly thereafter. The 50 mil A/S used in the computations maximizes the most used angles of sight rather than the large angles.

11. **Tables H and I**. One of the standards selected for making the FT is that of a non-rotating earth. Since the earth does rotate, corrections must be made for this fact. The effect of the earth's rotation depends upon bearing of fire, QE, projectile velocity, range and gun latitude. As these factors change, so do the corrections for them (see Chapter 3, Section 5).

12. **Table J**. Values are derived in the same manner as were those for Table F.

13. **TabIe K**. Correction to fuze settings for fuze M564 to obtain fuze setting for fuse M520A1.The correction listed is added to the setting listed for the M564 fuze.

FIRING TABLE LAYOUT

14. The layout is standardized by agreement with other NATO countries. The aim of this agreement is to standardize the format of gun/howitzer surface-to-surface FTs by specifying the sections of these tables and the type of information and layout of data using standard symbols where possible. Also, it makes it possible for NATO Forces to understand and use each other's FTs, especially when applicable to common equipment.

15. The introduction portion of the FTs provides the user with information for using the tables. Detailed information on the use of FTs and arguments for entry with examples is contained in B-GL-306-008/FP-001, Field Artillery, Volume 8, Instruments, and is the authority for use of the FTs in the Canadian Forces Field Artillery.

CHAPTER 9

AMMUNITION

SECTION 1

INTRODUCTION

GENERAL

1. This chapter is only an introduction to ammunition in its broadest context. The illustrations are not detailed but are included to indicate basic forms and general comparisons.

2. Details of specific ammunition and explosives are contained in the R-74-007-009/TA-000 and C-74-000-000/RR-01 5 manuals, the applicable Handbook of Equipment and Ammunition and appropriate Canadian Forces Technical Orders (CFTOs).

DEFINITIONS

3. **An Explosive**. An explosive is a substance which, on being suitably initiated, is capable of exerting a sudden and intense pressure on its surroundings. Initiation may be achieved by a blow, flash or friction. The pressure is produced by the extremely rapid decomposition of the explosive, which produces a large volume of gas, accompanied by extreme heat. An explosive can either explode or detonate. An explosive may be a chemical compound such as TNT, NG, or a mixture of chemical compounds such as TNT and RDX comprising compound B or a mixture of compounds and elements such as potassium nitrate, sulphur and carbon, which make up black powder. An explosive may be solid, liquid, or gaseous. Military explosives are chiefly solids, or mixtures so formulated as to be solid at normal temperature use.

4. **An Explosion**. An explosion is very rapid combustion, transferring heat through the explosive material. The combustion causes the liberation of gases which generate a high pressure. These gases are further expanded by heat caused by chemical reaction. The combustion can take place without the presence of atmospheric oxygen, as oxygen is self-contained in the majority of explosives. The velocity of combustion may be up to 400 m/s dependent upon pressure and temperature. Flash and sound accompany the liberation of gas and heat.

5. **A Detonation**. A detonation is the almost instantaneous disintegration of an explosive by a shock wave. The elements produced immediately reform in a different way, producing a sudden very high pressure, resulting in an intense shattering action. The detonating wave travels with velocities from 1 000 to 9 000 metres plus per second, according to the nature and density of the explosive. Once initiated, this velocity cannot be controlled.

6. An explosive that is capable of detonation is known as an HE. Some explosives are capable of decomposing initially by explosion, but on building up to a critical pressure, change to detonation. These explosives are said to burn to detonation.

SERVICE CLASSIFICATION

7. Explosives may be grouped in various ways. Service classification groups explosives by the use to which the explosives are put. There are three main groups:

a. **Low Explosives (propellants)**. Low explosives decompose or burn at controllable rates that are much slower than those rates associated with HEs. In most cases they are used to generate the necessary volume and pressure of gases to propel a projectile out of the weapon at a velocity.

b. **High Explosives**. HEs, when suitably initiated, undergo detonation and are used for their disrupture action. The more sensitive HEs are used as initiators while those less sensitive are used as bursting charges in projectiles.

8. An explosive, before it can be adapted for military use, should have the following characteristics:

a. chemical stability over extended periods of storage under normal conditions;

b. ability to withstand the mechanical shocks incident to loading, transporting and handling;

c. ability to withstand the shock of setback on firing;

d. susceptibility to complete ignition or detonation under the action of the preceding element in the explosive train;

e. brisance - shattering ability; and

f. a reasonable degree of economy in manufacture.

SECTION 2

PROPELLANTS

INTRODUCTION

1. A propellant is an explosive used to propel the projectile out of, or from a delivery system at a controlled velocity. It explodes at a predicted rate even though some, or all of its ingredients are capable of being detonated.

2. It is essential that the rate of burning of a propellant should be controlled to achieve:

   a. the desired velocity,

   b. ballistic regularity, and

   c. a safe maximum chamber pressure.

3. Modern propellants burn regularly because of their physical nature. The burning is purely on the surface and the rate of burning increases as pressure on the surface increases.

4. Control is achieved by varying the shape, size and composition of the propellant grains so that the surface available to burn and onto which pressure can be exerted, is predetermined. The variations in pressure obtained with different propellant shapes and sizes are discussed in Chapter 2, Internal Ballistics (see also Chapter 2, Section 2, Propellant).

PROPELLANT SHAPE

5. Typical gun propellant shapes and sizes are shown in Figure 9-1-1. Their burning characteristics are:

   a. **Cord**. The surface area and, therefore, time to **All Burnt** will depend on the diameter of the cord. During burning the diameter, and as a result the pressure, is not well sustained. The burning action of this grain is known as digressive (not used in artillery weapons).

   b. **Single-perforated (Tube)**. With this grain, the outer surface decreases and the inner surface increases. The surface area during burning remains practically constant and as a result, pressure is more sustained. The burning action of this grain is known as neutral.

c. **Multi-perforated (Multi-tubular)**. With this type, the total surface area is increased during burning since the perforated grain burns from the inside and outside at the same time. As a result, the pressure buildup is sustained. During burning, the seven tubular perforations cause the inside surface areas to increase much faster than the outside surface decreases. Since the total surface area increases, multi-perforated grains burn at a progressive rate and are known as progressive.

d. **Strip (Ribbon)**. This is ballistically similar to tube form in that the surface area during burning remains practically constant. Strip does not pack satisfactorily inside rigid cartridges. The surface should be rough to a certain extent to avoid strips sticking together and, thereby, completely altering the burning surfaces. If strips are roughened, it is almost impossible to get a satisfactory method of measurement through routine inspection. Square flake also exhibit the same characteristics. These propellants are used in mortars.

e. **Slotted Tube**. This form behaves ballistically like the ordinary tube form, ie produces an approximate constant burning surface. With the ordinary tube, as the inside burns, an excessive pressure is developed in the tube itself causing irregular burning. If the physical strength of the propellant is low, the internal pressure may burst the tube and cause a sudden increase in the burning surface resulting in irregularities of pressure and MVs. The slotted tube overcomes these defects by allowing gases that develop in the tube to escape freely through the slot.

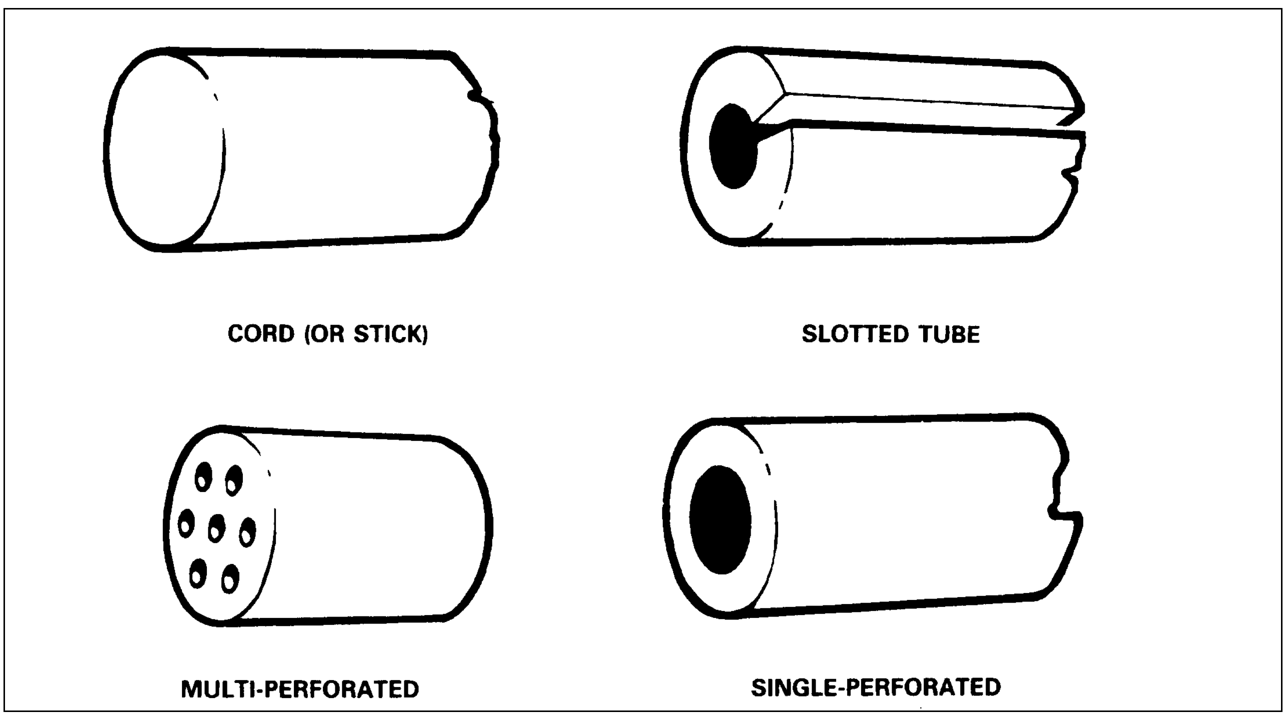


Figure 9-1-1 Share of Propellants

PROPELLANT DESIGN CONSIDERATIONS

6. Certain chemical and physical difficulties in composition make a compromise between some of the following requirements necessary when designing propellants. The requirements are:

a. regular ballistic performance,

b. absence of smoke,

c. absence of muzzle flash or after flash,

d. freedom from poisonous fumes,

e. minimum erosion of the bore and chamber,

f. absence of solid residue in bore and chamber,

g. ease of ignition,

h. stability in storage under any conditions, insensitivity to shock and friction,

k. non-hygroscopic (does not tend to absorb moisture from the air),

m. no tendency to detonate when used in a gun,

n. rapid, easy and safe to manufacture, and

p. maximum power for minimum bulk.

7. The pressures developed by the burning propellant are controlled by the selection of the propellant shape, size, composition and the amount used. All the foregoing have to be considered in relation to the size of the chamber, dimensions of the base and projectile weight. For these reasons, a propellant that is suitable for one gun may not be suitable for another. The ideal situation would be achieved where only one nature of propellant is used in any one equipment. This is not always possible.

8. The basis of all propellants considered in this chapter is NC. When a propellant is based on NC alone it is termed single base. Another type, termed double base, is composed principally of NC, the remainder being NG. A third type is made of major portions of nitro guanidine (picrite) with the remainder being NC and NG. This is known as a triple base propellant.

9. Most modern day propellants are either single, double or triple base. Composite base propellants are mainly produced by the US. Because current Canadian in-service equipments are of US manufacture, Canadian in-service propellants are single base (Ml) and are produced in Canada to US specifications (see Figure 9-2-1).

ADVANTAGES AND DISADVANTAGES OF SINGLE, DOUBLE AND TRIPLE BASE PROPELLANTS

10. **Single Base Propellants**. Single base propellants have certain advantages and disadvantages when compared with double base propellants. These are:

a. **Advantages**. The following are advantages of single base propellants -

(1) They are cooler burning due to the lack of NG content. As a result, they are less corrosive in the bore.

(2) They normally produce less flash.

(3) Their ballistic qualities are less affected by changes in charge temperature.

(4) As they are produced in granular form, they are readily adaptable for the filling of quick-firing (QF) cartridges.

(5) They are generally less expensive to produce because the NC base contains none of the oils or fats that are contained in NG.

b. **Disadvantages**. The following are disadvantages of single base propellants -

(1) They tend to be more hygroscopic and, therefore, deteriorate more rapidly in storage.

(2) They are more difficult to ignite.

(3) They are less powerful for given weight.

(4) A large amount of solvent is used in their manufacture and small amounts of the solvent remain in the finished propellant. These traces tend to decompose during extended storage ultimately altering the ballistic characteristics of the propellant (exudation).

(5) The finished propellant is very brittle and as a result, it is made in granular form. When this granular form is used in large breech loading (BQ cartridges, there is a tendency for the bags to lose their shape and become difficult to handle.

11. **Double Base Propellants**. Double base propellants are made up of NC & NG, NC being the major portion. Double base propellants burn very hot compared with single base propellants because of the high NG content:

a. **Advantages**. The following are advantages of double base propellants -

(1) greater ballistic potential,

(2) less complications in manufacture, and

(3) less hygroscopic;

Composition	M1 (per cent)	M2 (per cent)	M5 (per cent)	M6 (per cent)	M7 (per cent)	M8 (per cent)	M9 (per cent)	M10 (per cent)	M13 (per cent)	M15 (per cent)	M17 (per cent)	M26 (per cent)	M26A1 (per cent)	M30 (per cent)	M30A1 (per cent)	M31
Nitrocellulose:																
12.60 per cent N														28.0	28.0	20.0
13.15 per cent N	84.2			86.1	54.6			98.0	57.3	20.0	20.0	67.25	68.70			
13.25 per cent N		75.55	81.5			52.15	57.75									
Nitroglycerin		19.95	15.0		35.5	43.0	40.0		40.0	19.0	21.5	25.0	25.0	22.5	22.5	19.0
Barium nitrate		1.50	1.5									0.75				
Potassium nitrate		1.00	1.0			1.25	1.5					0.7				
Potassium perchlorate					7.8											
Nitro guanidine										54.7	54.7			47.7	47.0	54.7
Dinitrotoluene	9.9	1.0		9.9												
Dibutylphthalate	4.9			3.0												
Diethylphthalate						3.0										
Potassium sulfate								1.0	1.5						1.00	
2-Nitrodiphenylamine																1.5
Diphenylamine	1.0	0.75	0.75	1.0			0.75	1.0	0.2							
Ethyl centralite					0.9	0.6			1.0	6.0	1.5	6.0	6.0	1.5	1.50	
Graphite		0.25	0.25									0.3	0.3			
Carbon Black					1.2				*0.05							
Cryolite										0.3	0.3			0.3		0.3
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Figure 9-2-1 In-Service Artillery Propellants

b. **Disadvantages**. The following are disadvantages of double base propellants -

(1) very corrosive, and

(2) least stable of standard propellants.

12. **Triple Base Propellants**. Triple base propellants contain a predominant amount of nitro guanidine commonly called picrite. The use of picrite assists in making the propellant flashless and also offers the following advantages and disadvantages over single and double base propellants:

a. **Advantages**. The following are advantages of triple base propellants -

(1) They are cool burning and as a result are less corrosive.

(2) The quantities of NC and NG required are small.

(3) Less time is required in the manufacturing process.

(4) They give much less flash.

b. **Disadvantages**. The following are the disadvantages of triple base propellants -

(1) They are slightly less powerful than double base propellants (but more powerful than single base). They require an increase of approximately 15 per cent in bulk to achieve similar ballistics effects.

(2) They produce more smoke.

GRANULATION

13. Propellants are manufactured in different sizes and shapes (see Figure 9-1-1). With regard size, it can be said that propellant cartridges are either **single** or **dual** granulation, ie:

a. Single granulation cartridges are those that have one size/shape of propellant in their content.

b. Dual granulation cartridges are those that have two sizes or shapes combined in their content. FTsually the different propellant size and shape are not mixed throughout the cartridge but rather the cartridge will consist of some bags of one size or shape while the remaining bags of the cartridge will contain the other size and shape, eg the 105 mm M67 Propelling Charge.

FLASH AND SMOKE

14. The propellant gases generated on firing produce both smoke and flash on coming in contact with the air. The release of hot gases under great pressure is termed muzzle blast and on striking the ground may produce a large dust cloud adding to the smoke already produced. All this smoke, flash and dust are undesirable since they result in the loss of concealment and may interfere with laying and observation, particularly during direct fire.

15. Flash is caused by the release of very hot carbon monoxide (CO) and hydrogen (H) gases which are generated by the burning propellant coming in contact with atmospheric oxygen and igniting. Flash may be reduced by:

a. using cool burning propellant so that the gaseous release is not hot enough to combine with atmospheric oxygen and ignite;

b. including picrite in the propellant as this will generate a large amount of nitrogen, which largely dilutes the CO and H gases and prevents them from forming an ignitable mixture with the atmospheric oxygen; or

c. adding small amounts of certain compounds, eg potassium sulfate mixed with black powder, as this will dampen the reaction of the CO and H with atmospheric oxygen.

16. The class of propellants known as flashless and smokeless (designated as FNH) comprises compositions that are used mainly in field artillery. Whether a composition is flashless depends to some extent upon the gun in which it is used. For example, the M1 composition is flashless when used in a 75 mm gun, but in the 8-inch gun the propellant is not flashless. It should be desirable to have flashless propellants for all weapons but this objective has not yet been attained.

17. Modern cartridges have flash reducers incorporated in their manufacture in the form of pads sewn on the ends of charge bags. A typical cartridge incorporating flash reducers is shown in Figure 9-2-2.

18. Flashless propellants tend to be bulkier than the hotter variety, thus a larger charge is required to achieve comparative ballistics. They are also more difficult to ignite and igniter pads used with them usually contain more black powder.

19. As a rule, what tends to lessen flash will increase smoke and vice versa. For this reason, a balance between the two must be, and usually is accepted. To this date, no propellant has been developed that is completely flashless and/or smokeless. The smoke/flash problem is greatest in those equipments having high MVs with large propellant charges and large chamber pressures.

20. For indirect fire weapons, flash is considered to be less acceptable than smoke because of enemy locating techniques, whereas smoke is considered less acceptable for direct fire weapons as it restricts observation.

COMMON PROPELLANT ADDITIVES

21. A wide range of chemical substances is added to propellants to perform one or more of the following three functions:

a. **Stabilizers**. Stabilizers are substances that are used to prevent a propellant from decomposing in storage. The ideal stabilizer must be -

(1) capable of neutralizing any acid in the propellant;

(2) a substance that can be mixed with NC, NG and nitro guanidine;

(3) inert towards NC, NG, and nitro guanidine; and

(4) able to absorb nitrogen oxides.

b. **Solvents**. Solvents are used during the manufacturing process to render the NC, which is fibrous, into a jelly or gelatinous form. In this collodial form regularity of burning is achieved. Two of the common solvents in use are acetone and ethyl alcohol.

c. **Moderants**. These are ingredients added to the compositions of propellants to reduce the heat of burning and to provide a waterproofing medium.

22. A list of the more common propellant additives is shown in Figure 9-2-3.

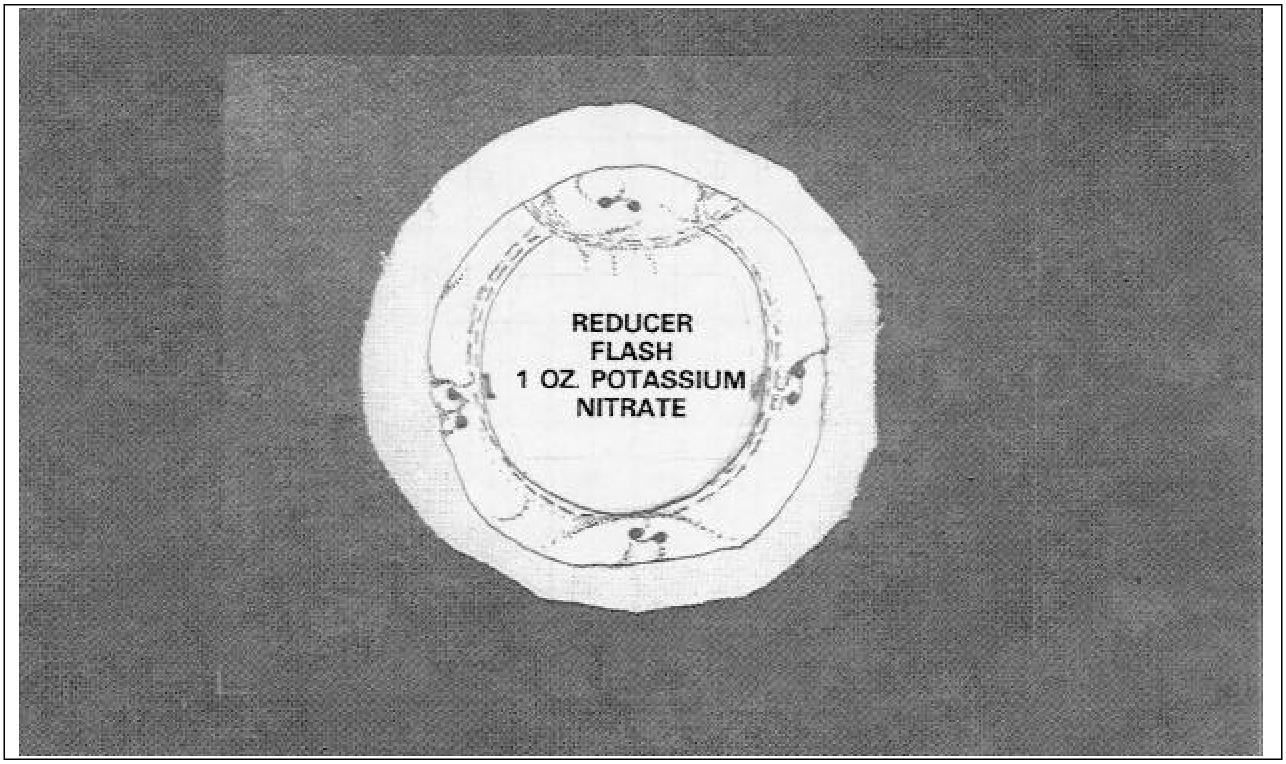


Figure 9-2-2 Typical Flash Reducer Additive

Material \ Purpose	Reduce Hygro-scopicity	Stabilizer	Plasticizer	Deterrent	Reduce Flame Temp	Reduce Flash	Reduce Bore Erosion	Increase Electrical Conductivity	Control Burning Rate	Source of Oxygen	Retards Ignition	Increases Ignita-bility	Moisture Proof Coating
Nitroglycerin (NG)	X		X							X		X	
Nitro guanidine					X	X	X						
Dinitrotoluene (DNT)	X		X	X			X		X				X
Methyl centralite			X	X		X	X		X				
Ethyl centralite *	X	X	X	X	X	X	X		X				X
Diphenylamine **		X											
Dibutylphthalate	X		X	X	X	X	X		X				
Diethylphthalate						X	X		X				
Barium nitrate						X							
Potassium nitrate						X							
Potassium perchlorate						X			X	X			
Potassium sulfate						X							
Tin (powdered) lead ***	D	E	—	C	O	P	P	E	R	I	N	G	
Graphite								X			X		
Carbon black												X	
Cryolite						X							
Triacetin			X			X							
2 — Nitrodiphenyldiamine		X	X										

* Stabilizer for double base propellants.
** Stabilizer for single base propellants.
*** Decoppering or weapon cleaning agents.
Ethylcellulose and Cellulose Acetate and Inhibiters.
Inhibiters retard or slow down burning rate.

Figure 9-2-3 Common Propellant Additives

SECTION 3

HIGH EXPLOSIVES

GENERAL

1. An HE is defined as any material that can be detonated and is normally employed to give a detonation. The ideal HE should possess the following characteristics:

a. **Power and Brisance**. Power is the ability of the explosive to do work and is dependent on the volume of gases formed at the temperature of detonation. Brisance is the shattering effect and is dependent on the velocity of detonation of the high explosive. Brisance determines the effectiveness of an explosive in fragmenting the shell, etc.

b. **Insensitivity**. It should be insensitive to ordinary shocks such as handling, transport, shock of discharge in a projectile, and with piercing shells, shock of impact.

c. **Freedom from a Tendency to Sympathetic Detonation**. Some HEs are found to be more liable to detonate when stored in a stack in which, or near which, a detonation takes place.

d. **Stability in Storage**. This is more important than with propellants, as the interior of a filled round is difficult to inspect.

e. **Stability Towards Damp and Extremes of Temperature** -

- (1) Moisture may cause the explosive to swell, giving rise to chemical reaction or the explosive may become soluble.

(2) High temperatures may give rise to liquefaction.

(3) Low temperatures may decrease the sensitivity.

f. **Stability Towards Metals**. The explosive should not form unstable or sensitive compounds with metals.

g. **Economy**. In wartime, large quantities of the explosive should be plentiful and easily manufactured from readily accessible and cheap raw materials.

h. **For Bursting Charges in Filled Ammunition**. The explosive should be easily loaded to a high density to obtain the maximum rate of detonation, to avoid set-back on firing due to open areas or cracks in filling and to decrease the sensitivity as a guard against prematures on firing. Packed tight, the explosive has more power and more brisance. However, packed too tight (dead pressed) it may cause a partial detonation or a dud. The explosive should provide some smoke for observation. HEs currently in use are shown in Figure 9-3-1.

MAJOR GROUPS OF HIGH EXPLOSIVES

2. HEs are, in the military sense, divided into four major groups:

   a. initiators (detonators and primers);

   b. intermediaries (boosters and auxiliary detonators);

   c. bursting charges; and

   d. disruptives.

	Brisance mesured by			Rate of detonation	
	Sand test, grams	Plate dent test per cent TNT	Fragmentation of shell per cent TNT	At density g/m³	Metres per second
TNT	47.5	100	100	1.56	6 900
Ammonium nitrate				0.90	2 700
Nitroglycerin	58.7			1.60	7 700
Nitrocellulose	48.7			1.20	7 300
PETN	61.2	127		1.70	8 300
Tetryl	54.0		121	1.71	7 850
Picric acid	47.9	107		1.70	7 350
Explosive "D"	36.8		99	1.63	7 150
Nitro guadinidine	36.8			1.55	7 650
Haleite	52.0	121	134	1.55	7 750
RDX	59.0	131		1.70	8 350
50-50 Amatol	38.5		82	1.55	6 535
80-20 Tritonal	46.0	93	91	1.72	6 700
50-50 Pentolite	54.0	121	131	1.65	7 450
70-30 Tetrytol	52.7	117	117	1.60	7 300
52-48 Picratol	44.6	100	102	1.62	6 940
55-45 Ednatol	49.0	107	124	1.62	7 340
Composition B	53.0	131	139	1.66	7 800
Torpex	58.2	120	126	1.81	7 600
Composition A-3	51.0	126	150	1.59	8 100
Composition C-3	53.0	114	133	1.60	7 625
Composition C-4	55.7	115		1.59	8 040
Lead azide	16.7			4.00	5 100
Mercury fulminate	22.1			4.17	5 400
Lead styphnate	10.5			2.90	5 200
Diazodinitrophenol	45.6			1.58	6 900
HMX	60.4			1.84	9 124

Figure 9-3-1 Current High Explosives

3. **Initiators**. Initiators (also known as primary explosives) are explosives that are used to start the action of combustion explosion or detonation. Initiators are of two main types - disruptive and igniferous:

a. **Disruptive initiators**. These are HEs that are so sensitive to heat, impact and friction that they undergo detonation when subjected to flame or percussion. As a result, they are used in small quantities, principally in detonators for disruptive fuzes, to initiate the detonation of a less sensitive high explosive.

b. **Igniferous Initiators**. These are one of the miscellaneous explosives and are not a true HE. They are used to start burning in the explosive train. The heat and flame required are produced by a combustible material and an oxygen carrier. Control of the rate of burning can be achieved by varying the size and density of the particles and by the mixture of other substances. They are found in primer caps and initiators of igniferous fuzes. They are sensitive to heat and friction caused by a blow or electrical shock.

4. The requirements of an initiator are:

a. **Efficiency**. Initiators must produce sufficient heat, flame or shock to initiate, with certainty, the system with which they are used. In some cases, regular burning at an acceptable rate is a requirement to ensure that the next component in the explosive train is ignited at the right time.

b. **Sensitivity**. Initiators must be sufficiently sensitive to respond with certainty to the initial impulse, ie percussion or friction, but insensitive enough to avoid premature functioning due to incidental shocks. In many cases, eg in fuzes, they must be capable of withstanding the effect of their own weight during rapid acceleration.

c. **Stability**. Initiators should be inherently stable and not liable to deterioration due to humidity and temperature variations, as inspection after filling is not possible.

d. **Reactivity**. They should not react chemically with any other components with which they might come into contact.

5. **Boosters (intermediaries)**. Boosters are relatively insensitive HEs that are used to build up the small but concentrated impulse given by the initiator and transform it into a sufficiently violent shock to detonate the bursting charge. UK systems use intermediaries in the magazine of disruptive fuzes and in the exploder system of projectiles filled with HE. US systems employ what they call a booster charge. Boosters may be incorporated within the fuze itself, or may be encased in a thin casing of metal or plastic that is screwed permanently to the fuze and handled as a unit with the fuze. This assembled casing with the booster charge is known as a booster. Most types of boosters are provided with a bore safety mechanism. These boosters usually contain one or more other charges in addition to the booster charge, such as an intermediate

detonator and/or lead charge. The newer fuzes employ a safety and arming mechanism and a booster cup.

6. **Bursting Charges**. Bursting charges are insensitive but very powerful explosives used to shatter the shell body and scatter small, high velocity fragments. Burster charges, in smaller amounts, are used in chemical shells and bursting smoke shells to break open the body and scatter the chemical content. Technical details of particular bursting charges can be found in Chapters 7 and 8 of R-74-007-009/TA-000.

7. **Disruptives**. Disruptives are extremely powerful explosives used in demolitions and mining. As they have no particular artillery application, they are not further discussed.

EXPLOSIVE TRAIN

8. An explosive train is a designed arrangement of a series of explosives beginning with a small quantity of sensitive explosive and progressing through a relatively large quantity of comparatively insensitive, though powerful, explosive. For example, a complete round of conventional HE artillery ammunition contains two explosive trains: the propelling charge explosive train and the projectile explosive train (see Figure 9-3-2).

9. **Propelling Charge Explosive Train**. The propelling charge explosive train is used to produce the energy required to impart the necessary velocity to the projectile to propel it out of the gun. It is initiated by the firing pin striking the primer. The primer, which contains a small amount of very sensitive explosive, emits a spit of flame that is transmitted to the igniter. The igniter intensifies the flame, sufficient to ignite the propelling charge.

10. In fixed and semi-fixed ammunition, the primer is contained in the body of the igniter and is an integral part of the cartridge case. In separate loading ammunition, the primer is a separate item and the igniter is sewn to the base increment of each cartridge. In super charges, in addition to the igniter pad, there is an igniter tube that extends throughout the length of the cartridge.

11. **Projectile Explosive Train**. The projectile explosive train can be either an expelling charge (low explosive) or a bursting charge (high explosive):

   a. **Expelling Charge Explosive Train**. In base ejection projectiles, the train consists of a time fuze detonator and a low explosive expelling charge. Action is initiated by the firing pin striking the detonator. The resulting flame ignites the expelling charge which in turn blows the base cover off the projectile and ejects the contents into the airstream.

   b. In nose ejection projectiles such as the APERS M546 (flechette) round, the train consists of a time fuze, detonators) and an expelling charge. Action is initiated by the firing pin striking the detonator. The explosive force of the detonators) rips open the nose of the projectile and at the same time, a flash is transmitted down a flash tube igniting the expelling charge at the base of the projectile. The expelling charge forces the contents of the projectile forward and out of the projectile.

c. **Bursting Charge Explosive Train**. The basic components that must be present in all bursting charge explosive trains are a fuze, a booster (intermediary) and a bursting charge. Other elements are sometimes required but these are fundamental. When initiated by the action of the firing pin or a flame, the detonator sets up a detonation wave. This detonation wave is small and weak such that it will not initiate a high order detonation in the bursting charge. The booster picks up the small and weak detonation wave from the detonator and builds it up to such an extent that the bursting charge is initiated with a high order detonation.

d. To gain the action necessary to control the time and place at which the explosive will function, other components are incorporated into the train. The action desired may be a burst in the air, a burst instantly on impact or a burst shortly after the target has been penetrated. The components that may be used to give the desired action are a primer, a black powder delay pellet or train, a detonator or any combination of these. Regardless of the component arrangement, the basic bursting charge explosive train remains the same.

MISCELLANEOUS EXPLOSIVES

12. Miscellaneous explosives are combustibles that undergo chemical reactions (exothermic reactions). These are used to produce light, heat, smoke and/or sound. They may not always contain sufficient oxygen for burning and in such cases, must use oxygen from the air. Miscellaneous explosives are divided into the following classes according to their uses:

a. illuminating composition,

b. signal composition,

c. incendiary composition,

d. smoke producing composition,

e. priming composition, and

f. tracing composition.

13. **Black Powder (Gun Powder)**. Despite its being very sensitive to moisture and its great generation of smoke, black powder still has many uses in the artillery. It is useful due to its ease of ignition and the high rate of burning at low pressures. It is a shock insensitive explosive but is very sensitive to flame or sparks as well as friction. Black powder is used in:

a. igniters for BL and QF cartridges,

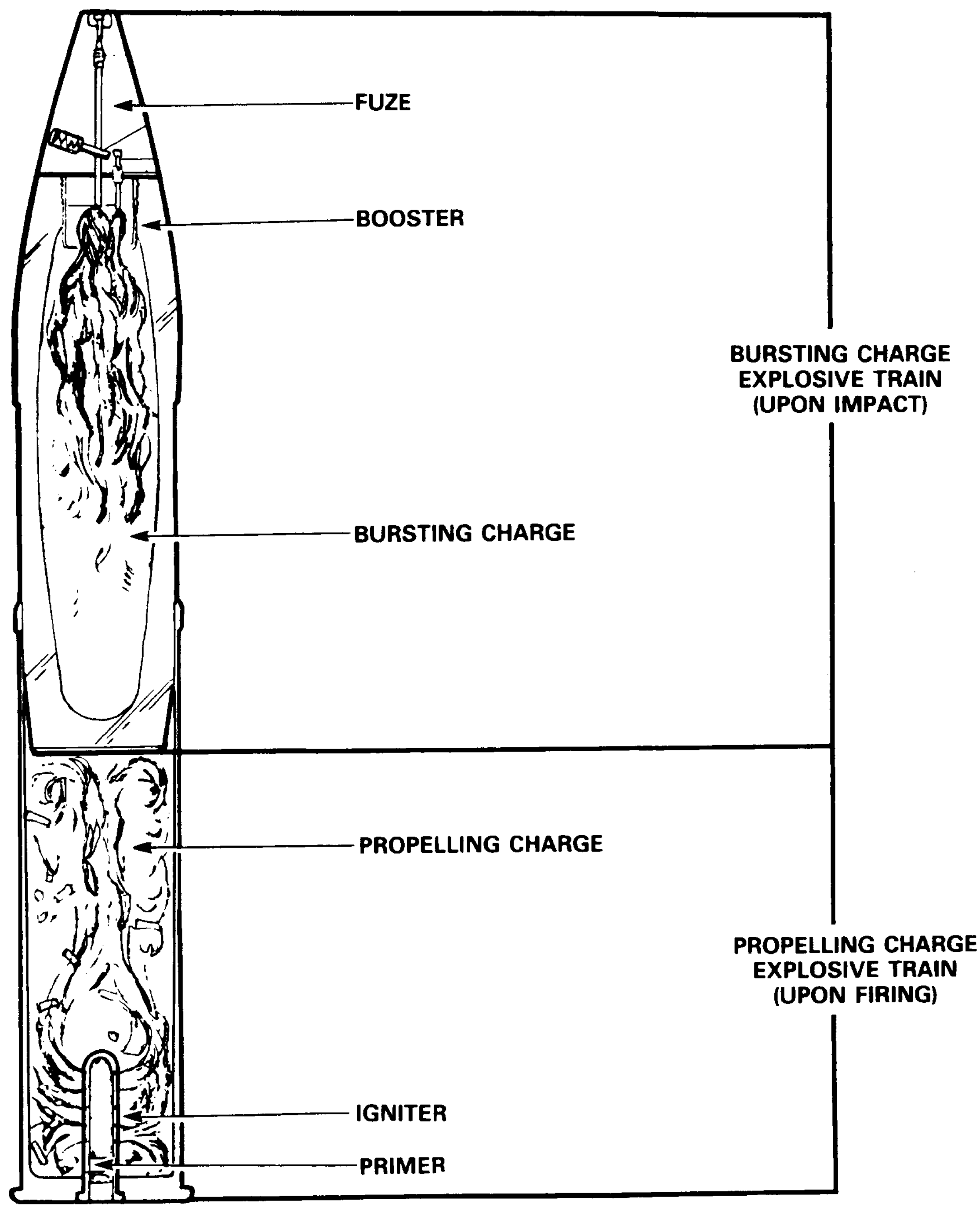


Figure 9-3-2 Propelling Charge and Bursting Charge Explosive Train

b. primer charges and primers,

c. expelling charge and nose ejection projectiles,

d. delay compositions (fuzes),

e. additives to reduce flash, and

f. saluting charges (blanks).

14. Details on military black powder and the composition of black powders and miscellaneous explosive compositions can be found in Chapters 6, 13 and 14 of R-74-007-009/TA-000. For further information on miscellaneous explosives see Chapter 9 of R-74-OR-74-007-012/TA-000.

SECTION 4

CARTRIDGE SYSTEMS

INTRODUCTION

1. **Definition**. A cartridge system is part of a round of ammunition, (propellant and its container) that provides the means of propelling the projectile to the target. All cartridge systems have containers that are manufactured from many different materials, eg brass, steel, cotton, rayon, nylon, plastic, etc.

2. **Classification**. Cartridges are classified as QF or BL. These terms (QF and BQ originated in the late 19th century at the time of the change from muzzle to breach loading guns. The first guns were called rifled breech loaders (RBLs). The R was soon dropped and they became known as BL equipments. The need for quicker loading saw the introduction of the cartridge case, and guns that needed this type of cartridge system were called quick firing or QF equipments and were, in general, of smaller calibre than the BL equipments.

3. The modern use of the terms denotes the method used by an equipment to prevent the escape of propellant gases to the rear (obturation). Obturation is achieved with:

a. QF equipments - by the cartridge case; and

b. BL equipments - by the breech mechanism.

QF CARTRIDGE (Figure 9-4-1)

4. With QF cartridges the propellant charge is contained in a cartridge case that is used to hold the charge and primer and to prevent the rearward escape of propellant gas from the chamber. This is known as obturation and is achieved by the action of the cartridge case mouth expanding against the chamber walls under the pressure of the propellant gases. The primer is either screwed or force pressed into the base of the cartridge case and has its own means of providing obturation. The primer can be activated by percussion and in some cases by electricity or both.

5. The propellant is either loaded directly into the cartridge case or into a charge bag or bags that are then placed into the cartridge case. Generally, charge bags are used only in multi-charge systems where the user can select the charge. A charge bag may be used in a fixed round where the charge weight is small in relation to the volume of the case and where in consequence, ignition failure might occur. The use of a bag helps to position the charge in relation to the igniter, eg High Explosive Squash Head (HESH).

6. QF cartridge cases may be made from a wide variety of metals, eg steel, aluminum, brass and non-metallic materials such as NC, Kraft plus PETN. Work has been conducted on combined cartridge cases using a short metallic base and continuing the length of the cartridge

wall in either a combustible or consumable material. This approach is useful in ammunition for tank and self-propelled (SP) guns as it reduces the size of the fired case to be disposed.

7. Metallic cartridge cases were traditionally made of brass (copper 70 per cent, zinc 30 per cent). The attractions of brass are:

a. It performs well in most equipments.

b. It does not corrode to give hard abrasive particles.

c. The metallurgy and techniques of fabrication are well known.

8. Steel alloy performs equally as well as brass but the manufacture is more difficult. During World War 11 the Germans, because of the shortage of copper, made considerable use of steel cases. The chief problem with steel cases is devising a treatment to ensure that they do not corrode in service. Aluminum is used in some low pressure weapons such as 84 mm Carl Gustav.

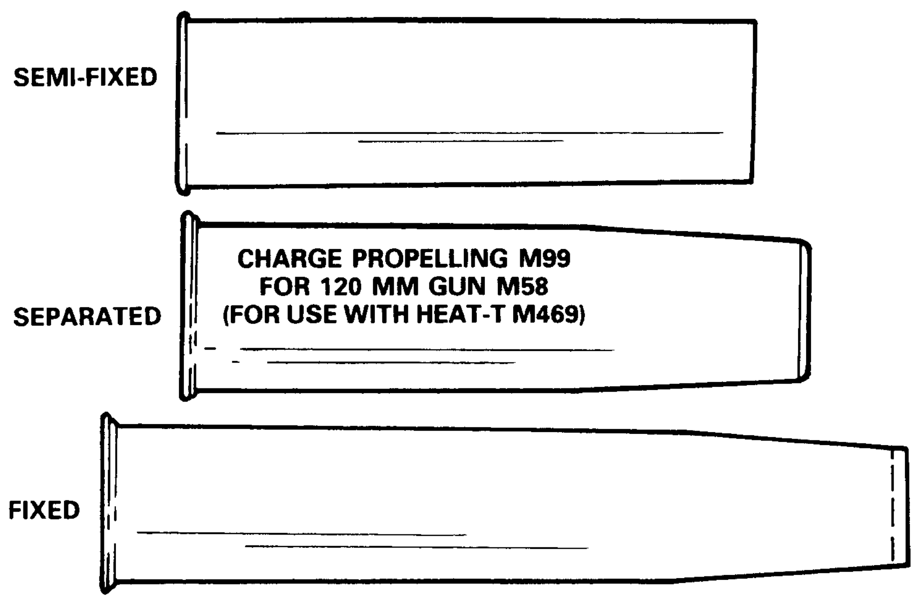


Figure 9-4-1 Types of Cartridge Cases

9. The tasks a cartridge case fulfils give an indication of the desirable properties of the case material. These are:

a. to protect the propellant in storage, transit and handling;

b. to provide an early seal by expanding as soon as the gas pressure starts to rise in the chamber;

c. to recover to a diameter less than the internal diameter of the chamber once the pressure drops;

d. to withstand the unseating and extraction forces applied by the breech mechanism and withdraw without jamming or breaking up;

e. in a fixed or semi-fixed round, to support the projectile that is secured in its mouth; and

f. to house the primer.

10. The material, therefore, needs to be strong enough to withstand high pressures and sudden blows and pliable enough to withstand pressure without splitting. It must also have good recovery potential. To provide sufficient strength at the base, the case is heat treated to give it a hardness gradient along its length. At the mouth, it must be soft enough to deform easily while towards the base it needs to be much harder.

BL CARTRIDGE (Figure 9-4-2)

11. In a BL cartridge the propellant charge is contained in fabric bags that have an igniter pad sewn to the bottom of the basic increments. As the entire charge and bags are burnt on firing, obturation becomes a function of the breech mechanism. The igniter pad is activated by a flash of flame passing through a vent in the breech mechanism. As in a QF cartridge, the primer can be either percussion, electric, or both. BL cartridges are normally used in large calibre equipments.

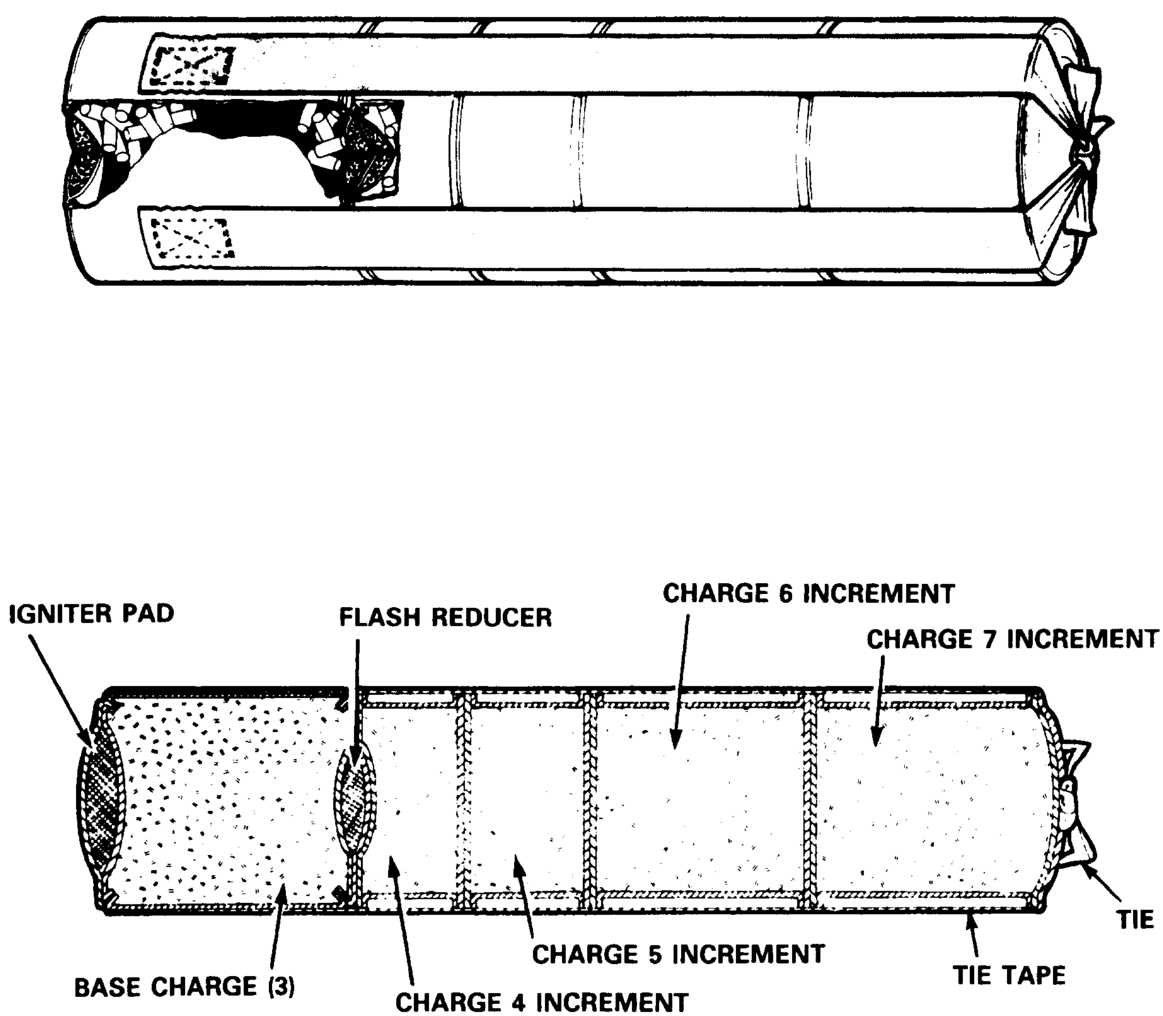


Figure 9-4-2 BL Cartridge System (M4 A2)

12. In bagged charge systems, the propellant is sewn into charge bags and tied in bundles. Particular care has to be exercised in the choice of bag material to ensure that only those that do not smoulder and leave no residue are used. The material must be stable with respect to the propellant. Silk, cotton, rayon, terelyne and ramie cloth have been used as bag material. All have the necessary strength and elasticity and are consumed completely with the burning of the propellant. The charge bag must also be resistant to rough and abrasive use while in and out of its package. It is UK practice to use only stick propellant in bag charges to improve rigidity and make the charge easier to handle. The US, however, uses granular propellant in charges of this type and imparts rigidity to the charge by lacing.

13. Cartridge design follows certain basic guidelines. In diameter, the cartridge should be large enough to ensure that some part of the powder in the igniter will receive the flash from the primer. In length, the cartridge should be long enough to ensure that under all conditions the igniter will be close to the mushroom head. Generally, it is desirable to have the cartridge occupy the entire length of the chamber rather than filling the width because short, thick charges that do not fill up the chamber can set up undesirable pressure waves.

14. It is clearly advantageous if everything that is loaded into the chamber plays some part in the ballistic effect to be achieved. Although charge bags have served fairly well, there is always the problem that with the bottom charges in a multi-charge system a disproportionate amount of cloth is loaded. At such low pressures, there is always the danger of incomplete combustion leading to smouldering debris being left behind in the chamber. Thoughts such as these have led to the introduction of combustible cases.

15. There are comparative advantages to both the BL and QF systems and their cartridges. These are:

a. **BL systems**. The following advantages are applicable to BL systems -

(1) They are economical in transport and storage space.

(2) They are cheaper and easier to manufacture in quantity (supplies of brass and steel may be restricted in wartime).

(3) It is easier to extract and eject a primer than a large cartridge case.

(4) The risk of obturation failure is probably less than the risk of a badly blown case. The consequent repair of the gun is also easier.

(5) In case of a misfire, the primer can be replaced without opening the breech.

b. **QF systems**. The following advantages are applicable to QF systems -

(1) The charge is better protected from flash, spray and moisture.

(2) Loading is slightly quicker because sponging out and reaming the vent is not required and the primer does not have to be inserted.

(3) There is a reduced risk of premature firing owing to smouldering debris from previous rounds.

(4) With fixed and semi-fixed ammunition -

(a) no ramming of the projectile is required,

(b) the round is more easily handled and loaded, especially at high angle fire, and

(c) there is no danger of double shooting.

(5) FTsually, it is easier for unloading.

16. In some cases, semi-fixed QF ammunition is preferable to fixed because:

a. The cartridge can be changed without changing the projectile.

b. With howitzers and any equipments using variable charges, semi-fixed ammunition is, at present, essential.

c. Except with small calibres, the fixed type is weak at the joint of the case and the projectile.

d. In general, it may be said that the advantages of the QF system decrease with weight and size of ammunition, but where bursts of very rapid fire may be required, fixed QF ammunition is essential, eg tank and anti-aircraft ammunition.

PRIMERS

17. Primers are generally made of the same metal as the cartridge case to avoid problems that could arise with differential expansion if dissimilar metals were used. The primer is either screwed or press-fitted into the base of the cartridge case. The primer must seal the escape of gases through the joint it makes with the case. It must possess sufficient strength to prevent the detachment of metal pieces on firing. Primers for separate loading ammunition are a separate unit. They are classified by method of initiation as:

a. **Percussion** (Figures 9-4-3 to 9-4-5). The cap of a percussion device is filled with a composition sensitive to impact and crushing. The flash from the cap is often boosted by a power pellet before igniting the main filling in the igniter primer magazine. The igniter is fitted with windows/ports covered only with paper and lacquer through which the flash can pass to the main propellant charge.

b. **Electrical** (Figure 9-4-6). The older type of electrical primer relied on the heating effect of a current passing through a bridge wire to ignite gun-cotton dust. The disadvantage of this system is its relative delicacy and tendency to unreliability. Bridge wires often broke as a result of rough usage. The more modern type of primers uses a cap that is sensitive to an applied voltage (see Figure 9-4-7). When a critical potential difference is produced across an explosive cap that conducts electricity, the cap fires. This arrangement is more robust than the bridge wire type but may be more susceptible to electrostatic hazards. However, it is relatively easy to screen the primer effectively.

c. **Combination Electrical/Percussion**. This type is designed to function by either means.

18. Gunpowder is the most commonly used filler for primer charges. However, for certain guns where the ignition system presents special problems, other mixtures, such as the propellants of the type used in small arms ammunition, may be used. Primers must:

a. produce adequate flash;

b. distribute the flash evenly over the propellant;

c. be self-obturating; and

d. be sensitive to a relatively light blow.

19. For additional information on primers see R-74-OR-74-007-012/TA-000 (TM 9-1300-203).

THE COMPLETE ROUND

20. A complete round of artillery ammunition is composed of all the components required to fire the gun once, ie primer, propellant, projectile and fuze (see Figure 9-3-2).

21. Artillery ammunition is classified, according to assembly, as:

a. fixed;

b. semi-fixed (adjustable for zone firing);

c. separated; and

d. separate loading (adjustable for zone firing).

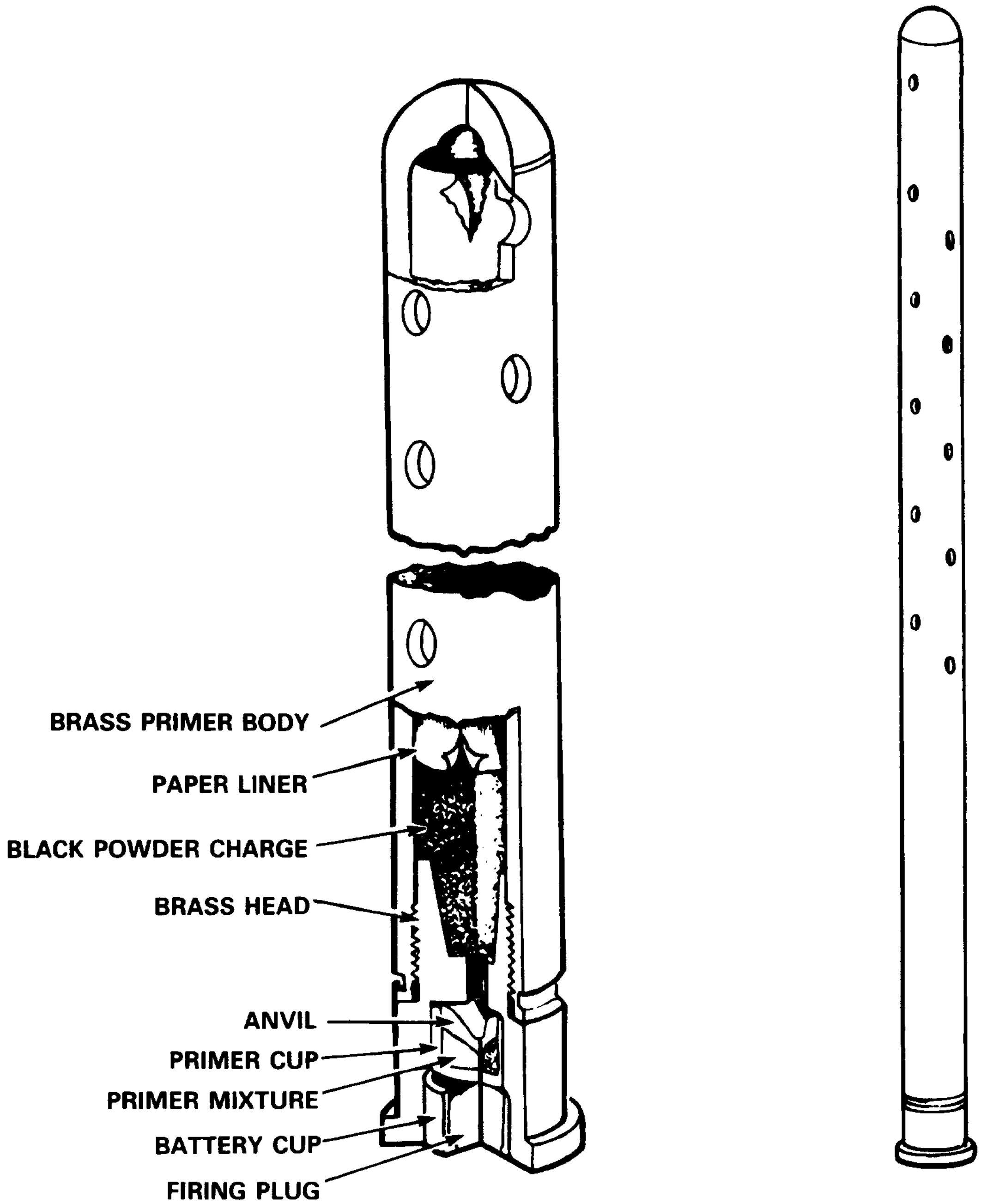


Figure 9-4-3 Primer used in QF Cartridges (M28 A2)

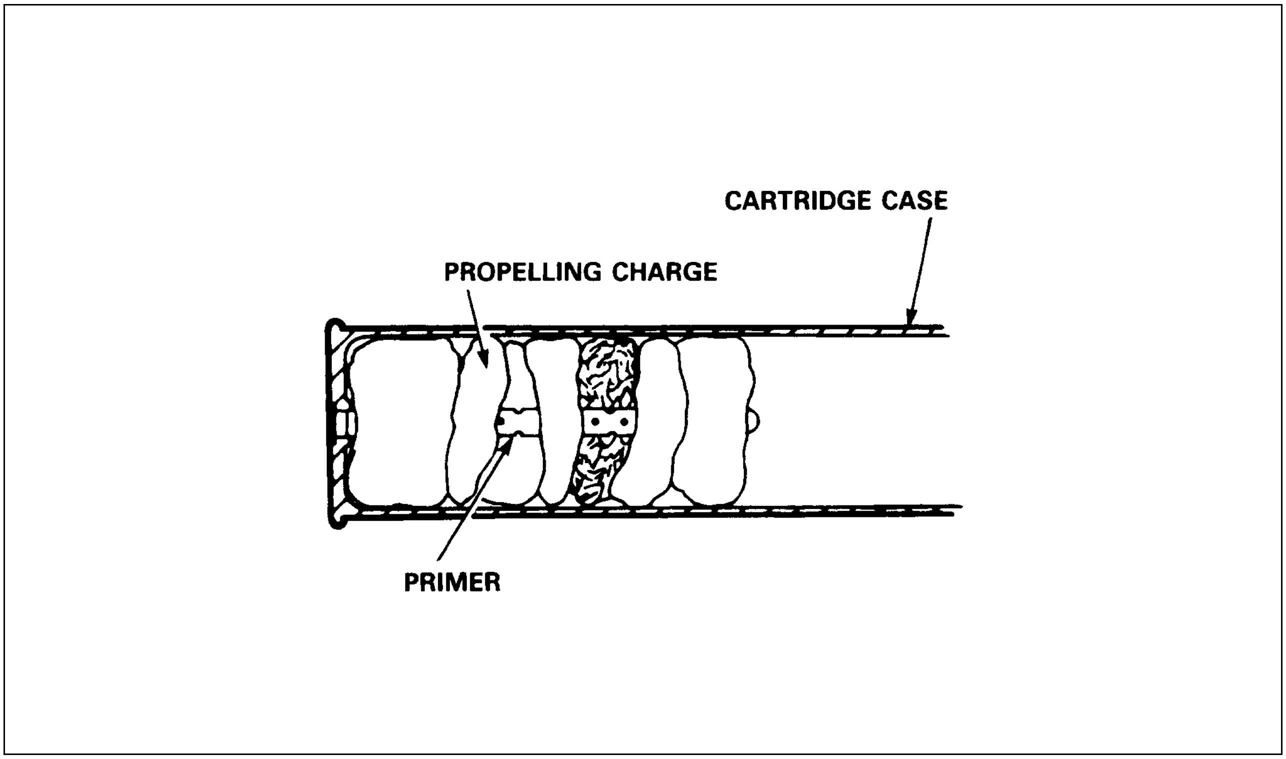


Figure 9-4-4 Primer in Place in QF Cartridge

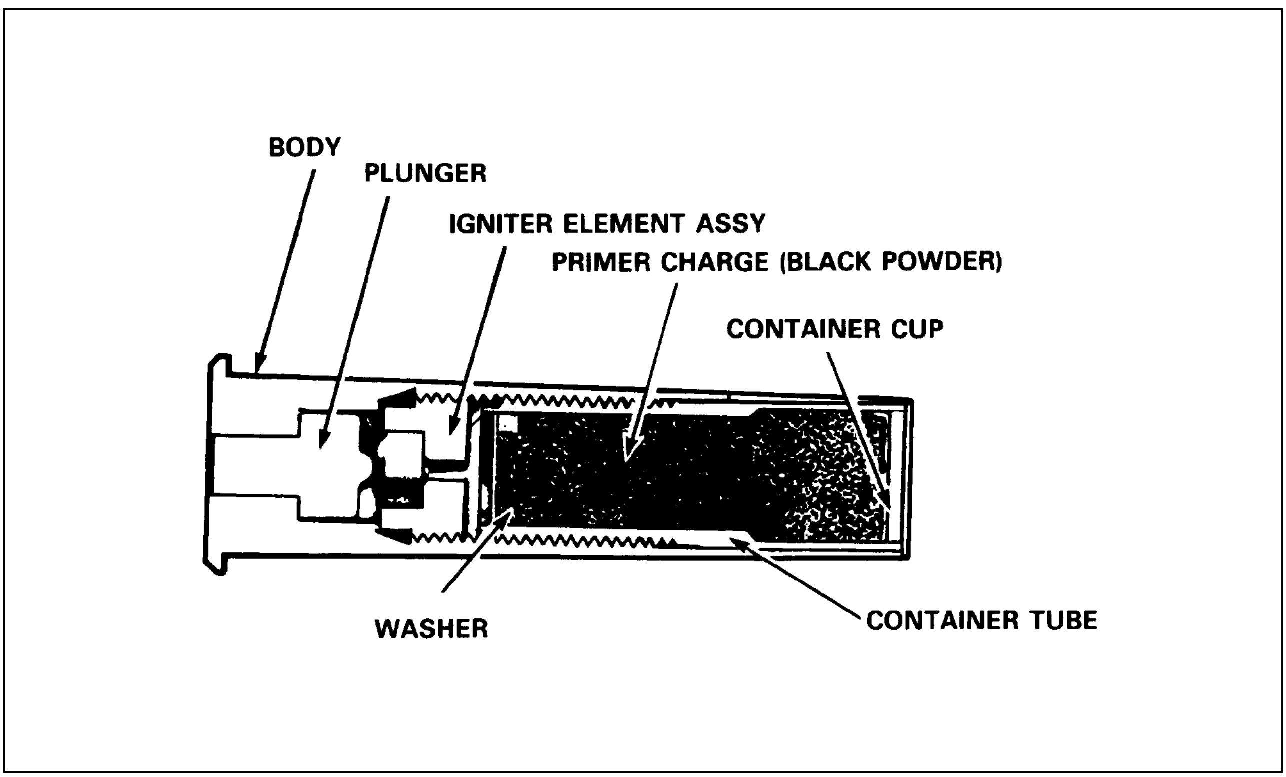


Figure 9-4-5 Primer used with BL Cartridges (M82)

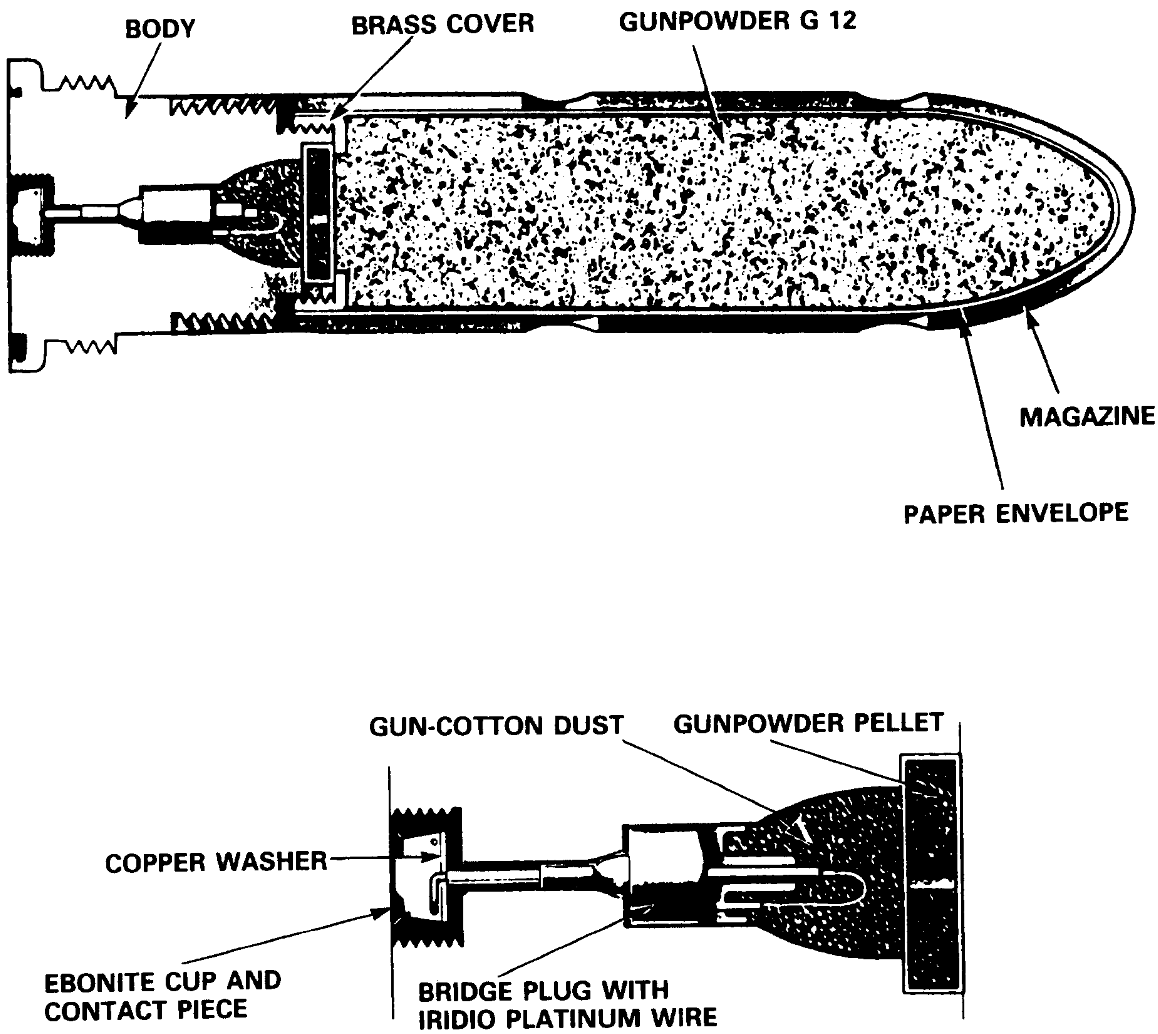


Figure 9-4-6 Electrical Primer (Bridge Type)

22. All of the previously mentioned artillery shell components form a complete round as they have the necessary components to fire the gun once. That they have different classifications is a result of arrangements to meet existing equipment requirements. These classifications are further discussed in subsequent paragraphs.

23. **Fixed**. The cartridge case and projectile are permanently mated, usually by a machine crimp. This means that fixed ammunition is non-adjustable with regard to propellant content.

24. **Semi-fixed**. The cartridge case and projectile, when mated, form a snug fit. They can be separated, one from the other, in order to adjust the propellant content for zone firing. The propellant charge is adjusted as required and the projectile mated before loading.

25. **Separated**. This type of complete round is loaded in one operation but the cartridge case and the projectile are not permanently mated. The charge is not adjustable as it is contained in the cartridge case by a closing plug. The type of primer associated with fixed and semi-fixed ammunition is also used with separated ammunition.

26. **Separate Loading (BL)**. The complete round is loaded in three distinct steps. The projectile is fuzed and rammed, seating it securely in the bore. The bags containing the propellant are adjusted as required and placed in the chamber. At this point, the breech is closed and the primer is inserted in the firing mechanism.

27. **Separate Loading (QF)**. The complete round is loaded in two distinct steps. The projectile is fuzed and rammed, seating it securely in the bore. The charge bags contained in the cartridge case are adjusted as required and placed in the chamber.

PRACTICAL CONSIDERATIONS (Care and Handling)

28. **Care, Handling, Preservation and Storage Ammunition**. Consult the following:

a. The applicable Handbook of Equipment and Ammunition.

b. R-09-IR-09-153-001/TS-001, Ammunition and Explosive Standards.

c. C-09-153-005/TS-000, Explosive Safety Manual, Volume 5.

29. **Protection from Moisture and Damage**. While all types of cartridges are well protected when in their unopened packaging, some cartridges, when opened, are far more prone to deterioration than others.

30. **QF Cartridges (Fixed)**. The propellant charge and primer are always well protected by the cartridge case, but the case itself, being malleable, is liable to be dented and gouged.

31. **QF Cartridges (Not Fixed to Projectile)**. These propellant charges and primers are also well protected from physical damage by the cartridge case. However, moisture will soon find entry unless precautions are taken. This is particularly so when packages are opened and the

ammunition prepared and left unused for some time. The cartridge case is also susceptible to damage.

32. **BL Cartridges**. These propellant charges, once unpacked, have no protection at all and due to the woven material from which the bags are made, moisture will find a ready entrance. The black powder igniter pads are extremely susceptible to moisture. BL primers, because of their small size and the material from which they are made, can be compared to fixed QF cartridges, in that they are relatively waterproof.

33. **Propellant Residue**. Propellant residue will depend on the type of cartridge:

a. **QF Cartridges (Not Fixed to Projectile)**. Particularly when firing low charges, loading and extracting will become more difficult as residue builds up in the chamber. This is not a major problem in equipment using cartridge cases.

b. **BL Cartridges**. Smouldering residue is to be expected in equipment firing BL cartridges. As this residue could easily ignite subsequent charges, great care must be taken to ensure that the chamber is free of such residue before loading. BL primers can foul the vent through which their ignition flash passes to such a degree that misfires may occur. Care must be taken to ensure that this does not happen.

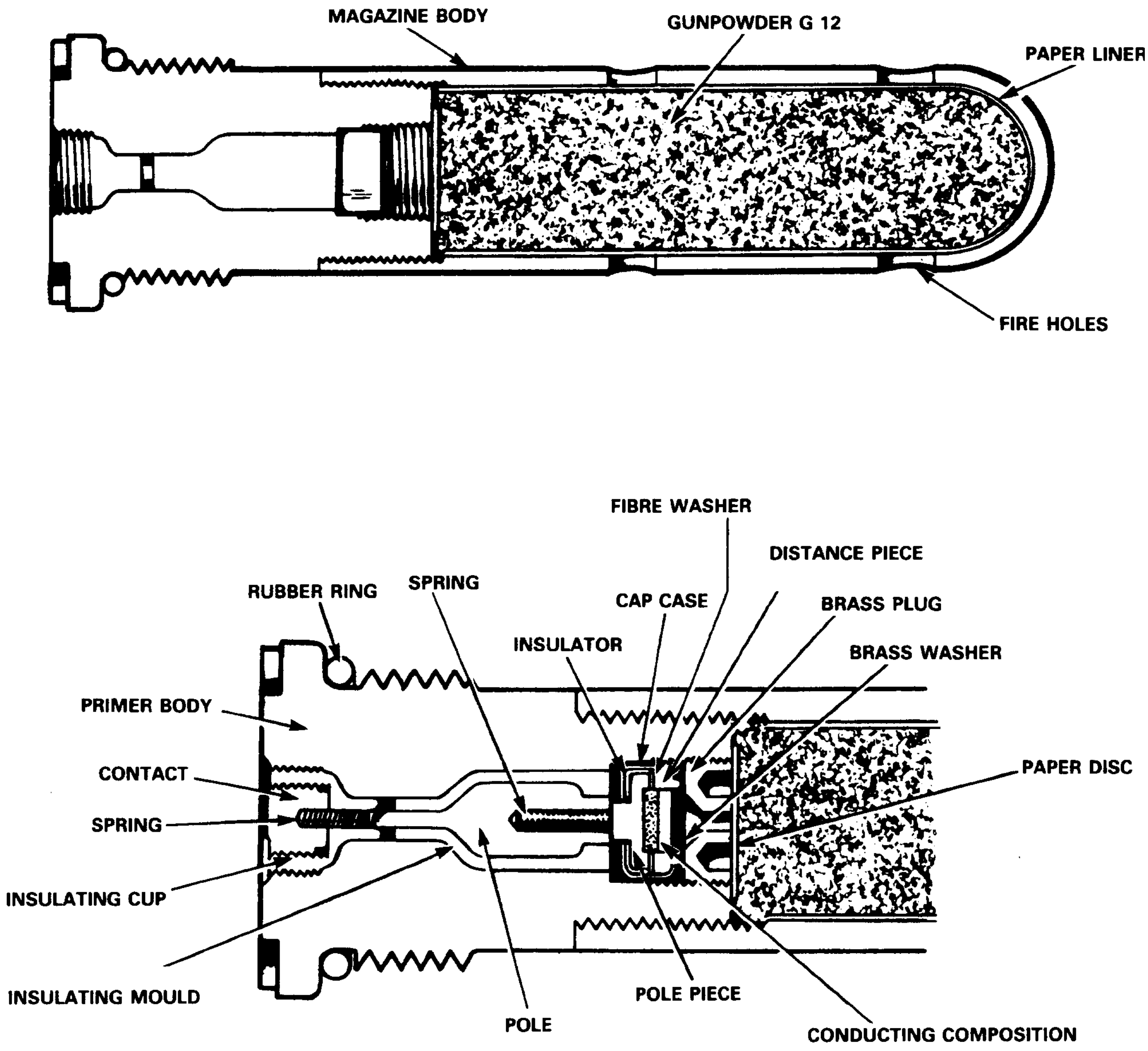


Figure 9-4-7   Electrical Primer (Conducting Cap Type)

34. **Primers**. The following precautions should be observed in the care and use of primers:

a. To prevent any risk of a premature, no attempt must be made to drive a jammed cartridge into the chamber by any operation which involves tapping of the case.

b. Cartridges must not be stood on their base.

c. The proper tools for removal or insertion must be used.

d. Do not oil, it may render the cap inert.

e. Do not clean with any abrasive material.

f. Special care must be taken not to strike the cap on any hard substance.

g. Primers that have been struck but not fired are liable to be sensitive to shock and special precautions must be taken with these misfires.

h. Misfire drill must be strictly adhered to.

CHARGES

35. The following types of charges are in general use:

a. **Service**. This is the normal full charge in use with any equipment, eg 155 mm Howitzer M109A2/A3 charge 7.

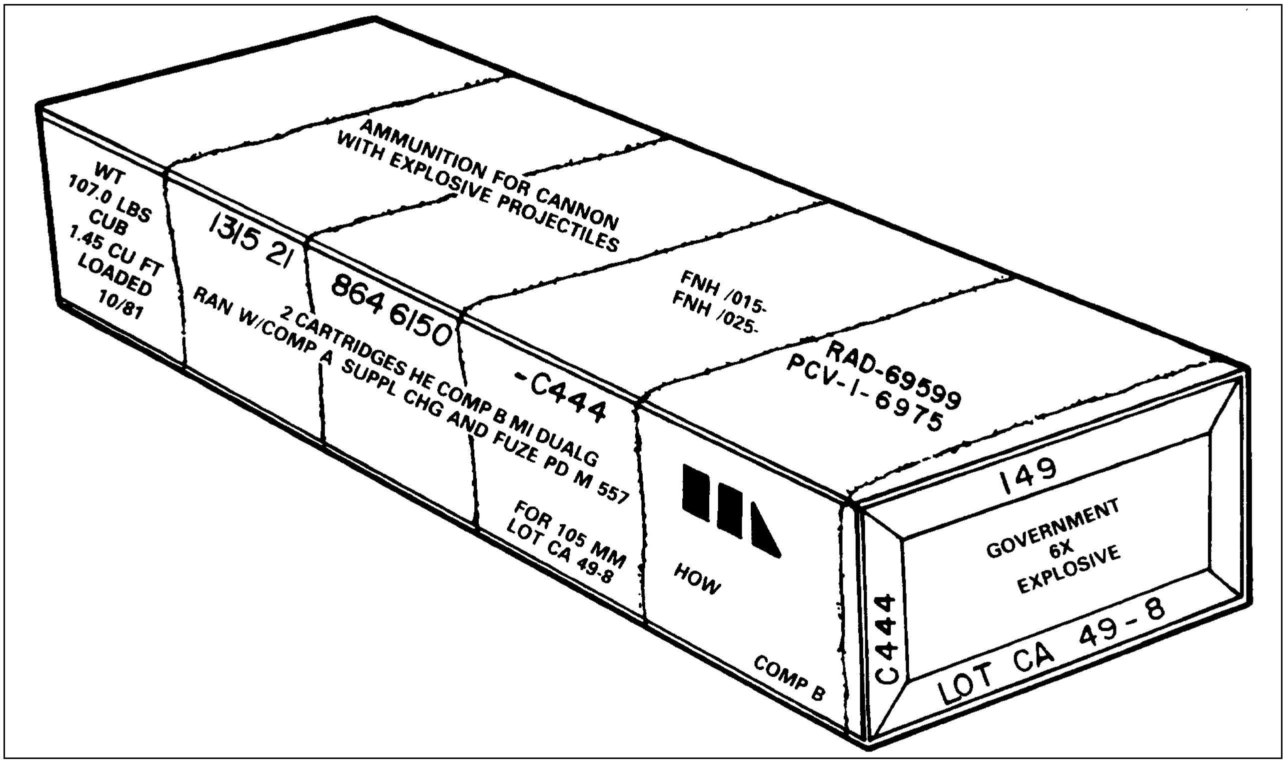


Figure 9-4-8 Typical Packaging

b. **Special Charge**. These are non-adjustable charges designed to yield specific ballistics for a given projectile, eg HESH, squash head/practice (SH/PRAC), high explosive plastic tracer (HEPT).

c. **Blank**. These are non-adjustable charges designed to simulate battle noises or used for salutes. They are not used with projectiles. Blanks are made of black powder or small arms powder.

36. The following charges may also be encountered:

a. **Super Charge**. These charges are used to extend the normal maximum range of a given equipment, eg charge 8, 155 mm Howitzer M109A2/A3. Their design is computed in conjunction with the ballistic capability of the appropriate projectile and gun. Super charges are not usually used in training due to the increased rate of wear.

b. **High Velocity Charges**. These charges are used with solid armour piercing (AP) penetrators, which are the primary anti-tank projectiles for tank guns. Because of the overall weight of the projectile being lighter than that of a standard projectile, MVs in excess of 1 500 m/s are achieved. This charge is non-adjustable and is also computed in conjunction with the ballistic capability of the gun.

c. **Reduced**. These charges are used in high velocity guns when a reduced MV is required to fire ammunition that would not withstand the usual velocities developed. Reduced charges are used to reduce wear and minimize ricochet ranges. A reduced charge is also used in tank guns to fire HE and smoke rounds to the maximum ranges required for observed fire.

PROPELLANT PROOF AND CHARGE ADJUSTMENT

37. To ensure that each new lot of propellant manufactured gives a ballistic performance of a standard quality it is necessary to proof each lot and then, for minor variations, adjust the weight of propellant for a given charge. In this way, the user can be confident that different lots of ammunition will perform the same way under all circumstances.

38. There are various methods available to conduct proofing but the principle remains the same in each case. A series of rounds of a standard propellant of proven ballistic performance is fired alternately with the propellant being proofed. Variations from round to round are noted and the resultant differences in propellant are calculated. In this way the charges of the new lot can be adjusted to yield the same ballistic performance as that of the standard.

39. These tests and subsequent charge adjustments are carried out under exacting conditions and comply to the following rules:

a. The standard for that particular nature of ammunition must be used.

b. Only in-service ammunition components will be used when testing.

c. Charges of varying propellant temperature will be fired.

d. The gun used to conduct the test must be one of proven consistency and conditioning or warming rounds will be fired before the propellants are tested.

e. Any other conditions specified by the Design Authority must be met.

40. Because of the high degree of sophistication found in current propellant manufacturing techniques, the charge adjustments normally encountered are relatively minor.

SECTION 5

PROJECTILES

INTRODUCTION

1. A projectile is defined as "an object, projected by an applied exterior force and continuing in motion by virtue of its own inertia, as a bullet, shell, or grenade". Artillery projectiles are of the same basic shape in that they have a pointed head, a cylindrical portion and a flat or hollow base that may or may not be tapered.

2. The primary projectile of any artillery gun/howitzer weapon system is the HE projectile. It is filled with HE and is designed to inflict casualties through fragmentation, or damage through impact with the target.

3. In addition to the primary HE projectile there is a number of different types of projectiles known as carrier projectiles. The carrier projectile differs from the HE projectile in that the body of the carrier projectile plays little or no part in defeating the target. Carrier projectiles are diversified and are used to carry any one of a number of contents, each having a specific purpose.

4. There are three main methods used to disperse a payload onto the target. These are:

   a. **Bursting Shell**. Bursting shells are designed to rupture under the action of an impact or time fuze activating the burster charge. The force used to rupture the projectile body is also employed to scatter the contents. The filling either detonates or enflames on its own or may need to be raised to its ignition temperature by the heat of the explosion. The payloads most frequently dispersed by this type of projectile are smoke and chemical. As with HE the contents are carried, to a large degree, forward and as a result the full effectiveness of the burst is often lost.

   b. **Base Ejection**. In this method the payload is preloaded into containers. If the contents of the container require ignition, a central flash channel is provided and lined with a flash receptive priming composition. The projectile is fitted with a time fuze that activates the expelling charge. The charge generates pressure that acts indirectly on the base by thrusting on the end surface of the payload containers. The base plug is resistant to external pressures but fails easily under internal pressures. In effect, the baffle plate and the contents are **blown out**. The flash ignites the payload containers if required.

   c. **Head Ejection**. In projectiles of this type there is a weakened section towards the nose at the end of the parallel position of the body. A time fuze ignites an expelling charge which exerts pressure on a full cavity-diameter pusher plate that is secured to the bottom of the projectile. The pressure forces the plate forward and it shears the weakened section of the nose. The contents of the projectile are then pushed forward and out. If the payload consists of discreet particles then they are further dispersed by the spin of the projectile case. The flechette round uses radial detonators to split the nose of the projectile and to expell the contents.

PROJECTILE DEFINITIONS

5. The main projectile definitions are given below and are illustrated in Figure 9-5-1:

a. **Ogive**. The ogive is the curved portion that streamlines the front of the projectile and reduces nose resistance.

b. **Shoulder**. The shoulder is the point where the ogive meets the bourrelet.

c. **Bourrelet**. The bourrelet is the carefully machined portion immediately in rear of the shoulders that rides on the lands of the barrel. It centres the projectile in the bore and prevents wobbling in the barrel.

d. **Body**. The body is the major portion of the projectile.

e. **Driving Band**. This is a band of metal or plastic that engraves into the lands and grooves of the barrel and imparts spin to the projectile.

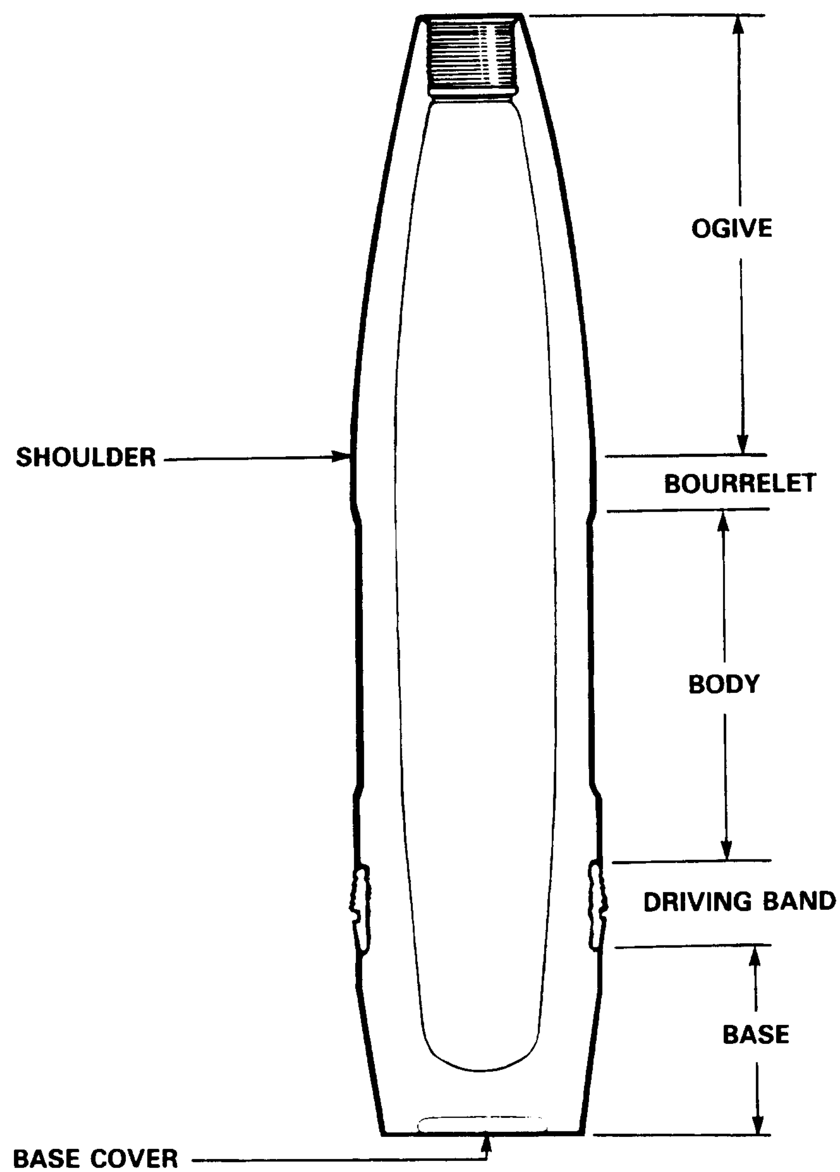


Figure 9-5-1 Main Projectile Details

f. **Base**. The base is the part in rear of the driving band. It can either be tapered (boat-tail), square base or hollow base.

g. **Base Cover and Base Plug**. The base cover is welded to the base of HE projectiles to prevent hot gases entering through tiny cracks or pores. The base plug is used in base ejection projectiles so the contents can be expelled. It may be connected to the projectile by threads, shear pins, twist pins or a combination of these.

FACTORS AFFECTING PROJECTILE DESIGN

6. The factors affecting projectile design are:

   a. the effect required at the target (see Chapter 4, Terminal Ballistics);

   b. ballistic performance. This factor is the ability of the projectile to maintain its velocity in flight;

   c. the strength to withstand firing stresses;

   d. the simplicity and ease of handling; and

   e. the economy of manufacture.

FACTORS AFFECTING BALLISTIC PERFORMANCE

7. The factors affecting ballistic performance are:

   a. **Diameter**. The work done in penetrating the atmosphere depends upon the size of the hole that the ballistic performance must **bore** through the atmosphere - the thinner the projectile the better.

   b. **Weight**. A heavy projectile maintains its velocity better than a lighter one of the same shape and size, eg a golf ball can be thrown farther than a ping pong ball.

   c. **Shape**. The nature of air resistance can be considered under headings -

      (1) **Nose resistance**. Nose resistance increases steadily with velocity up to the speed of sound, 340 m/s approximately. Thereafter, it increases sharply and the rate of increase, increases in the supersonic zone.

      (2) **Tail drag**. Tail drag is due to low pressure behind the base of the projectile. Drag increases with velocity until at about the speed of sound the pressure is almost zero. Drag, therefore, does not increase significantly at supersonic speeds.

(3) **Skin friction**. Skin friction, except in long thin projectiles, eg rockets, gives the least effect of the three sources of resistance.

d. **Steadiness**. Steadiness is closely connected with the dimensions and shape of the projectile. From the previous article concerning weight, diameter and shape, a thin but heavy and, therefore, long projectile with a tapered base to overcome tail drag and a long pointed head to overcome nose resistance would seem ideal. A long thin projectile, however, does not stand up well to the stress in the bore and requires a high rate of spin, or fins, to keep it stable in flight. A tapered base allows the propellant gases to escape at shot ejection in a way that may cause instability and is the reason why high velocity projectiles normally have a cylindrical base. Finally, a long head on a projectile of fixed overall length could result in the projectile being inadequately supported in the bore (because of the bourrelet being too far to the rear). This would cause high initial yaw and loss of stability. The effect of the factors affecting the carrying power of a projectile is expressed as the C_o.

PROJECTILE STRESSED ON FIRING

8. Except for projectiles required for the attack of armour, the greatest stresses imposed on a projectile are those experienced whilst it is still in the bore. These are caused by the following:

a. The propellant gases exert a pressure of up to 275 MPa (20 tons per square inch) on the base. This pressure gives rise to an acceleration of up to 50 000 g.

b. Because of the inertia of the projectile, each part sets back on the position in rear of it - the base taking the force exerted by everything forward of it. The magnitude of this **Set Back Force** can be appreciated by considering that a component weighing approximately 28 grams (1 oz) under an acceleration of 35 000 g sets back with a force of about 8.9 kN (thousand pounds-force = 4.448 222 M). Because of this pressure, the wall of the projectile is thickened towards the base. This section of maximum stress is known as the **Governing Section**.

c. The engraving of the driving band causes a stress towards the axis of the projectile. This can be severe immediately under the driving band.

d. The filling sets back and presses outward such as to cause an internal radial pressure on the wall of the projectile. This pressure is increased by centrifugal force during rotation.

e. Rotation of the projectile gives rise to a torsional stress (twisting effect) from the driving band forward. This stress is small in comparison with the other stresses. Stresses are resolved into an equivalent stress. The amount of stress will govern the thickness of the walls with the grade of steel that must be used. This in turn will affect the size of the cavity.

DRIVING BANDS (Figures 9-5-2 and 9-5-3)

9. All conventional projectiles fired from rifled equipments are fitted with driving bands, primarily to:

a. impart spin for stabilization; and

b. seal the propellant gases behind the projectile in order to ensure uniform ballistics and to prevent **gas wash** or erosion in the bore which could be caused by the gases rushing by the projectile.

10. The driving band also performs the following subsidiary functions:

a. Centres the projectile in the bore.

b. Provides support to the rear of the projectile preventing it from slapping the interior of the barrel. This would cause damage to the projectile as well as the barrel and would affect the ballistic performance of the projectile.

c. Holds the projectile in the rammed position when the gun is elevated to high angles.

d. In BL equipments, it performs the function of a ramming stop for the projectile. If projectiles are not correctly rammed, that is, without the correct distance and pressure each time, irregular ballistics will occur causing large variations in range.

e. Holds the projectile until shot-start pressure is achieved.

11. The driving band material must possess particular physical and mechanical properties to enable it to carry out its tasks. It must deform/f law easily under a wide range of pressures without fanning or stripping itself from the projectile. It should not cause undue abrasive wear on the bore and preferably should not be prone to corrosion during its shelf-life. It should not react with the atmosphere over extended periods to form metallic oxides which could cause damage to either the projectile or the gun.

12. In some cases, an obturating band/ring is fitted that may also be part of the driving band (see Figure 9-5-3). An obturating band is designed to seal the escape of the gas.

Figure 9-5-2 Typical Driving Bands

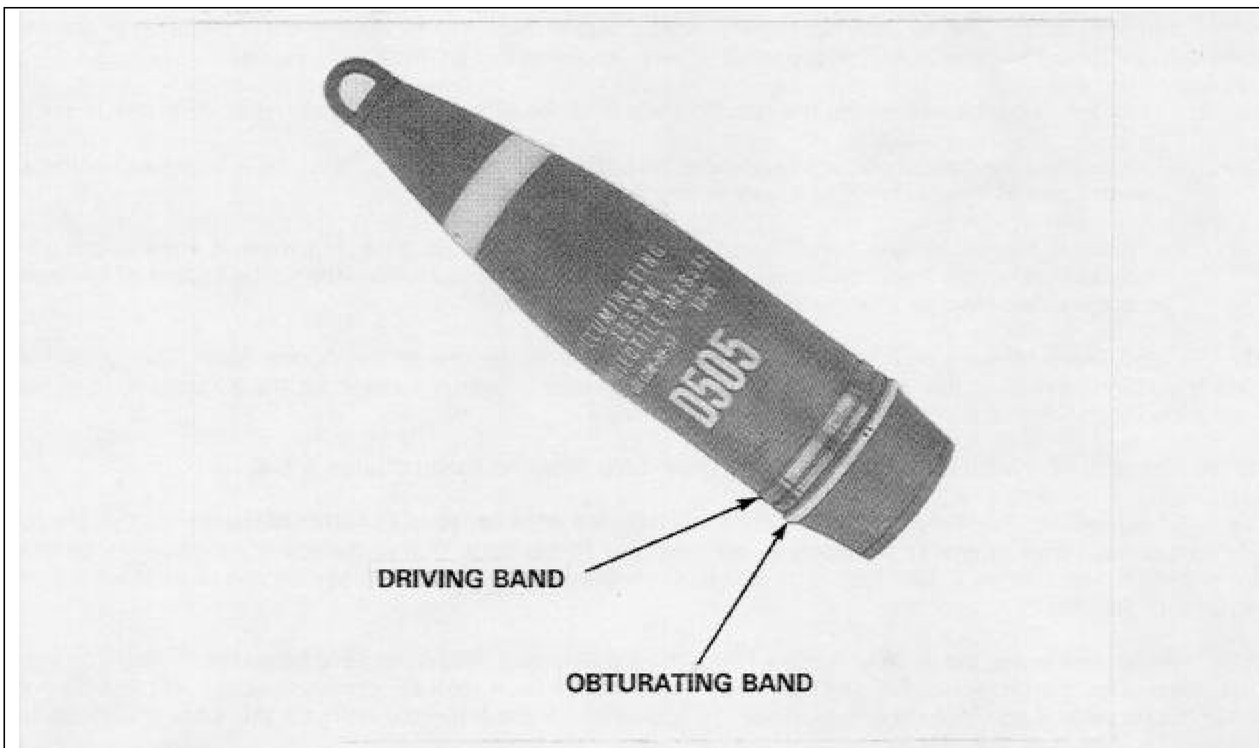


Figure 9-5-3 Obturating and Driving Bands

13. Driving bands can be made from a wide variety of materials. When metal is used, it must be soft enough to cause the least possible wear in the gun, but it must not be so soft as to strip under the rotational and engraving processes in the bore. Copper and gilding metal are normally used for driving bands. When copper is used, it must be as free as possible from impurities to ensure uniform hardness. Variations in the hardness of driving bands due to the presence of impurities can cause appreciable variations in ballistics, particularly in the case of smaller calibres. Gilding metal (90 per cent copper, 10 per cent zinc) is used because it reduces coppering of the bore. Both have lead to a requirement for the incorporation of decoppering agents in propellants.

14. Neoprene or nylon driving and obturating bands may be encountered on high velocity projectiles. They have been used successfully on projectiles that have been protected during storage and handling from damp and moisture by, for example, a cartridge case. These bands are discarded at the muzzle, generally by break up. For low velocity projectiles, there are ballistic advantages in a discarding band. Because of debris in the vicinity of indirect fire weapons, such a band should be non-metallic and should break up at the muzzle into particles/fragments that do not cause casualties. A band of this sort has been developed for 105 mm and 155 mm projectiles.

15. To gain the greatest steadiness in the base, the band should be positioned as near the base as possible. In practice, this is limited by:

a. the tendency to cause eddy waves and so reduce ballistics when a band is placed too near the base;

b. the tendency for a press-on band to tear off the metal behind it owing to the force of engraving;

c. the fact that boat-tailed projectiles must have the band in front of the boat-tail; and

d. the fact that in fixed ammunition, the band must be far enough forward to allow the projectile to be firmly secured to the cartridge case.

16. There is no set formula for the design of driving bands. A well designed driving band is one that gives good accuracy with both new and worn guns. The principle cause of inaccuracy due to the band is either forming of the extruded copper due to centrifugal force, which causes increased air resistance, or shearing of the band owing to the rotational inertia of the projectile. There are a number of subsidiary causes:

a. They are centered badly with the resulting effect of the groove marking on the body of the projectile.

b. The depth of the band must be of sufficient thickness to take the rifling, fill up the grooves and withstand the stresses at the moment of greatest angular deviation.

c. In general, narrow driving bands give less dispersion than wide ones, but there is a minimum width necessary to impart the required rotation and to prevent undue erosion due to the escape of hot gases. In some cases, two or more narrow bands are employed.

17. Most projectiles are designed with a **fringing groove** to the rear of the driving band. This groove is a fine milled indentation in the outer projectile wall. The groove provides a space for the accumulation of band materials when the material is pushed back or stripped.

HIGH EXPLOSIVE PROJECTILE (INTERNAL FORM AND DIMENSIONS) (Figure 9-5-4)

18. The most efficient type of HE projectile is one having a large capacity. For practical purposes, this capacity in most cases, varies in weight between 14 per cent and 20 per cent. Due to the density differences between steel and HE, it is normal to find that large calibre projectiles have a greater HE percentage of total weight than smaller projectiles.

19. In general terms, the most important factor to be considered when designing projectile bodies is to realize the stresses on the projectile. For this reason, projectiles fired from high performance equipment will normally have thicker walls than those fired from lower MV equipment. If the projectile walls are thicker to withstand high stress, it is apparent that the HE content will be lower.

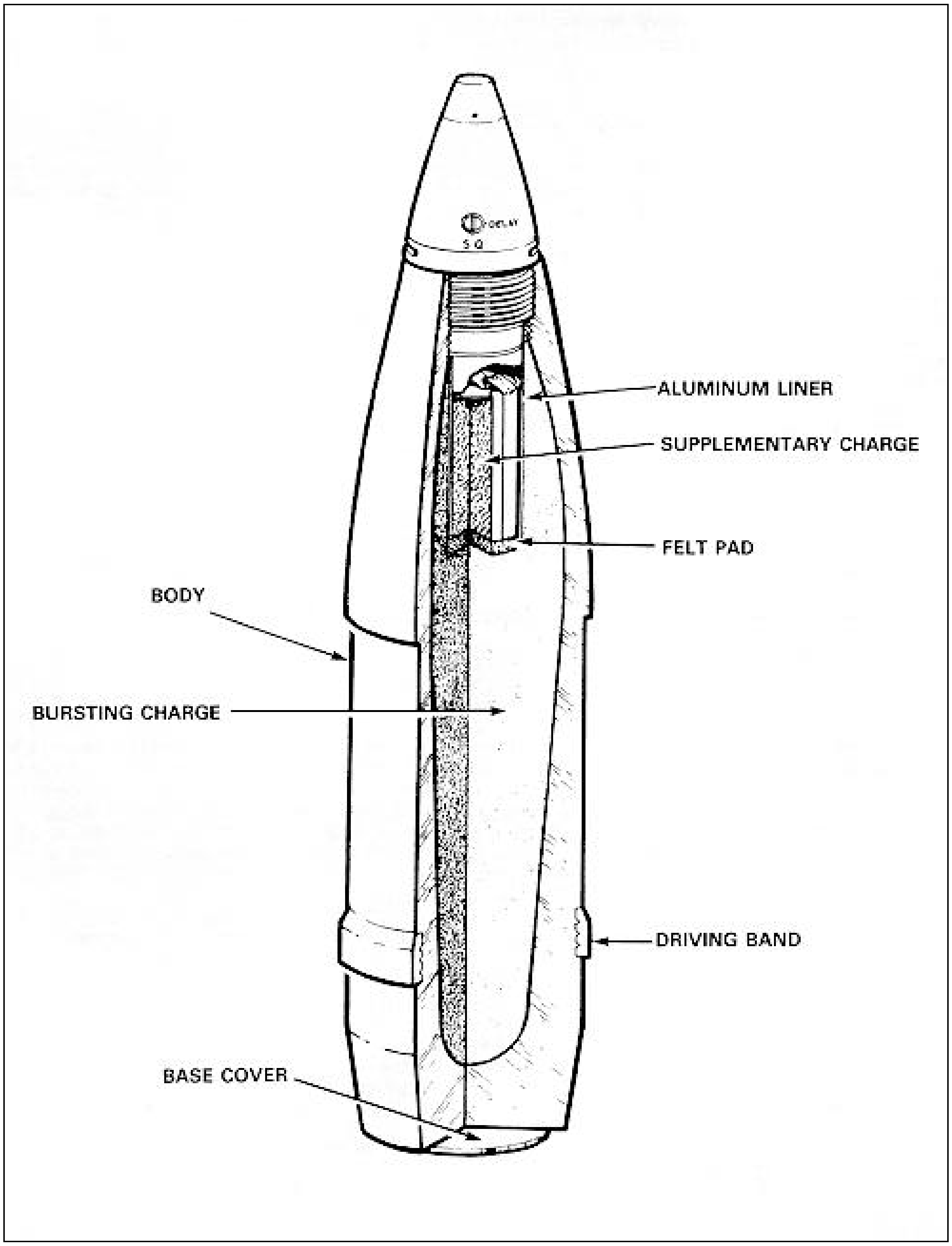


Figure 9-5-4 Typical HE Projectile Filled with HE (Projectile, 105 mm, HE, M1, W/Suppl Chg)

20. As a result of the previously mentioned factors, it becomes evident that no projectile should ever be fired without using the authorized propellant charge for which it was designed. In the same manner, no projectile should be fired from an equipment for which it was not especially designed, ie 105 mm Howitzer projectile fired from a 105 mm gun.

CARRIER PROJECTILES (Figures 9-5-5 to 9-5-7)

21. Carrier projectiles are fitted with a small explosive charge used to open the projectile and free its contents. Depending on the type of fuze used, the projectile can be made to function on impact or in the air. There are numerous types of carrier projectiles. The more important are discussed in the following paragraphs.

22. **Smoke (coloured, white and phosphorus)**. These are required to provide the user with a means of obscuring the enemy's view/field of fire and to give a measure of protection to one's own troops during tactical movement. Mixtures usually produce white or grey smoke but some work has been done to produce brownish/greenish smoke. The mixture chosen for a particular application depends on some extent on the method of operation of the particular projectiles. Bursting smokes are generally unpleasant chemicals, such as white phosphorous, that enflame spontaneously on contact with the air. However, recent research has bean directed to producing bursting smoke mixtures with less noxious properties. Other screening smoke mixtures most commonly met are based on hexachlorethene (HC). Coloured smokes are required for signalling or target indication purposes and most of them are used in base ejection projectiles, because the considerable heat generated from a bursting projectile tends to volatilize the dyestuff that is used as colouring materials.

23. **Chemical**. Chemical projectiles are filled with various gases that are either harassing, incapacitating or toxic. These projectiles are not held in Canadian inventories.

24. **Illuminating**. There is a continuing requirement for battlefield illumination and illuminants will be used to enable targets to be engaged, once improved surveillance and night vision devices have indicated their presence.

25. **Anti-personnel**. There are four types of anti-personnel projectiles. These are:

a. **Shrapnel**. This is mentioned for historical interest only since it was the first attempt at controlling the fragment sizes in bursting projectiles. A similar approach is met in a number of current anti-personnel and anti-tank devices dispersed by Improved Conventional Munitions (ICM).

b. **Canister Shot**. This type of projectile has been developed to counter the threat posed by massed infantry to unsupported armoured fighting vehicles (AFVs). It is essentially a short range weapon and consists of a thin metal case that contains a number of metal fragments of a preferred size. These are generally either spherical or cylindrical in shape and as many as possible are packed into the available volume. The projectile breaks up at the muzzle and the payload is dispersed in part by the inherent spin of the container to produce a cone-shaped pattern. Some canister rounds tend to cause high wear at or near the muzzle of the gun. Problems can arise in producing canister shot that can be safely fired through muzzle brakes.

c. **APERS M546 Flechette Round (Figure 9-5-8)**. The APERS M546, flechette round, commonly referred to as the Beehive round, is intended primarily for anti-personnel use at close and long range. It is effective against personnel in the open or in dense foliage. The projectile consists of a two-piece aluminum body, an aluminum fuze adapter and a hollow steel base. The fuze adapter, which is threaded to the body, contains four radially oriented detonators, a flash tube, a relay and an axially oriented detonator. A central steel flash tube extends from the projectile base to the detonator in the fuze adapter. The projectile body is loaded with 8 000 eight grain steel flechettes (darts). A mechanical time fuze is assembled to the projectile. On firing, the fuze starts to arm immediately and will function as set - either on leaving the muzzle, called muzzle action (MA), or at a pre-set time. When the fuze functions, the four radially oriented detonators rip open the forward skin of the projectile ogive and the flechettes in the forward section of the projectile are dispersed by centrifugal force. At the same time, the axially oriented detonator and relay cause a flame to flash down the flash tube and to ignite the base expelling charge. The pressure built up by the burning of the base expelling charge forces the flechettes and black marker dye in the rear of the projectile forward and out of the projectile.

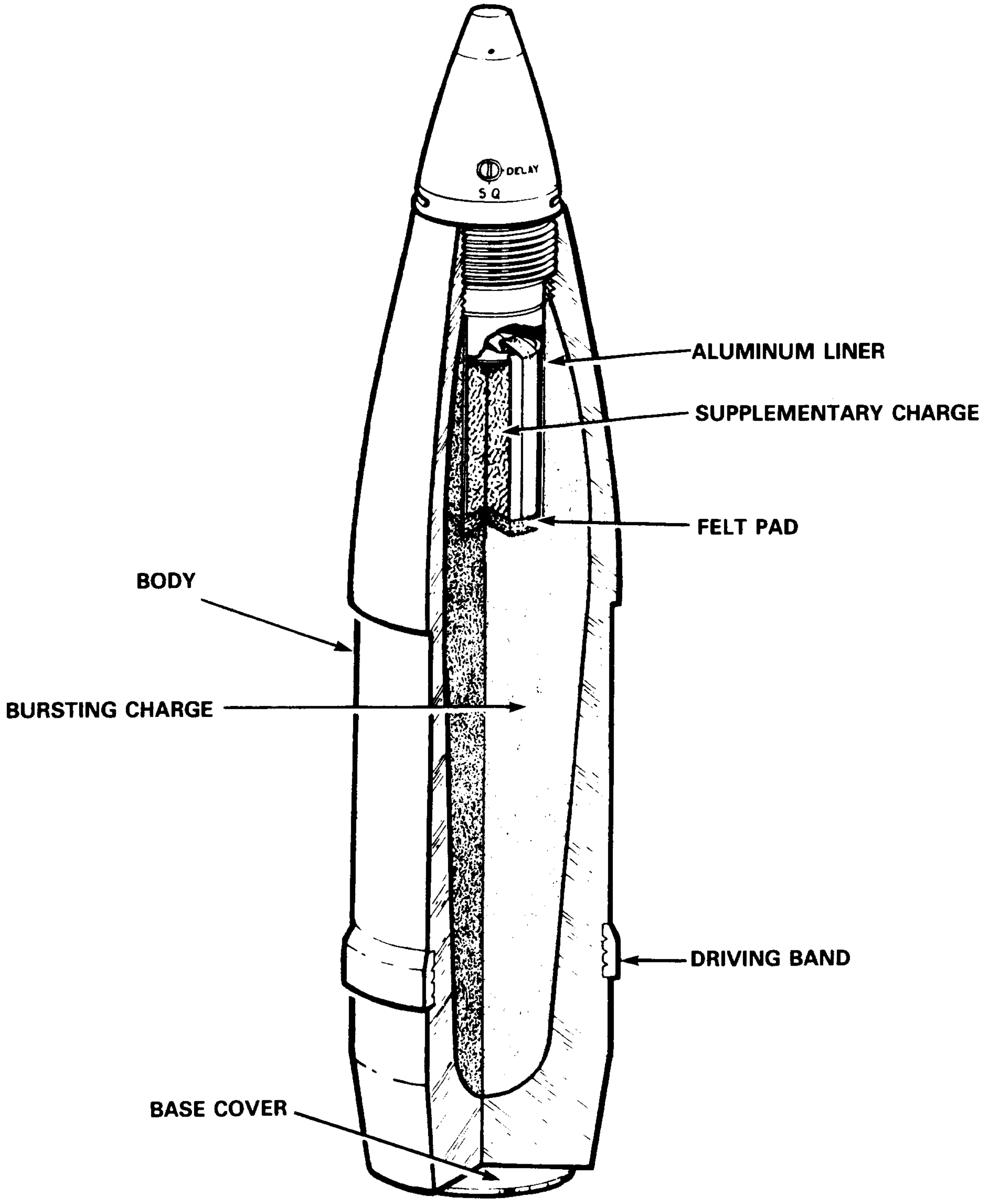


Figure 9-5-5 Bursting Carrier Projectile (Projectile 155 mm Smoke WP, M110)

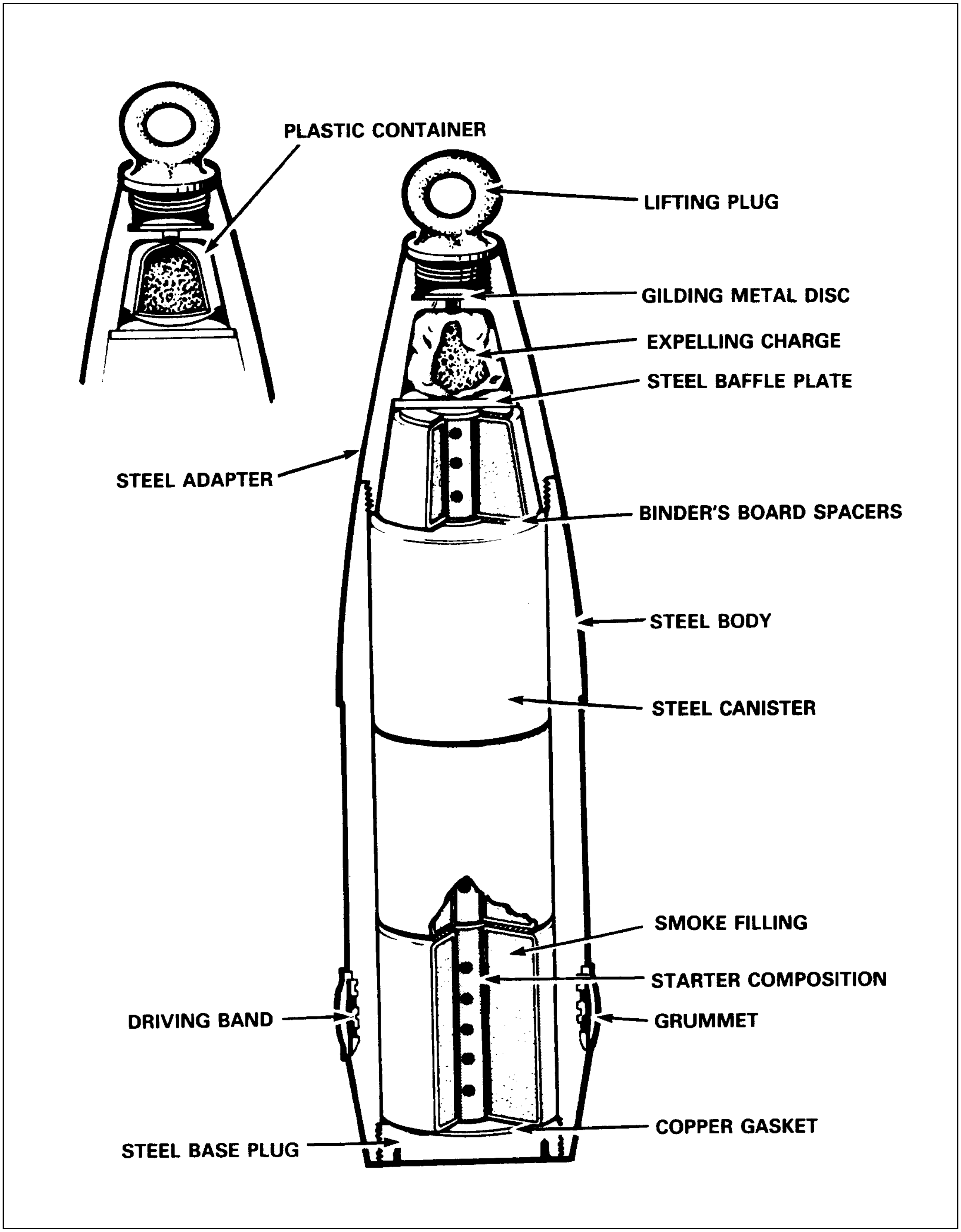


Figure 9-5-6 Base Ejection Projectile (Projectile 155 mm Smoke, Base Ejection, M116)

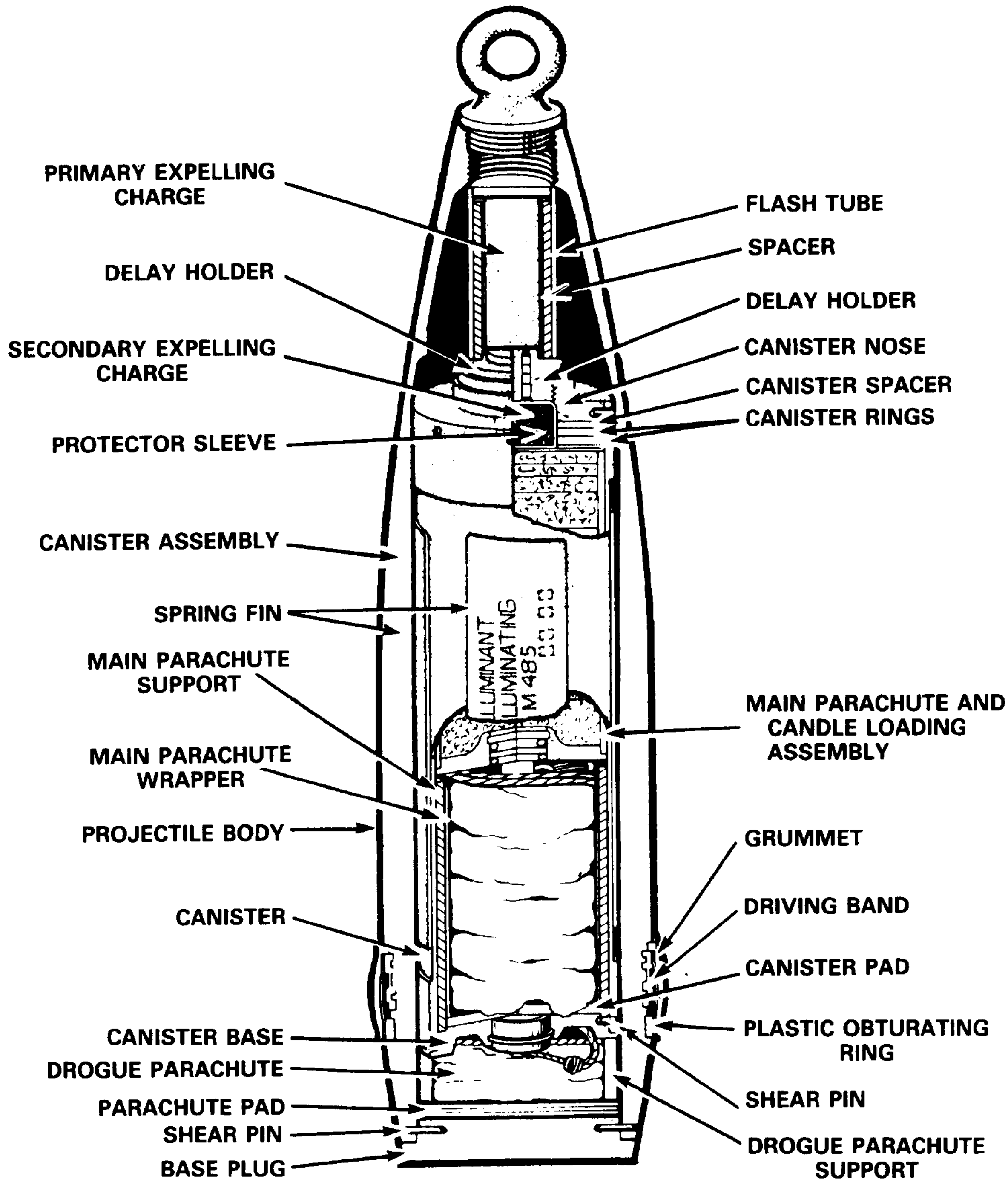


Figure 9-5-7 Base Ejection Projectile (Projectile 155 mm Illuminating, M485)

d. **Improved Conventional Munitions**. There are two types of ICM projectiles available for field artillery howitzers: the old single purpose anti-personnel projectile for the 105 mm, 155 mm and 8-inch howitzers; and the new dual-purpose anti-personnel-anti-material projectile for the 155 mm and 8-inch howitzers. There is no anti-personnel-anti-material projectile for the 105 mm Howitzer. The basic difference between the new and old is the type of grenade (anti-personnel-anti-material) used as submunitions with each type of projectile. In both cases, the projectile is merely the means of transporting the grenades to the target area; it is the grenades that do the work -

(1) **Anti-personnel Projectile**. The grenade used in the anti-personnel projectile contains a steel ball filled with explosive. When the grenade strikes the target, it hurls the ball 1 to 2 metres (4 to 6 feet) into the air where it detonates and scatters over the target area. The 105 mm projectile (Figure 9-5-9) contains 18 grenades M39. The 155 mm projectile contains 60 grenades M43. When the fuze on the projectile functions, it ignites the black powder expelling charge in the projectile. The burning black powder builds up pressure that forces all of the grenades out through the base of the projectile. Small vanes on each grenade flip upward and arm the grenade. The vanes keep the armed grenade in a vertical position as it falls through the air so that the striker plate at the base of the grenade strikes the target area. This action causes the expelling charge in the grenade to hurl the steel ball 1 to 2 metres (4 to 6 feet) in the air and detonate the HE, which blows the metal ball to bits and projects the fragments over the target area.

(2) **Anti-personnel-Anti-material Projectile**. The grenades used in the anti-personnel-anti-material projectile are the dual-purpose grenades M42 and M46 (Figure 9-5-10). These grenades have an HE shaped charge and are equipped with a ribbon streamer that arms the grenades after they have been expelled from the projectile in a manner similar to that described in paragraph 25d (1). The ribbon also keeps the grenade in a vertical plane as it falls to the target. When the grenade hits the target, the HE shaped charge is detonated. The shaped charge is very effective against material or personnel. The M483A1 projectile for the 155 mm Howitzer contains 88 shaped-charge grenades, and the M509A1 projectile for the 8-inch Howitzer contains 180 grenades. The M42 and M46 grenades are identical except that the M46 grenade has a stronger body. The M46 grenade is placed in the bottom three rows of the M483A1 projectile to absorb the setback force of the remaining 64, M42 grenades.

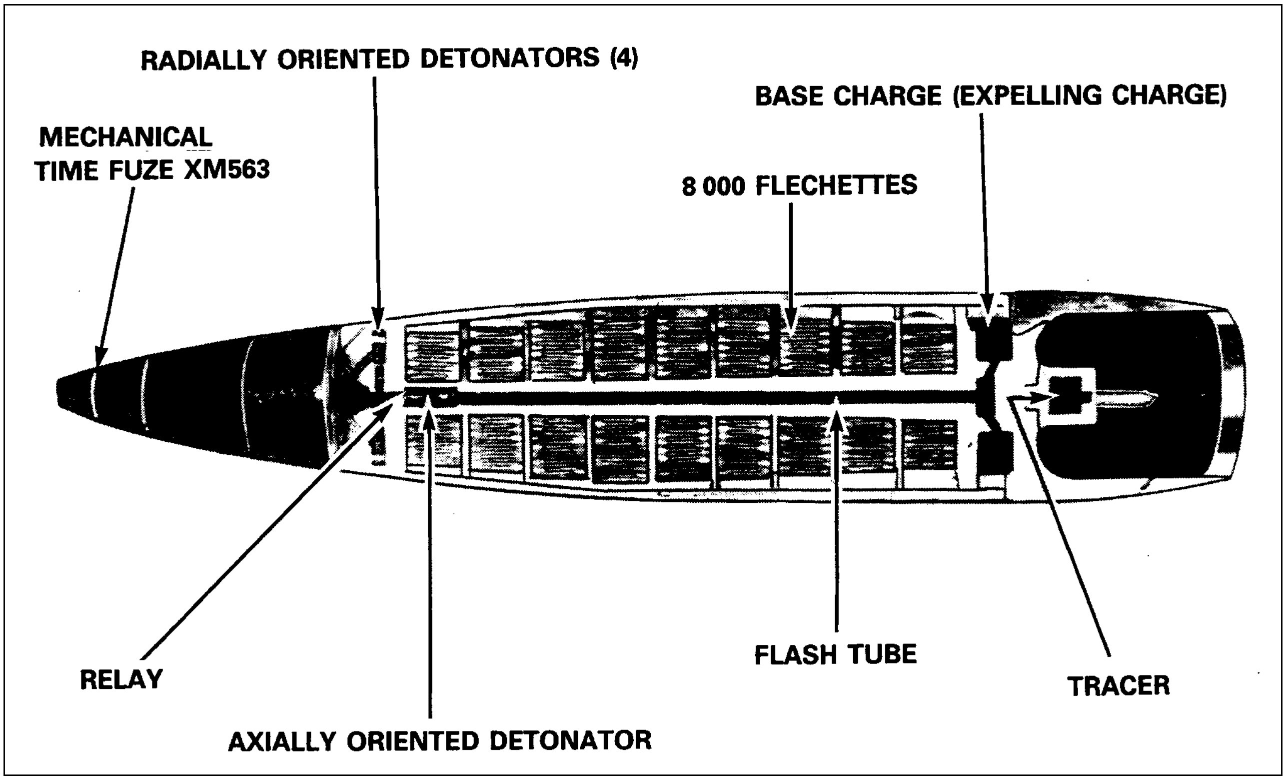


Figure 9-5-8   APERS M546 Flechette (Beehive)

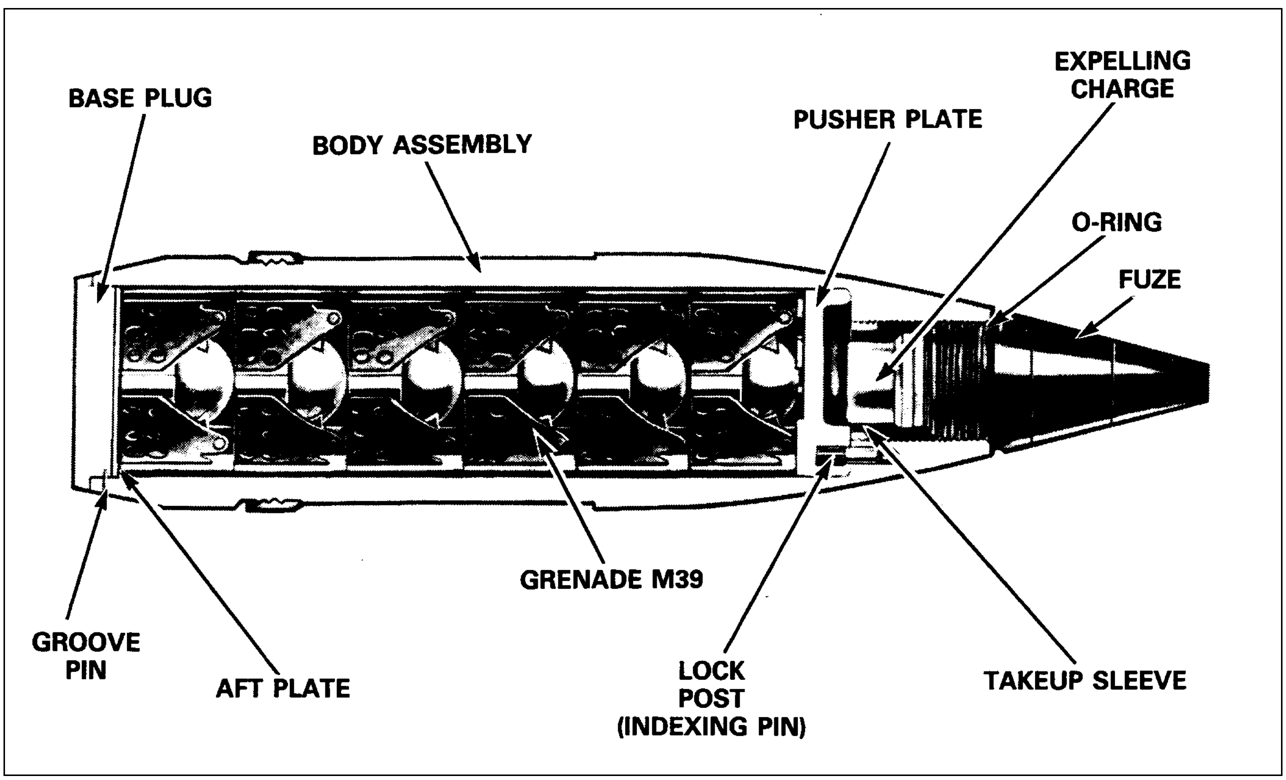


Figure 9-5-9   Improved Conventional Munitions (ICM) Projectile

e. **Family of Scatterable Mines Projectiles**. There are four base ejection type projectiles of the M483A1 projectile family used in the 155 mm Howitzer that are known as the Family of Scatterable Mines (FASCAM) projectiles. All four of these projectiles are painted olive drab with yellow markings and include yellow triangles around the ogive of the projectile. Two of these projectiles contain 36 anti-personnel mines and two of them contain nine anti-tank mines. The yellow triangles have either a letter "L" or "S" painted inside the triangle. These markings identify the self-destruct time of the anti-personnel and anti-tank mines and are used in selecting the right projectile to fire when artillery delivered mines are needed to deny or delay access to a particular area for a specific time period. The letter "L" signifies a long time (more than 24 hours) before self-destruction if not activated and the "S" indicates a shorter period of time (less than 24 hours) before self-destruction. The actual times of "L" and "S" are classified; the data can be found in TM 43-0001-28-1 (C) -

(1) **M692/M731 Area Denial Artillery Munitions**. The M692 and M731 projectiles are known as the area denial artillery munitions, or ADAMs for a short title. These are projectiles that contain anti-personnel mines used to deny the enemy use of certain areas for a period of time. This action is accomplished by firing the ADAM projectile so that the 36 mines are ejected over the target area. After each mine comes to rest on the ground, seven sensor trip lines deploy up to 6 metres (20 feet) from the mine. After another short time delay to allow the munition to return to rest, the trip line sensors are activated causing the mine to be completely armed. Disturbance of a trip line completes an electronic firing circuit. A thin layer of liquid propellant, which by gravity rests under the kill mechanism, is initiated shattering the plastic munition body and projecting the spheroid kill mechanism upward. At a position 0.5 to 2.5 metres (2 to 8 feet) above the ground, the kill mechanism detonates projecting approximately six hundred 1-1/2 grain steel fragments in all directions. If the mine has not detonated or functioned within the factory set time (long or short self-destruct time) the mine will automatically self-destruct, thereby, clearing the area.

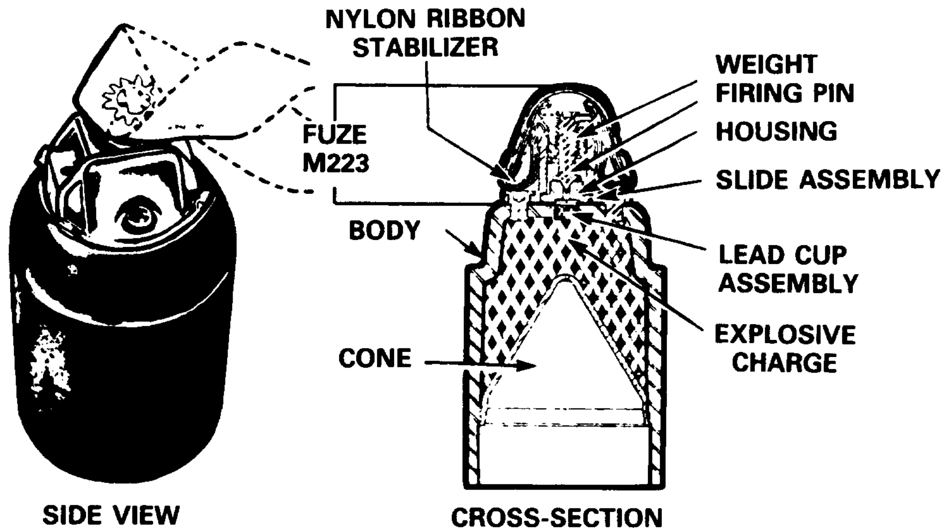


Figure 9-5-10 ICM Grenade M42

(2) **M718/M741 Remote Anti-Armour Mines System**. These projectiles are used to deliver anti-tank mines in front of enemy armoured forces to deny or delay access to a particular area for a specific time period (long or short time). They are called Remote Anti-Armour Mines System (RAAMS). Each projectile contains nine mines that can be expelled into the target area. The mines are scattered over an area and become armed within a few seconds after landing. Any metallic object such as a tank, self-propelled vehicle, or other type unit passing over the mines will cause them to activate and damage or destroy the equipment. If after a certain period of time these mines have not been activated, they also contain a mechanism for self-destruction. Scattered among the mines are some that have an anti-disturbance firing mechanism that can cause casualties if disturbed by enemy personnel attempting to clear the mined area.

f. **Countermeasure**. These are carrier projectiles used to distribute leaflets for propaganda purposes, or to jam radar sets, etc.

g. **Practice Rounds**. Practice rounds are designed to simulate the ballistic properties of service projectiles and are used for marksmanship and training purposes. They may be made from completely inert-loaded projectiles or made from different metal parts. Some may contain tracer and/or spotting charges.

SECTION 6

ANTI-TANK PROJECTILES

GENERAL

1. There are two main types of modern anti-tank projectiles: one carries a solid penetrator and is mainly used by tank guns; the other carries HE and is used by tanks and howitzers.

2. Since artillery anti-tank guns are being replaced by guided missiles and shoulder fired recoilless weapons, there is no need to discuss solid penetrators any further, for they require an MV in excess of that provided by howitzers.

3. Anti-tank HE projectiles do not depend on velocity for penetration of the target. The HE projectile when detonated against the target, will either send a shock wave through the target material and cause high velocity **scabs** to break away on the inside as in HESH/HEP or the target is penetrated by a high velocity jet causing flaking on the inside as with HEAT. The latter effect was discovered in 1888 by C.E. Munroe and is known as the **Munroe Effect** or **Hollow Charge Effect**.

4. HE anti-tank projectiles are fast becoming obsolete because of the development of new armour. For tank guns, the tendency is towards solid penetrators with MVs in excess of 1 500 m/s, such as Armour Piercing Fin (APFSDS). Additional information can be found in C-74-315-JAO/TA-000.

HIGH EXPLOSIVE ANTI-TANK PROJECTILES

5. **High Explosive Anti-Tank (Figure 9-6-2 (A) and (13))**. The HEAT projectile uses the **Hollow Charge Effect**. If a column of explosive with a hollow space at one end and the detonator at the opposite end is detonated against a steel plate, the penetration will be deeper than that of a flat-ended charge. If the hollow space has a metal liner (copper) and the whole column of explosive is removed a short distance from the target, **stand off distance**, a high velocity jet is formed that exerts a pressure of several hundred thousand atmospheres (some 308 MPa) against the target. This pressure so greatly exceeds the yield strength of the target material that it is simply pushed aside from the path of the metallic jet (see Figure 9-6-1).

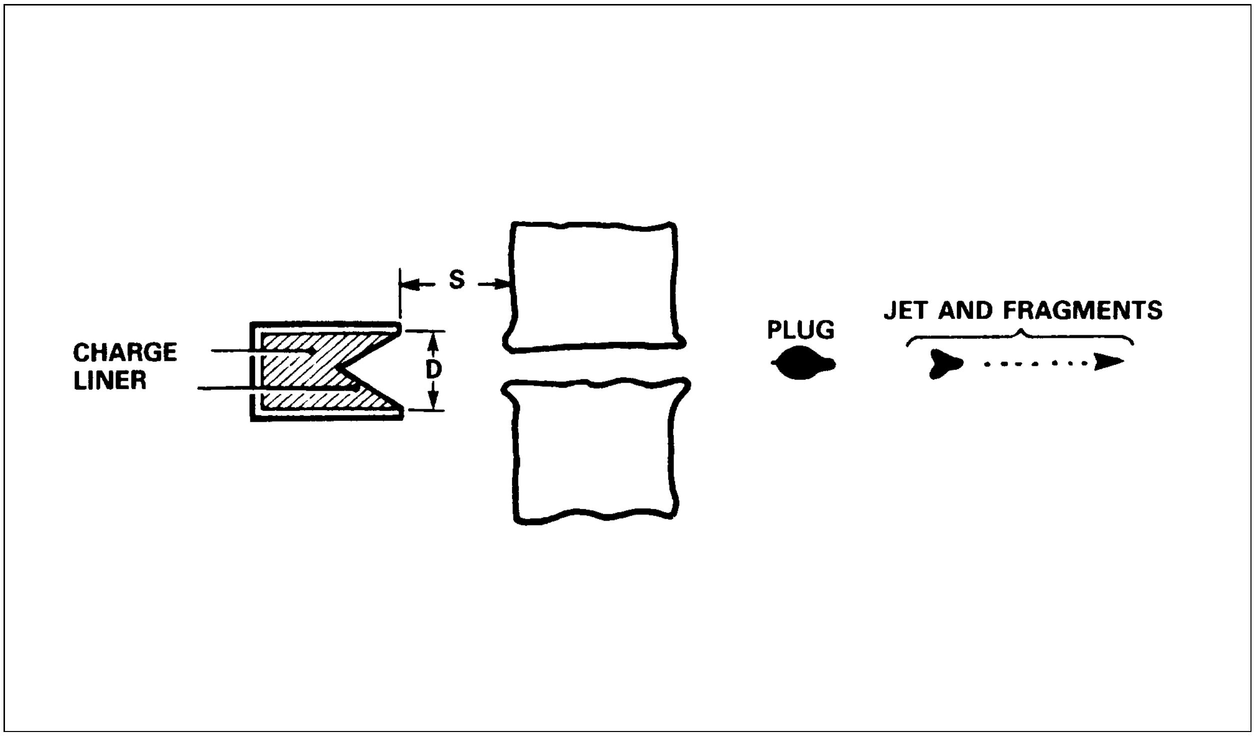


Figure 9-6-1 Hollow Charge Effect

6. About 20 per cent of the metal liner goes into the metallic jet, which has a velocity gradient from its tip of approximately 8 000 m/s to 9 000 m/s and to its tail of about 1 000 m/s. The remaining 80 per cent of the liner forms a plug that follows the jet at a much lower velocity - in the order of 300 m/s. When the jet exits in the interior of the tank, much flaking and spalling is caused. These pieces of metal fly with great velocity around the inside of the tank, killing personnel and detonating explosives. The penetration achieved by a HEAT projectile is quite spectacular and (in terms of weight of HEs used) small charges can penetrate considerable thicknesses of plate. The power of penetration is decreased up to 50 per cent in spin stabilized projectiles. Modern projectiles are fin stabilized and use a distance tube (standoff spike) instead of a ballistic cap for stand off distance (see Figure 9-6-2 (B)). Detailed information on the Munroe Effect can be found in TM9-1300-214, Chapter 5.

7. **High Explosive Squash Head**. Figure 9-6-3 shows a typical HESH/HEP projectile. Because this projectile relies on pure explosive force to defeat armour, it requires a large HE content. Upon impact the shell walls collapse and the inert filling in the nose absorbs the shock allowing the plasticized HE to spread against the target. The instant this occurs, the base detonating fuze activates, detonating the **wad**. The very powerful shock wave caused by the detonation passes through the armour until it reaches the inner surface where, because it cannot cross the air gap presented, reverses itself and travels back through the armour. This reversal causes the inner surface of the armour to flake off or **scab** in a large piece that is projected into the interior of the fighting compartment at a velocity of up to 300 m/s. The damage caused on the inside is not apparent from the small indentation left on the outside of the target. HESH/HEP rounds, because of their plastic HE content, are successful at wide angles of engagement and the angle of incidence formed with the target will not affect its performance unless very large.

HESH/HEP projectiles are also fired from high performance equipment (105 mm tank guns at an MV of 732 m/s) and the hit probability, using current range finders, is acceptable.

8. Both HEAT and HESH/HEP are effective in defeating concrete and other **hard** targets.

9. HESH/HEP has little or no effect against spaced armour.

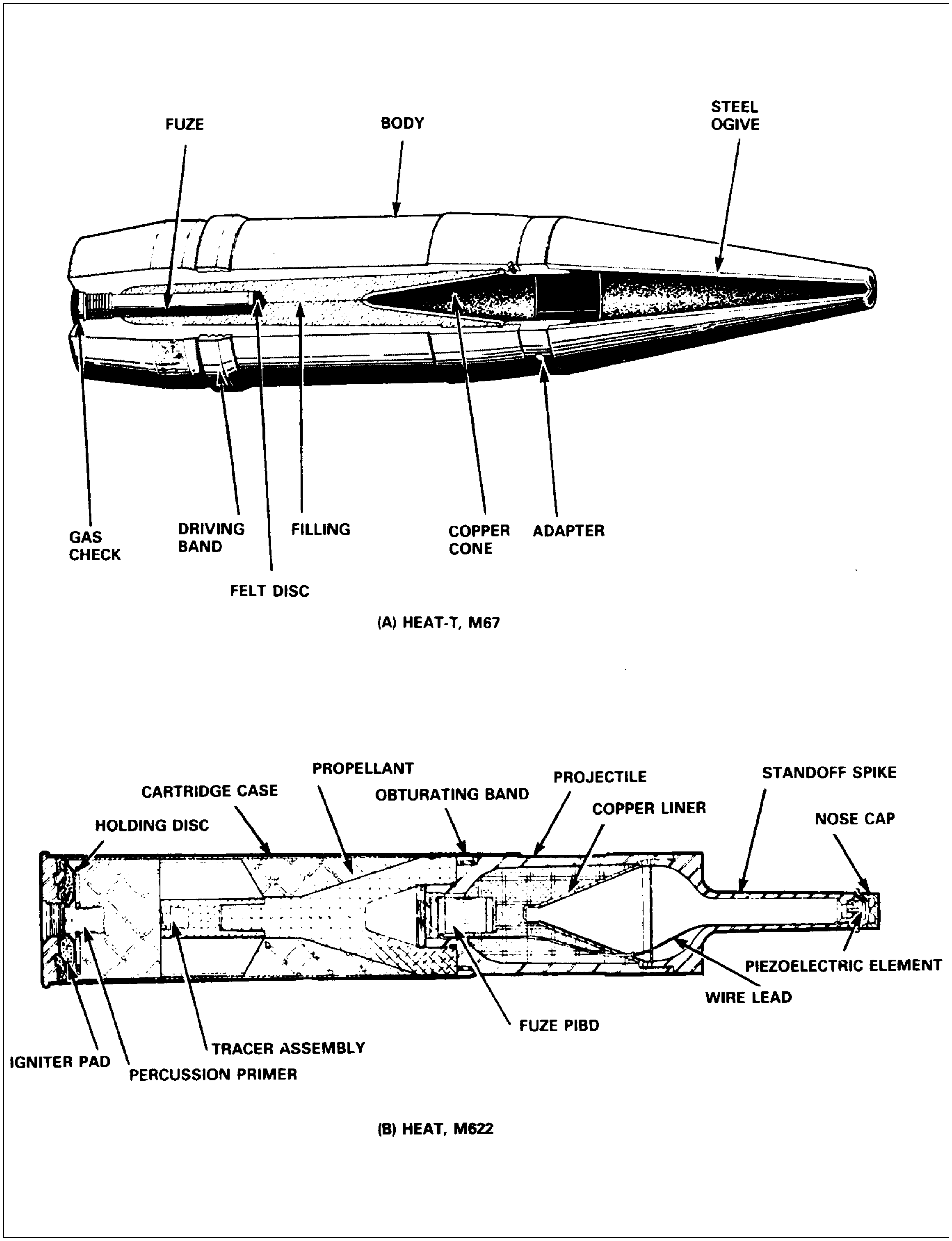


Figure 9-6-2   Typical High explosive Anti-Tank Projectiles

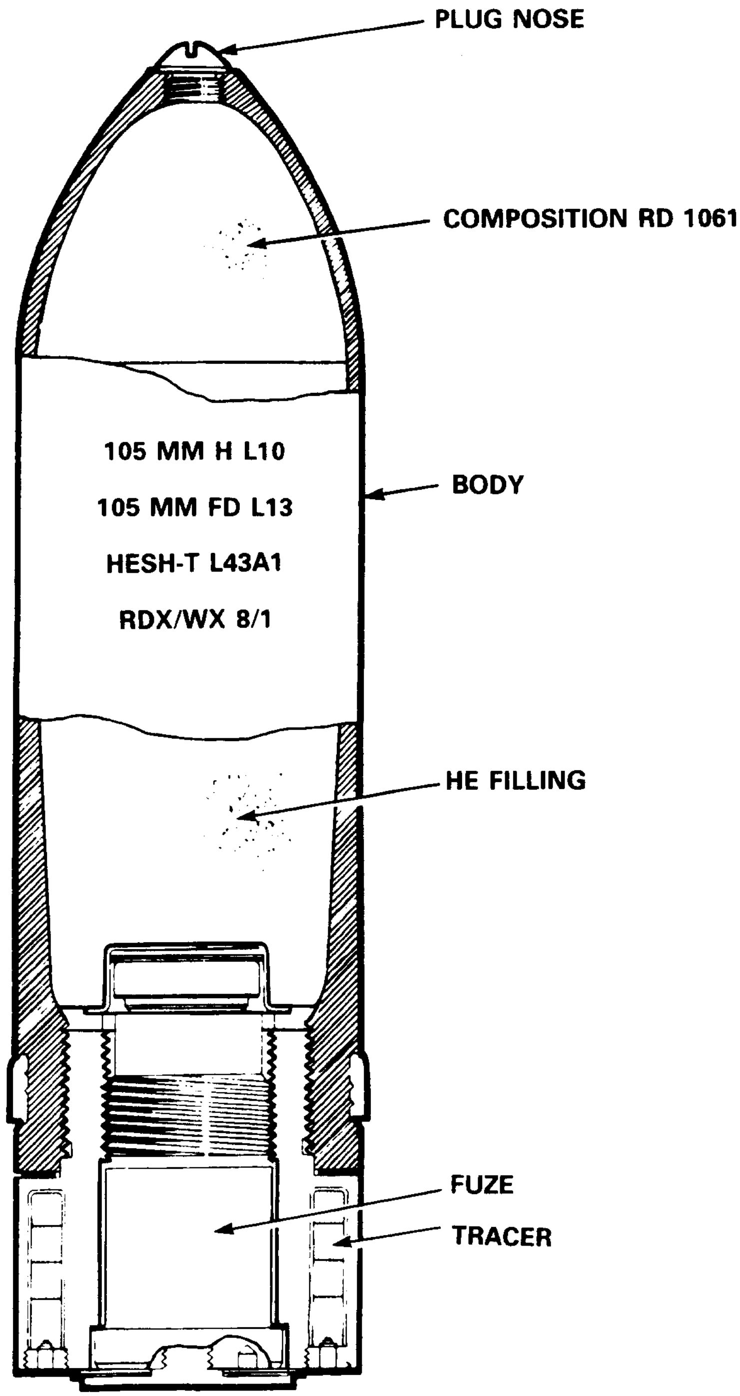


Figure 9-6-3 High Explosive Squash head (HESH) Projectile

SECTION 7

FUZES

INTRODUCTION

1. Every type of projectile, except solid shot and certain practice projectiles, has a fuze that is designed to cause the projectile to function at the time and under the circumstances required. This may be at some point along the trajectory, or at the end of the trajectory in the case of impact fuzes. Since the functioning of the projectile at or near the target depends on the fuze, it follows that the principal requirements are reliability and simplicity.

DESIGN PRINCIPLES

2. The following design principles are used in the assessment of the fuzing systems:

   a. The system must act at the right time and at the right place.

   b. The system should be designed to have the necessary strength and safety to meet all specified environmental conditions.

   c. The materials (explosives and compositions used in the system) should be chosen so that they are safe in their application, and remain free from the risk of the formation of unduly sensitive or dangerous compounds, under the full range of conditions encountered during storage and use.

   d. The system should be designed so that it cannot be assembled in an unsafe condition.

   e. The system should be designed so that inspectors can check the safety arrangements during and after assembly.

   f. The system should ensure that sensitive compositions are separated from the main filling by a physical obstruction (shutter, rotor, or interrupter) and that the explosive train is positively interrupted by mechanical means until arming is required. The rotor and/or interrupter should remain locked in the safe position under all conditions and should only unlock when arming parameters are reached.

   g. The system should remain safe for a specified distance of travel or other parameter, after launching, firing or release. Within these specified limits, it should not function if it strikes an obstacle or receives a firing signal.

   h. The system should be designed to prevent any single circumstance from initiating and completing fuze functioning before the safe distance is reached. Arming should not be possible except as a result of normal firing, launching, release or conditions simulating such events.

j. The system should be designed to prevent accidental functioning in the presence of electromagnetic fields, or under the effects of electrostatic charges.

k. Electrical initiators should require as high an operating energy for functioning as the system permits.

3. The principal user requirements for fuzes are safety and reliability. The prime requirement is that the user should be free from the risks of a malfunction. When a fuze is to be used in a number of different equipments, or in a single equipment with a multi-charge system, the requirement for safety may conflict with the requirement for reliability. This can occur when the forces available to arm the fuze when fired are only slightly greater than the accelerations brought about by rough handling.

4. The user also requires some or all of the following requirements depending on the task to be done:

a. optional delay setting,

b. easy time setting,

c. minimum preparation time for use, and/or

d. multi-role to minimize re-fuzing.

FORCES USED IN ARMING FUZES

5. A large variety of forces are available for actuating all or part of a fuze mechanism. Of these, the following are the principal forces used:

a. **Set Back**. Set back arises from the reaction of the mechanism to the forces of acceleration applied to the fuze by the gun on firing. It has the effect of locking all free components hard down on their seatings. During the acceleration phase, the set back force is greater than the spin force so that no centrifugal movement of a component is possible during this phase. The physical backward movement or anchoring of components compresses any springs that are placed axially in the fuze.

b. **Creep Forward**. This action occurs as the acceleration phase ends. Components that have been locked tend to ease forward on their seatings. Springs that have been compressed begin to re-exert themselves. This gradual unlocking process permits stored energy forces, ie springs, to act upon components susceptible to them.

c. **Stored Energy**. Stored energy consists of clockwork mechanisms, radio, springs, electric motors, etc, that work in conjunction with the other forces to control the functioning of the fuze.

d. **Centrifugal Force**. This force acts on any component whose centre of gravity is off the axis of the fuze. These components tend to be thrown outwards by centrifugal force which is generated by the angular velocity (spin) imparted to the projectile. The force is used to operate rotor mechanisms, interrupters and other components.

e. Spin Delay. Spin delay occurs as the projectile loses **its angular velocity**. This decrease in angular velocity can be used to trigger various self-destruct devices.

6. Most fuze mechanisms operate in a fashion similar to a combination lock. As a lock requires that numbers be fed in a predetermined sequence, fuzed mechanisms will only function provided the necessary stimuli are applied in the correct sequence. The common method of functioning is the three stages of:

a. unlocking a component by set back forces;

b. easing it on its seating during creep forward; and

c. swinging it to an armed position by the application of centrifugal force.

CLASSIFICATION

7. All fuzes are classified as to the method in which they function. This could be either impact, time or proximity (see Figure 9-7-1). Impact fuzes may also be classified as to their location on the projectile, eg point detonating or base detonating fuze. Further, some fuzes can be caused to function in either an SQ or delay.

8. There are a great number of fuzes in service at this time (the US has over 75 different ones). They all belong to one of the three secondary classifications, ie impact, time or proximity, and work in the same fashion with minor differences. The following paragraphs will dwell only on the main characteristics of these different classifications. There is currently an attempt being made to reduce the number of fuzes in production and to develop fuzes that will be adaptable to all calibres of projectiles.

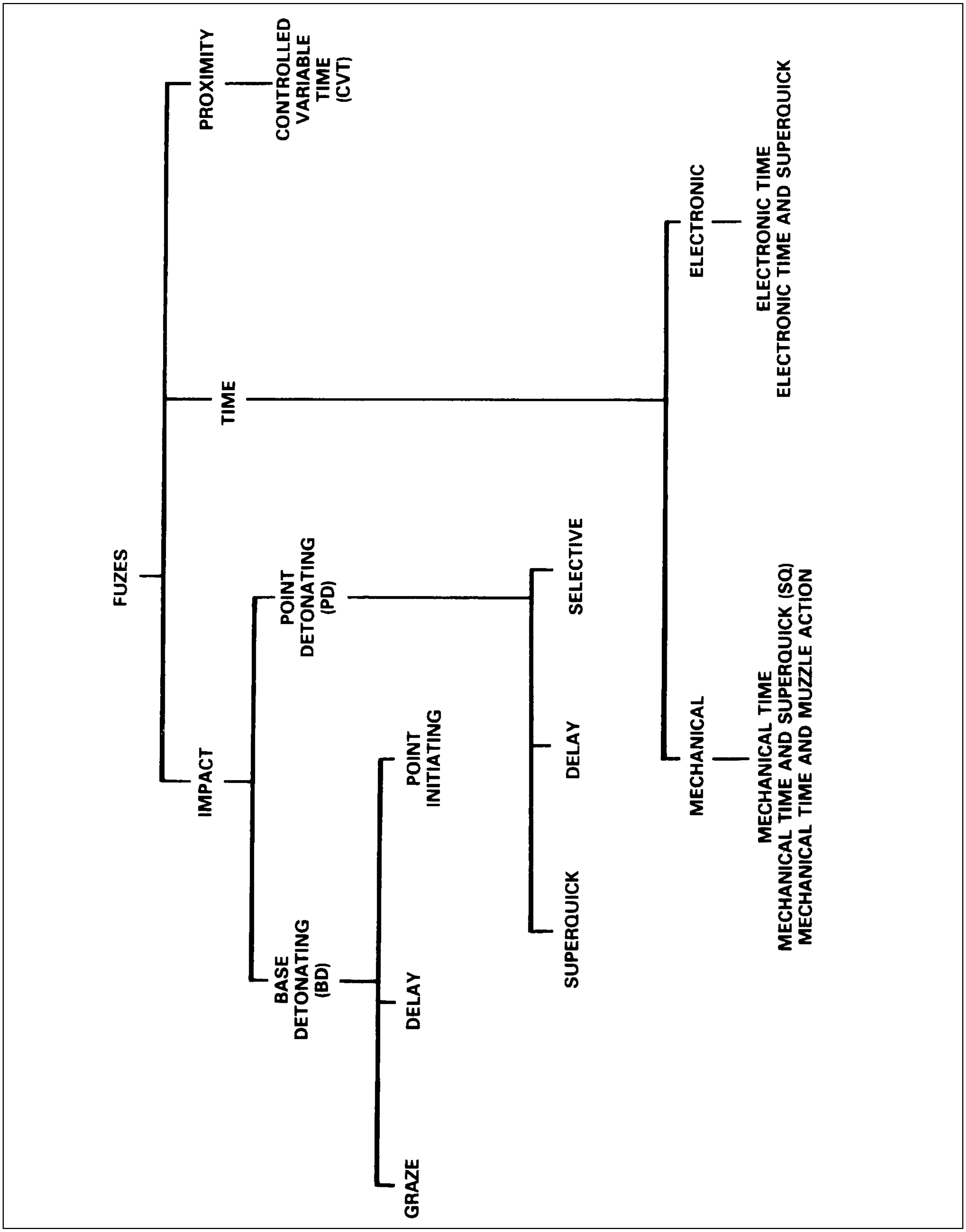


Figure 9-7-1 Fuze Chart

IMPACT FUZES

9. Impact fuzes may be either point or base detonating and both will function when a fuzed projectile strikes an object in its trajectory. According to the speed at which they at they can be subdivided into the following types:

a. SQ,

b. graze,

c. delay, and

d. non-delay.

10. **Superquick**. SQ fuzes belong to the point detonating (PD) class. A static firing pin in the SQ element of the fuze (located in the nose of the fuze) is driven onto a detonator by the crushing action caused by impact. This will cause the almost instantaneous detonation of the projectile filling (bursting charge). This action will occur at all but the smallest angles of impact where, with large projectiles, ricochet can be expected due to the failure of the fuze nose to be crushed (see Figure 9-7-2).

11. **Graze**. Graze action is incorporated in most PD and base detonating (BD) fuzes and acts under the force of inertia. Inertia is the action caused when loose objects are thrown forward when the body containing them is suddenly arrested. When a projectile strikes an object at an angle that would normally cause a ricochet, this **glancing** or **grazing** blow is sufficient to throw the graze action mechanism forward onto a firing pin initiating the contained detonator. This will subsequently detonate the explosive filling with an almost instantaneous action.

12. **Delay**. Delay fuzes may be PD or BD and, in principle, work in the same manner as graze action. If the detonator in the delay mechanism is separated from the explosive filling by a slow burning or delay action element, then the projectile will partially bury itself or pierce the object it strikes before detonation, thus giving a delay action.

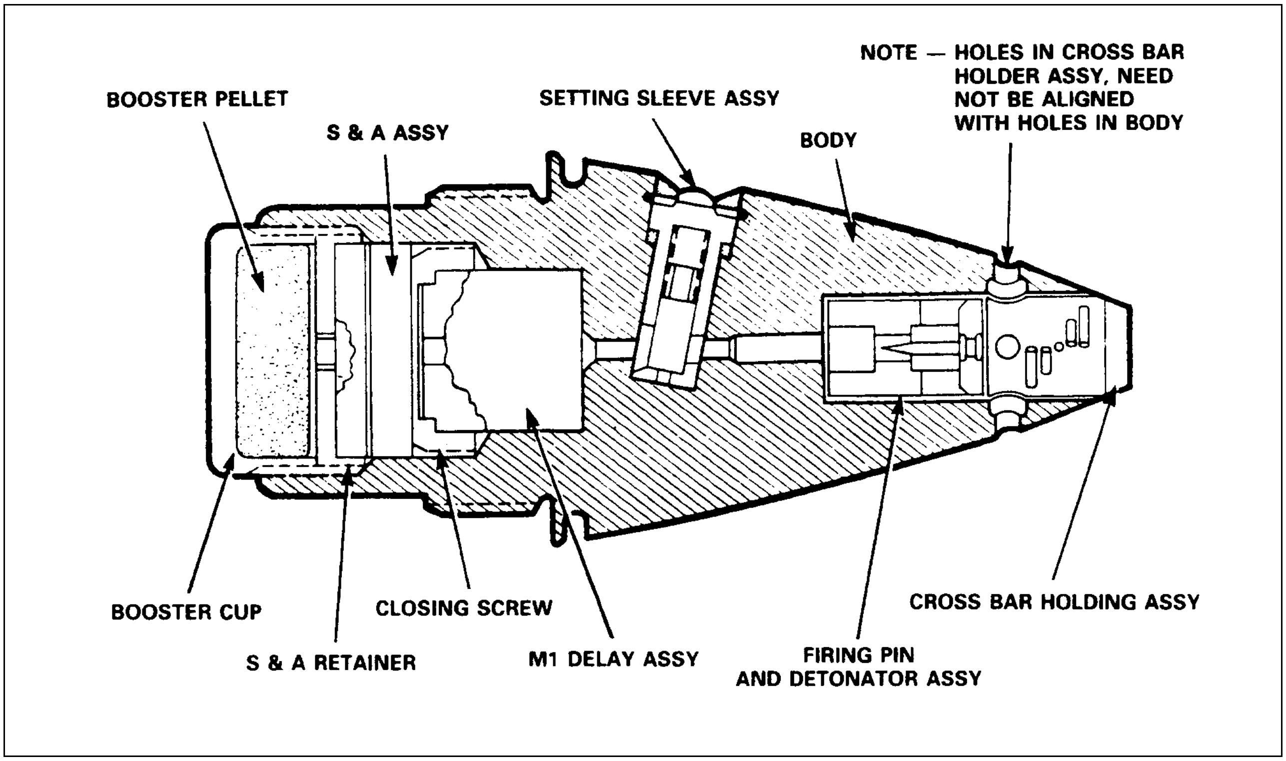


Figure 9-7-2 Typical Point Detonating Selective Fuze with Superquick Element, Delay Assembly and Booster (M739)

13. Most modern PD fuzes are termed **selective** in that, by a simple adjustment to the fuze, the user can select the mode of action required, ie SQ or delay.

14. **Non-delay**. An example of this is CP.M78 (white nose), no PD element in nose and no delay pellet in plunger assembly.

15. Two examples of BD fuzes are shown in Figures 9-7-3 and 9-7-4.

TIME FUZES

16. Time fuzes are those that function after a pre-set time of flight and are used to achieve airburst, or to expell the contents of a carrier projectile at a point along the trajectory. There are several types of time fuzes available and a number under development. The timing mechanism can be powered in a number of ways, eg centrifugal weights, wound up spring and by battery. A typical mechanical time fuze is illustrated in Figure 9-7-5.

MECHANICAL TIME MECHANISM

17. Mechanical time fuzes utilize a mechanical clock work mechanism to control the time of burst. There are three distinct types of mechanical time mechanism. These are described in the following paragraphs.

18. **Thiel Mechanism**. The thiel mechanism is found in the UK designed mechanical timed (MT) fuzes (see Figure 9-7-6). It is a spring-driven mechanism controlled by an escapement through a chain of gear wheels. The spring, which is wound before assembly, drives a spring-loaded hand. Above the hand is a platform (hand race) across which a slot is cut. The hand race is rotated when the fuze is set. On set back, the hand is released for rotation. At the end of the setting time it is coincident with the slot in the hand race, into which it rises. A muzzle safety bridge prevents the hand rising until 0.72 seconds after firing (approximately 400 metres from the muzzle). The rising of the hand frees a lever attached to the striker. This in turn allows a cam on the striker to be rotated off its supporting pillar by the striker spring and then forces the striker onto the detonator. A centrifugal safety catch prevents the striker reaching the detonator before the projectile leaves the muzzle.

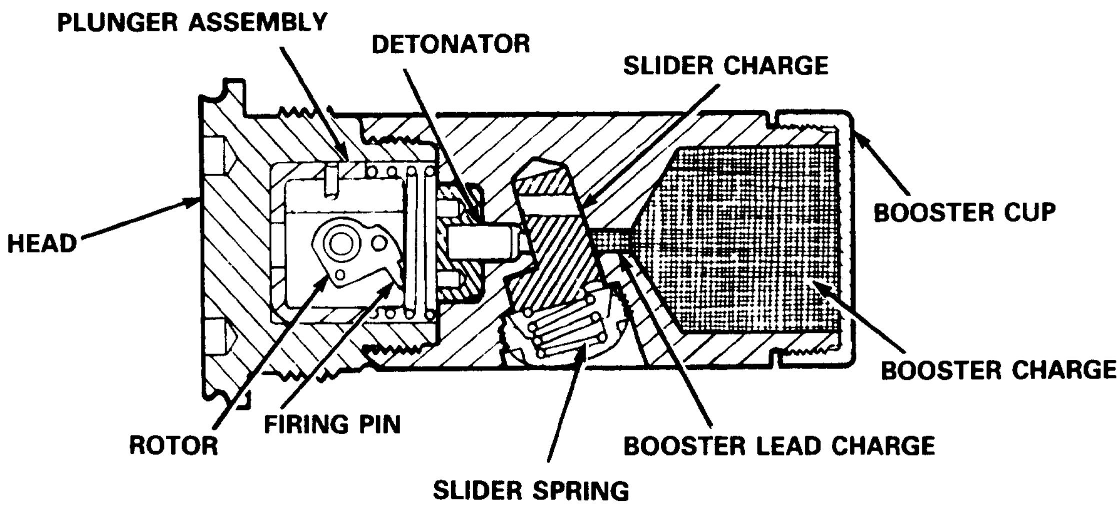


Figure 9-7-3 Base Detonating Fuze M62

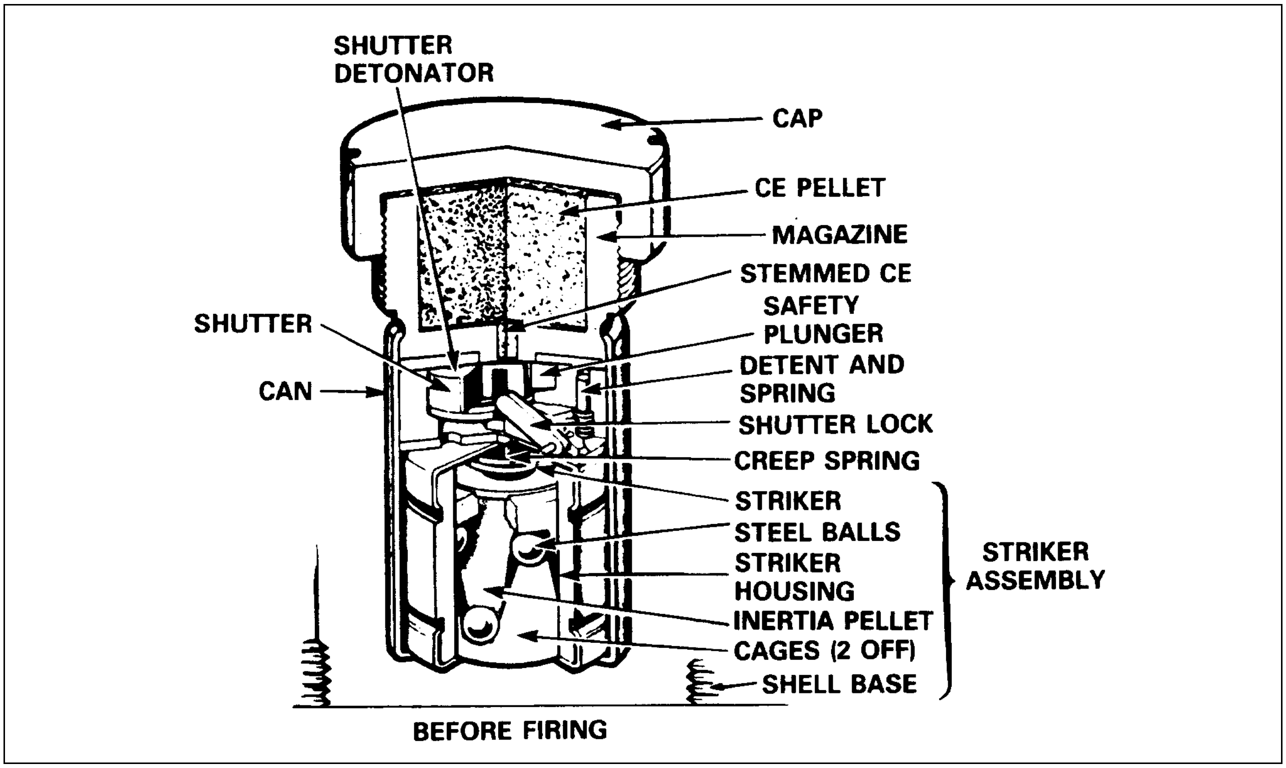


Figure 9-7-4 Base detonating Fuze L58A1

19. **Junghans Mechanism**. The junghans mechanism is found in the US designed MT fuzes (see Figure 9-7-7). The mechanism is driven by a centrifugal weight mounted on gear segments and is controlled by an escapement. Setting the fuze rotates a timing disc, which is a friction fit, onto the central arbor of the gearing. On set back, this timing disc is released for rotation. A slot is cut in the periphery of the timing disc and a finger of the firing arm bears on the periphery. At the time set, the finger and slot are coincident and the finger moves into the slot under the action of centrifugal force acting on the opposite end of the arm. A safety leaf prevents functioning at less than 1.5 seconds after firing by masking the slot. The rotation of the firing arm, as the finger moves into the slot, allows a safety plate to rotate. This plate supports the firing pin which is now free to move onto the detonator under the action of the spring.

20. **Dixi Mechanism**. The dixi mechanism is found in the Swiss designed fuzes (see Figure 9-7-8). The mechanism is driven by the action of centrifugal force acting on driving balls, which are engaged between vertical grooves in a driving cone and spiral grooves in the fuze body. The speed at which the driving balls (moving under centrifugal force) may turn the cone is controlled by a gear train and escapement. Setting the fuze turns the driving cone, thereby moving the driving balls a certain distance along the spiral grooves. On deceleration, centrifugal force causes the balls to move the remaining distance along the spiral channels, at a speed controlled by the driving cone and timing mechanism. One of the spiral grooves is connected by a channel to the striker. A driving ball, on reaching this channel, is projected onto the striker.

21. The following factors affect the time of running of mechanical time fuzes:

a. **Composition and manufacture**. Mechanical time fuzes are carefully tested and any slight variation from clock to clock is adjusted before leaving the factory.

b. **Storage**. The mechanism is not affected by long term storage up to at least 5 years. If there is any doubt as to the correct tension of the main spring, it can be retested and adjustments made.

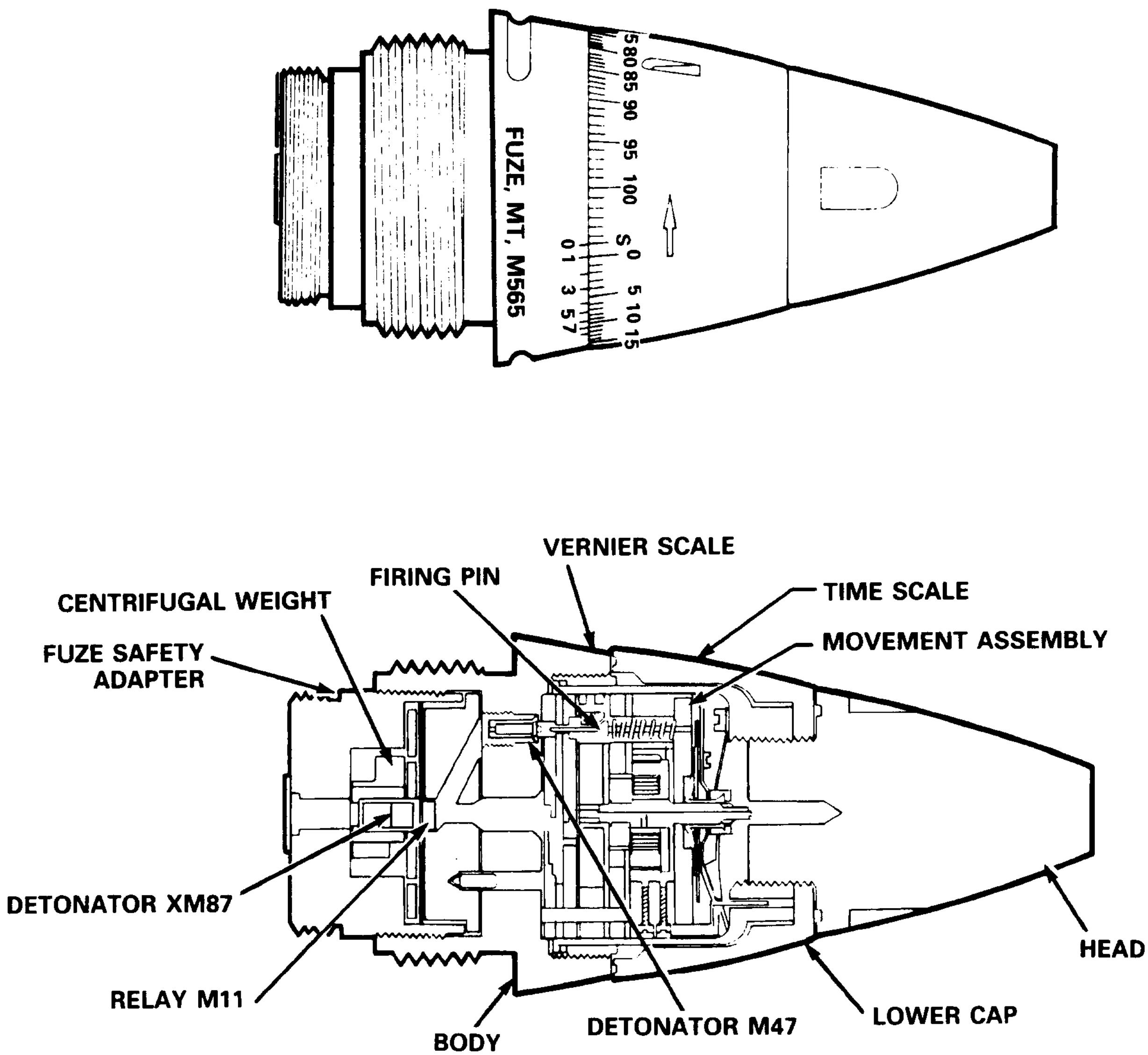


Figure 9-7-5 A Typical Mechanical Time Fuze (M565 or C29)

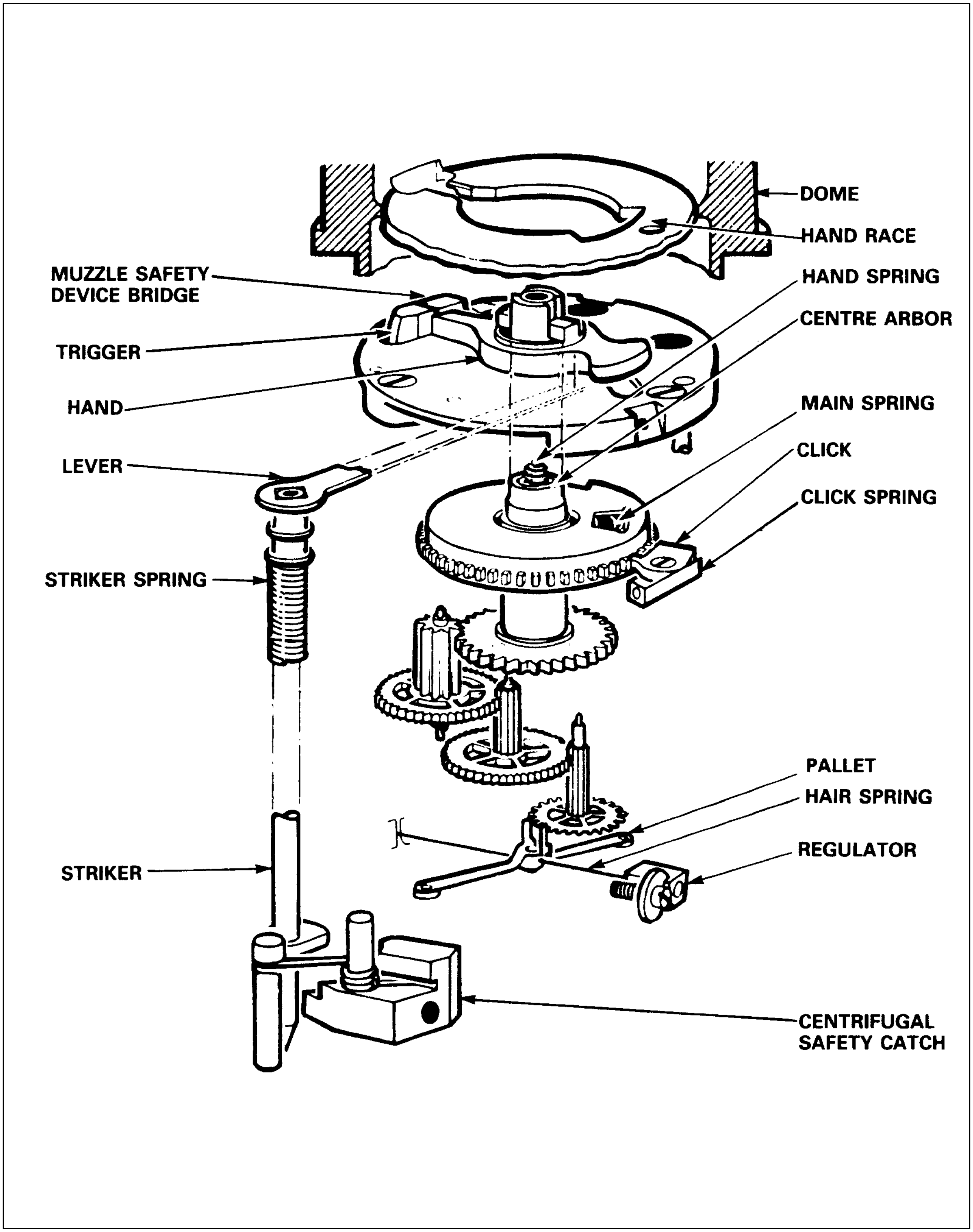


Figure 9-7-6 Thiel Time Mechanism (UK)

c. **Spin**. The effect of spin is negligible even at high rates, unless the balancing wheels are very much off centre. Any part of the mechanism which would be affected by spin is normally placed in the centre of the fuze.

d. **Pressure**. There is a complete absence of variation due to either atmospheric or dynamic pressure. The extremes of variation are not sufficient to affect the clock.

e. **Temperature**. The chamber temperature might affect the clock slightly if at absolute extremes, ie subtropical or arctic. Changes in atmospheric temperature along with the trajectory are not sufficient to affect the mechanism.

22. **Setting Graduations**. The inaccuracies which arise from the physical factors of spin, pressure, etc, and which differ from charge to charge, are so small in the mechanical fuze that the time of running can be deemed constant for different charges and equipment. The graduations are in seconds and should agree very closely with the TOF listed in the applicable FTs.

23. **Torquing**. Once a fuze is set, it is essential that there should be no further movement while handling, loading and during flight. Should the rings become loose, the following may happen:

a. a loss of waterproofing, thereby permitting the ingress of moisture;

b. alteration of fuze setting owing to the rotational acceleration when the weapon is fired; and

c. when a fuze is correctly torqued turning of the time ring with the fingers is impossible.

24. Time fuzes are normally fitted with an SQ element that will allow the fuze to function at impact. If the fuze fails to function at airburst, it will function on impact, although the target may be overshot. When time fuzes are fitted with an SQ element they are known as mechanical time superquick (MTSQ).

25. Further development of fuzes is continuing and many improvements have been made. For example, electronic time fuzes and electronic fuze setters are now in service with the US Artillery.

ELECTRONIC TIME FUZES

26. Electronic time fuzes use an electronic clock to control the time of functioning. They have a battery that is in a dry state until fired. Upon firing, an ampoule holding electrolyte breaks and is forced through the battery plates. This gives power to run the electrical clock and at the appropriate time, fires the electrical detonator. This fuze will function electrically, mechanically or on impact. The fuze is set with an electronic fuze setter.

BOOSTERS

27. All current HE fillings are relatively insensitive to shock and must be able to withstand the stresses of firing. The small amount of explosive contained in detonators is usually insufficient to guarantee that the action of the fuze will in fact detonate the HE filling. In order to ensure that this will occur a booster charge is included in the explosive train.

28. Boosters are found in all disruptive fuzes and are attached to the base of the fuze to provide an explosive link between the detonator and HE filling. The relatively weak impulses of the detonator are sufficient to detonate the booster which in turn generates enough shock to ensure the detonation of the HE filling. Boosters like MT fuzes, usually have mechanical gearing that act as safety devices to ensure the projectile is not detonated before it is well clear of the gun position. Figures 9-7-9 and 9-7-10 show the internal gearing of a modern booster.

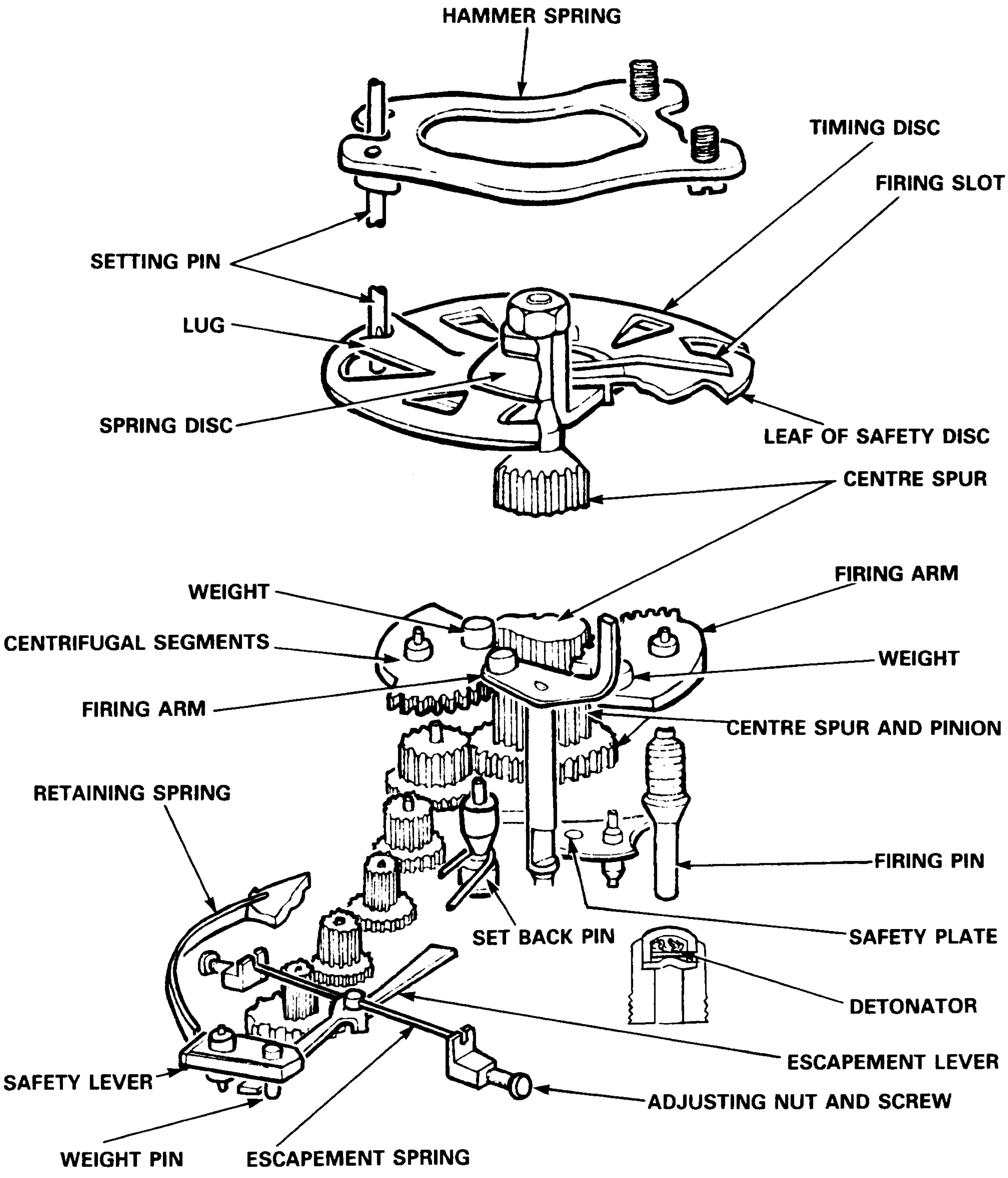


Figure 9-7-7 The Junghans Time Mechanism (US)

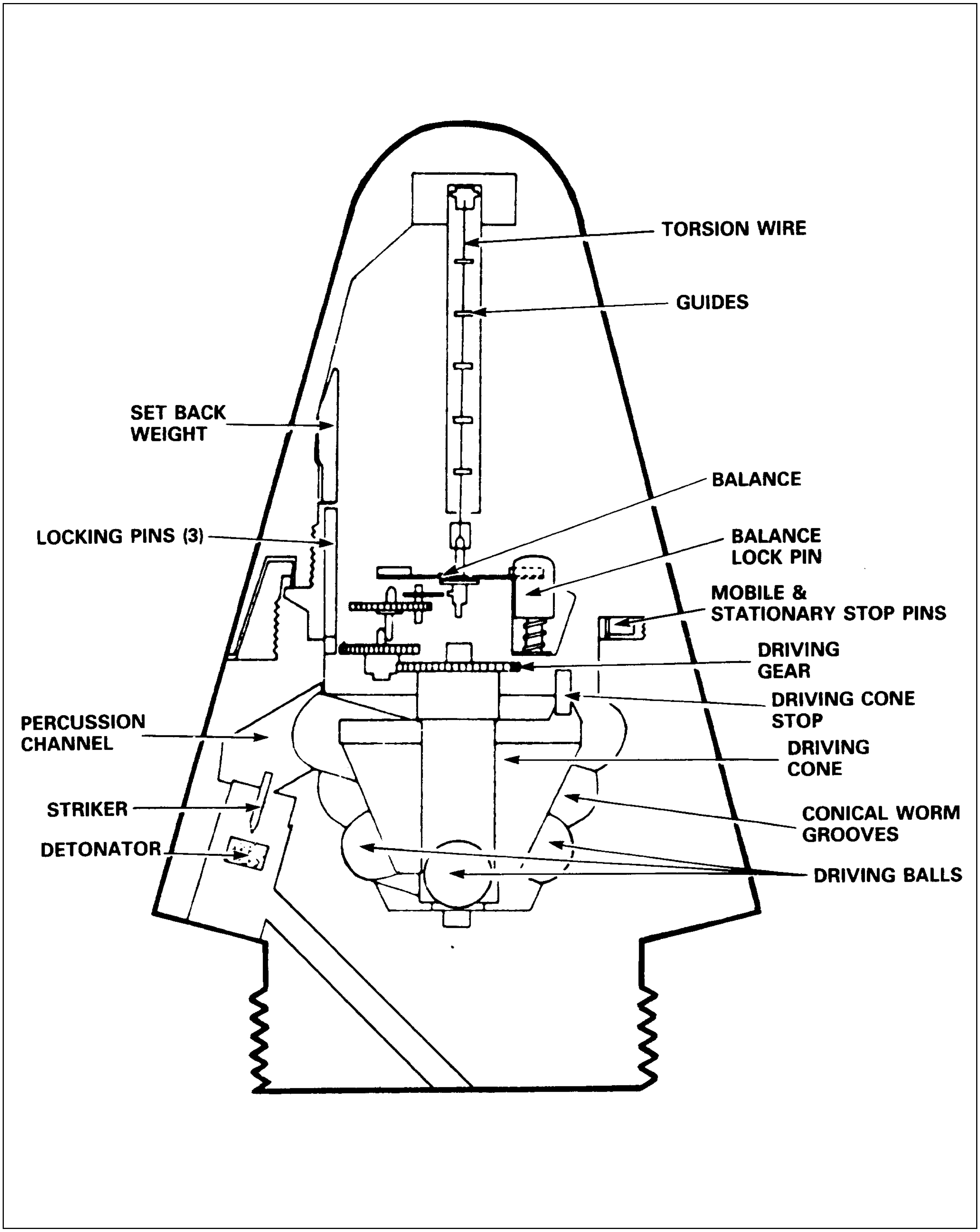


Figure 9-7-8 The Dixi Time Mechanism (Swiss)

PROXIMITY FUZES

29. Current proximity fuzes in service are essentially self-powered radio transmitting and receiving units (see Figures 9-7-11 and 9-7-12). Power is supplied by a battery that is assembled in an inert dry state. An ampoule of electrolyte breaks on set back and the electrolyte is distributed over the battery plates by centrifugal force. The battery provides current for heating tubes, grid bias and charging the firing condensers. A continuous radio wave is transmitted. The reflected waves, when of a predetermined amplitude, trigger a tube causing the proximity condenser to discharge through an electric detonator. A clockwork mechanism (Junghans) is employed to arm the proximity firing circuit a few seconds before its arrival at the target and an impact condenser is fitted to function on impact. If the proximity action fails, the fuze will function on impact when a switch is closed to enable the impact condenser to discharge through the electric detonator.

30. Proximity fuzes consist of four main sub-assemblies:

a. **The Plastic Nose** houses the radio transmitter receiver and associated antenna as well as the electrical PD activating switch.

b. **The Steel Base** forms a supporting base for the plastic nose and contains the radio bundle whose task it is to control the operation of the components in the plastic nose.

c. **The Sleeve** is a cylindrical steel tube threaded externally to fit the fuze well of the projectile. It contains the battery, battery fluid or electrolyte and the safety electrical shorting devices that render the fuze safe until fired. It also contains an electrical detonator and associated circuits required to cause the fuze to function.

d. **The Auxiliary Detonating Fuze**, screwed into the base of the sleeve, functions in the same way as boosters in HE projectiles. The auxiliary detonating fuze also contains a mechanism to ensure bore safety.

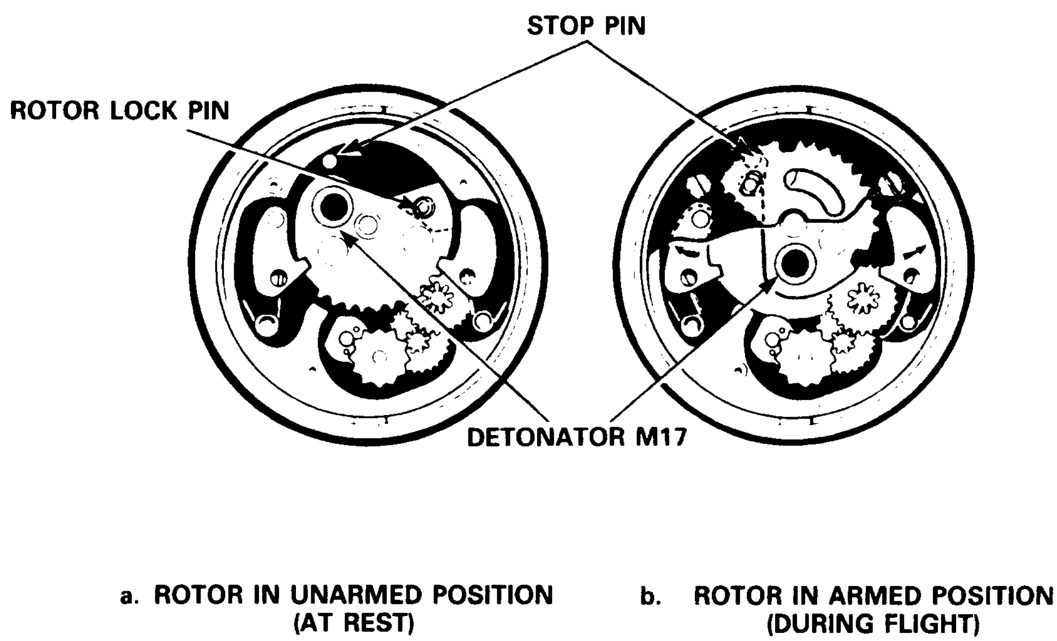


Figure 9-7-9   Typical Booster Mechanism (M125A1)

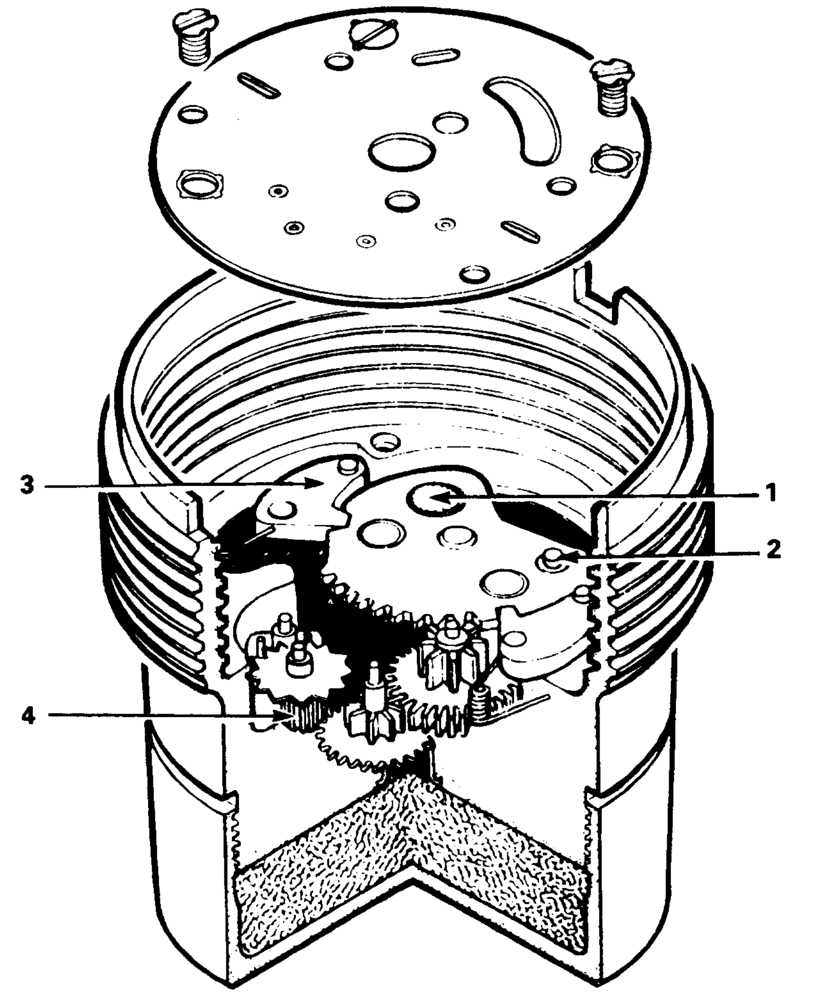


Figure 9-7-10 Illustration of a Typical Booster

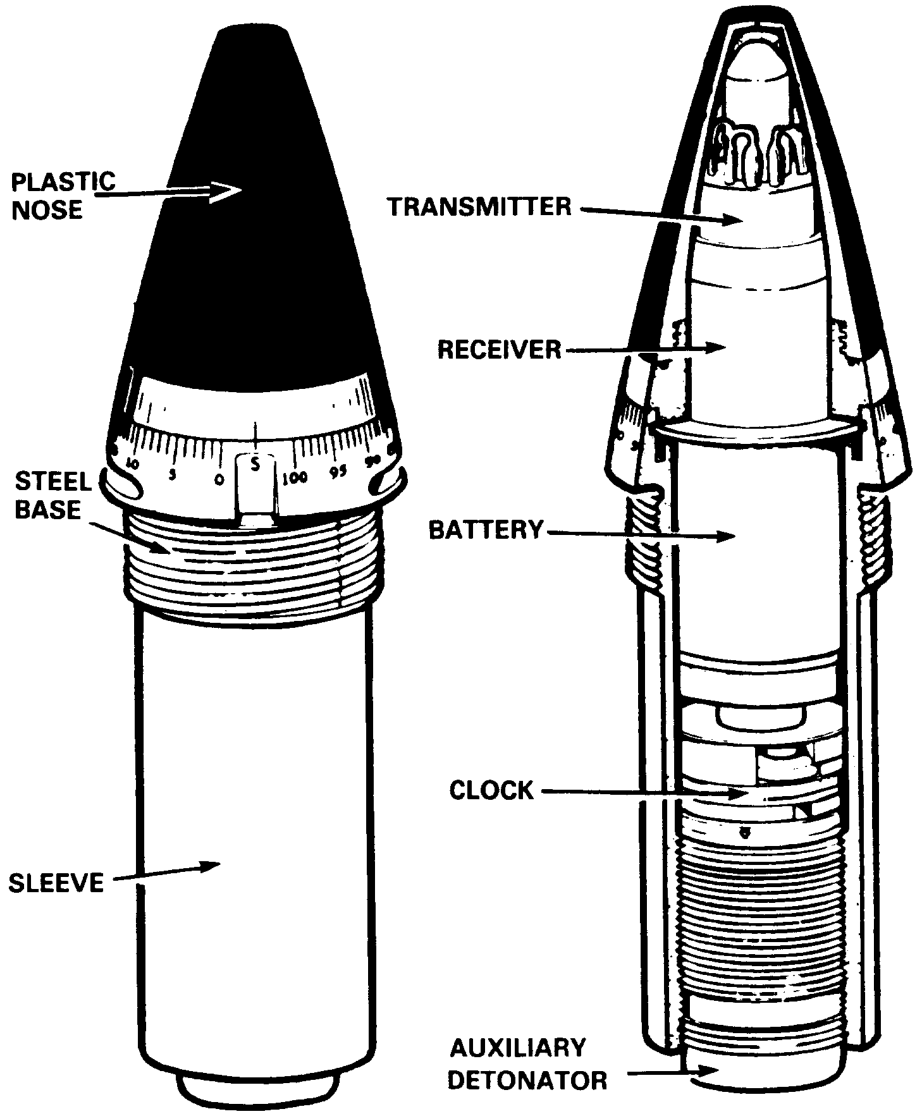


Figure 9-7-11 Illustration of a Typical Proximity Fuze

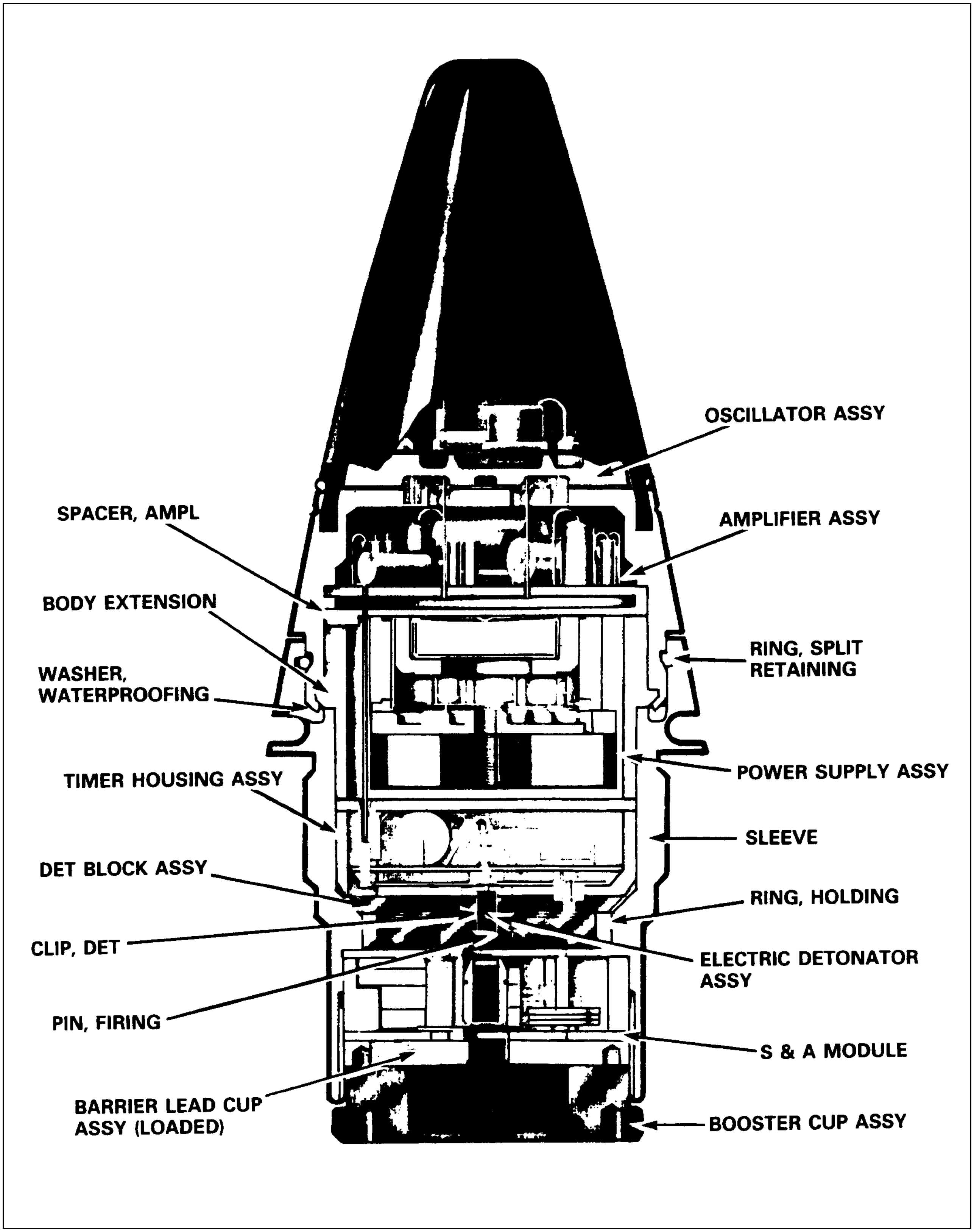


Figure 9-7-12 Detailed Illustration of a Modern Proximity Fuze (M732)

SECTION 8

AMMUNITION MARKING

GENERAL

1. Ammunition is primarily identified by the use of various colours. The paint not only enables ammunition to be identified, but also acts as a preservative and a method of camouflage. In addition to painting, each complete round will have its components stamped and stencilled with various code numbers and symbols. This enables individual parts to be identified and traced if difficulties or defects appear.

2. In addition to Figure 9-11-1, which shows painting only, further details of ammunition marking can be found by referring to CFTO C-74-300-AD1/NJ-000, Identification of Ammunition, D-09-002-004/SG-000, Standard to Ammunition Colour Coding and C-74-300-A01/DA-000, Basic Ammunition Colour Chart.

SECTION 9

AMMUNITION SORTING

GENERAL

1. To achieve the maximum obtainable accuracy when shooting, it is necessary to ensure that ammunition be sorted. Sorting is done in the following way:

a. for cartridges -

(1) Cartridges are always sorted by propellant types and should never be mixed under any circumstances.

(2) Cartridge lots will not be changed when special engagement procedures are being used, ie Danger Close or other procedures as laid down in B-GL-306-004/FP-001, Field Artillery, Volume 4, Duties at Regimental Headquarters and the Gun Position.

(3) Cartridge lots should not be mixed during an engagement when propellant temperatures are likely to differ.

b. Projectiles are sorted by nature, lots and subsequently divided into groups by weight/mass so that the necessary adjustments can be made to the firing data.

c. Fuzes are sorted by nature.

ADDITIONAL INFORMATION

2. Additional specific information concerning ammunition sorting may be found in the applicable Handbook of Equipment and Ammunition.

SECTION 10

AMMUNITION PREPARATION

GENERAL

1. The projectile, regardless of its nature, is the weapon that produces the required effect at the target. Propellant charges, although not the weapon, are also of great importance because without them the means of delivery would be lacking. All other resources, personnel, equipment and guns are of no value if the weapons, for lack of care or maintenance, do not have their full effect on the target. As a result, the care of ammunition is of paramount importance and in some cases, if not given sufficient emphasis, could lead to the death or injury of gun detachments and friendly troops.

2. **Projectiles**. Projectile characteristics and the condition of the projectiles will affect their performance:

a. Projectiles have the following characteristics -

(1) They are a machined object that fit very closely into the barrel.

(2) They have a particular shape to achieve ballistic stability.

(3) Both the projectile and its contents are subject to deterioration from climatic conditions.

b. From the previously mentioned characteristics it will be appreciated that -

(1) Dirt or burrs on a projectile will interfere with its free passage up the bore. This can lead to damage and affect the trajectory of the projectile.

(2) Serious deformation of the projectile/fuze combination will affect the trajectory.

(3) Prolonged exposure to extremes of climate may adversely affect a projectile's ultimate functioning at the target.

3. **Fuzes**. Fuzes have much the same characteristics as projectiles but, because they all have various small machined parts, they are more likely to be a source of malfunction than any other part of the projectile. For this reason, all fuzes must be treated as finely machined instruments.

4. **Cartridges**. Cartridges have been discussed in previous paragraphs and the implications of handling them are clear. Care must be taken to ensure that QF cartridges are not dented or scratched when handling. BL cartridges must be protected from tearing and particularly from moisture.

5. **Propellants**. Propellants are poor conductors of heat and, therefore, they require time to adjust their temperature to the temperature that surrounds them. Every effort must be made to protect propellants from extremes of temperatures that would affect their ballistic consistency. Accurate propellant temperature readings must be taken and compensatory corrections made by the command post (CP) staff. A damp propellant may lead to misfires and/or have a serious effect on its ballistics.

6. **Safety Precautions**. As with other potentially dangerous articles **COMMON SENSE** must be applied. Ammunition is only dangerous when one becomes overly familiar with it. Any attempt to disassemble or make souvenirs of various parts will ultimately lead to tragic accidents. Ensure that instructions regarding the shipping, handling and storage of ammunition are strictly adhered to.

SECTION 11

PREMATURES

GENERAL

1. Prematures are a rare happening. The circumstances that cause them can generally be traced to one of three things:

   a. failure by the user to observe the correct rules regarding **CARE**, **MAINTENANCE** and **HANDLING**;

   b. failure on the part of the fuze itself; and

   c. defects in HE filling.

2. If the user fails to observe the correct handling procedures, it does not mean that there will definitely be a premature, but the odds in favor of creating one are definitely increased. No amount of skill, design, or manufacturing technique can compensate for the failure of users to obey safety rules and common sense.

3. Actual fuze-caused prematures seldom occur. This is as a result of fuze design, manufacturing techniques and skills and an extremely rigid and detailed series of product inspections.

4. Despite all the precautions taken, there will be the occasional premature. Also, it has been found that certain fuzes are more prone to prermatures than others. As a result, C-09-216-001/TX-000, **Ammunition Restrictions** is published. This CFTO outlines special procedures to be used when certain projectiles/fuze combinations are to be fired. It is essential that the Ammunition Restrictions be maintained and kept up to date.

5. The risk of damage to fuzes and subsequent prematures is greater when projectiles are transported with the fuze in place and unprotected by packing containers. Smaller calibres are packaged in a fuzed state and, providing the container is always used, there is little danger of fuze damage. Large calibres are transported on pallets with lifting plugs instead of fuzes in place. Any large projectile that has been fuzed in readiness for firing must be unfuzed when it is not fired and subsequently loaded into vehicles. In case of SPs, there are special racks for securing fuzed projectiles and they must be used.

6. When fuzing projectiles, each fuze must be inspected for obvious faults and any fuze, even if it only appears damaged, must be set aside and not fired. Ammunition personnel must ensure that each fuze used is screwed fully home into the fuze well. A gap left between the fuze base and projectile is very dangerous as the fuze may be subjected to an overly severe shock at shot start.

7. BL and some QF equipments require that projectiles be rammed. Most modern equipments have hydraulic ramming devices which ensure that the ramming is done at a constant pressure to ensure uniformity. When ramming must be by hand, personnel must ensure that each projectile is rammed with a uniform pressure sufficient to hold the projectile steady at all angles of elevation. Failure to do so may cause the projectile to fall back into the chamber on elevation and may cause a premature on firing. If a premature does not occur, damage may be done to the chamber and barrel. The following must be observed:

a. The rammer must be kept clean.

b. The bore and chamber must be kept clean and examined for damage between engagements.

c. The loading tray must be kept clean.

d. Application of uniform pressure must be maintained when ramming by hand.

8. When a premature does occur, it is vital that it be reported and recorded as quickly as possible so that restrictions and subsequent investigations can be instituted. In every reported case of a premature, exhaustive studies are made to determine the cause. This can only be done if units experiencing prematures use the correct procedure for recording and reporting. Full procedural instructions are contained in CFAO 71-4.

Serial	Type of Ammunition	Colours			Notes
		Body	Marking	Bands	
	GUN, HOWITZER, AND MORTAR PROJECTILES				
1	HE	Olive drab	Yellow	None	5"/54 shell rounds of US Naval origin have a yellow band on the ogive.
2	HEP or HESH (CDN & US Production)	Olive drab	Yellow	Black	
3	HESH (British Origin)	Olive drab black	Yellow	None	
4	HEAT	Black	Yellow	None	
5	APDS or AP SHOT	Black	White	None	
6	AP or SAP Shell W/HE Bursting Charge	Black	Yellow	Yellow	
7	Smoke HC	Light green	Black	None	5"/54 shell of US Naval origin has olive drab body and a brown band.
8	Smoke, coloured	Light green	Black	None	Coloured CCCS indicate colour produced.
9	Smoke WP	Light green	Light red	Yellow	5"/54 shell of US Naval origin has olive drab body, a brown band, a light green band, WP in red with other markings in black.
10	Chemical HE Burster	Grey	Red, green or violet	Yellow red, green or violet	Marking colour (red, green or violet) corresponds to colour of agent band.
11	Chemical Low	Grey	Red, green or violet	Brown, red, green or violet	Marking colour (red, green or violet) corresponds to colour of agent band.
12	Incendiary	Light red	Black	None	
13	Illuminating				
	(1) Unpacked or Palletized	Olive drab	White	White	a. Rounds of US Naval origin also employ a brown band indicating a low explosive.

Figure 9-11-1 (Sheet 1 of 2) Painting and Marking of Ammunition

Serial	Type of Ammunition	Colours			Notes
		Body	Marking	Bands	
	(2) Packed (Cylinders, boxes)	White	Black	None	b. Both (1) and (2) colour applications are standard. However, for land artillery ammunition, separate loading ammunition (normally unpacked) (1) is used. For fixed and semi-fixed ammunition (normally packed) (2) is used.
14	Countermeasure (window)	Aluminum	Black	None	
15	Practice (Inert)	Light blue	White	None	Orange band(s) may be employed to facilitate recovery.
16	Practice (W/HE Spotting Charge)	Light blue	White	Yellow	
17	Practice (W/Low Charge)	Light blue	White	Brown	
18	Canister	Olive drab	White		
19	Flechette (W/HE Burster Charge)	Olive drab	White	Yellow	A circumferential band of white diamonds.
20	Dummy	Dark blue or bronze	White or black	None	
21	ICM	Olive drab	Yellow	None	Circumferential band of yellow diamonds.
22	FASCAM (ADAM) (RAAM)	Olive drab	Yellow	None	Circumferential band of yellow triangles. "L" or "S" in triangles denotes LONG or SHORT self-destruct.
23	CLGP	Black	Yellow	None	
24	TP	Blue	White	None	

NOTE

1. Dark green bands denote harassing.
2. Violet band denotes incapacitating.
3. Dark red bands denote toxic.

Figure 9-11-1 (Sheet 2 of 2) Painting and Marking of Ammunition

EXAMPLE COMPUTATION OF IN-VACUUM TRAJECTORY

1. **Symbols and Abbreviations**. The following symbols and abbreviations are used in the example problems:

A/D	- angle of departure
MV	- muzzle velocity
m/s	- metres per second
ϕ	- angle of elevation
g	- gravitational force (9.8 m/s^2)
H_v	- horizontal component of velocity
V_v	- vertical component of velocity
R	- range to the level point
T	- time of flight to the level point
t	- any given time
h	- projectile height at time t.

2. **Formulae**. The following formulae are used in the computation of in-vacuum trajectories.

$$H_v = MV \cos \phi$$
$$V_v = MV \sin \phi$$
$$h = MV \sin \phi \times t - 1/2\, gt^2$$
$$T = \frac{2\, MV \sin \phi}{g}$$

3. The example problems given in this Annex were solved using the Table of Natural Trigonometric Functions given in the introduction portion of the firing tables (FTs).

4. **Example Problem One**. A projectile is fired in a vacuum at an A/D of 300 mils and an MV of 379.5 m/s.

a. Find the H_v:

$$H_v = MV \cos \phi$$
$$H_v = 379.5 \times 0.9569$$
$$H_v = \mathbf{363.1\ m/s}$$

b. Find the V_v:

$$V_v = MV \sin \phi$$
$$V_v = 379.5 \times 0.2903$$
$$V_v = \mathbf{110.2\ m/s}$$

c. Find R:

$$R = \frac{MV^2 \sin 2\phi}{g}$$

$$R = \frac{379.5^2 \times \sin 600}{9.8}$$

$$R = \frac{144\,020.25 \times 0.5556}{9.8}$$

R = **8 165.06 metres**

(as a check, H_v x t = R, 363.1 x 22.48 = 8 162.49 metres)

d. Find T:

$$T = \frac{2MV \sin \phi}{9}$$

$$T = \frac{2 \times 379.5 \times 0.2903}{9.8}$$

T = **22.48 seconds**

e. Find time (t) to vertex:

$$t \text{ to vertex} = \frac{MV \sin \phi}{9}$$

$$t \text{ to vertex} = \frac{379.5 \times 0.2903}{9.8}$$

t to vertex = **11.24 sec**

f. The vertex height and height of projectile are:

(1) Find the height -

$h = MV \sin \phi \times t - 1/2\, gt_2$

$h = (379.5 \times 0.2903 \times 11.24) - (0.5 \times 9.8 \times 11.24^2)$

h = 1 238.30 - 619.05

h = 619.25 metres

(2) To find the height of the projectile at t use the formula given in 4f (1) and insert the applicable time (t), eg what is the height of the projectile after 8 sec TOF?

h = (379.5 x 0.2903 x 8) - (0.5 x 9.8 x 8^2)
h = 881.35 - 313.60
h = **567.75 metres**

g. Find vertical velocity at time (t):

Vertical velocity = MV sin ϕ - gt (if t is 8 seconds).

(379.5 x 0.2903) - (9.8 x 8) = 31.77
Vertical Velocity at t = 8 seconds is **31.77 m/s**

h. The maximum range and maximum height are:

(1) For maximum range -

$$\frac{MV^2}{9} = \frac{379.5^2}{9.8} = 14695.94 \text{ metres}$$

Maximum range is attained with an A/D of 800 mils.

(2) If A/D is 1 600 mils, the projectile will reach its **maximum height** (max h) -

$$\text{max h} = \frac{MV^2}{2g} = \frac{379.5^2}{19.6}$$

max h = 7 347.97 metres

5. **Example Problem Two**. A projectile is fired in a vacuum from the M109A2/A3, at an elevation of 743 mils with an MV of 684.3 m/s (charge 8).

a. Find R:

$$R = \frac{MV^2 \sin 2\phi}{9}$$

$$R = \frac{468\ 266.49 \times 0.9937}{9.8}$$

R = 47 481.27 metres

NOTE

The range given in the FTs for an elevation of 743.2 mils is 18 000 metres. This reduction in range is caused by air resistance.

b. Find T:

$$T = \frac{2\ MV \sin \phi}{9}$$

$$T = \frac{1\ 368.6 \times 0.6665}{9.8}$$

T = **93 seconds**

c. Find the vertex height (t = 46.54 seconds):

$$h = MV \sin \phi \times t - 1/2\ gt^2$$
$$h = (684.3 \times 0.6665 \times 46.54) - (1/2 \times 9.8 \times 46.5^2)$$
$$h = 21\ 226 - 10\ 613$$

h = **10 613 metres**

NOTE

The maximum ordinate (vertex) given in the FTs for an elevation of 743.2 mils is 5 258 metres. Since the gravitational effect has been accounted for in previous example, the reduction in maximum ordinate can only be caused by air resistance.

EXPLANATORY NOTES ON SOME SI UNITS

Acceleration. The metre per second squared (m/s^2) is the SI unit of acceleration.

Area. The square metre (m^2) is the SI unit of area. The square centimetre (cm^2) and square millimetre (mm^2) are also commonly used for small areas and cross-sections.

Coulomb. The coulomb (C) is the quantity of electricity transported in 1 second by a current of 1 ampere (A).

Density. The kilogram per cubic metre (kg/m^3) is the SI unit of mass density, also known simply as density.

Electric Charge. The coulomb is the SI unit of electric charge. The charge of a battery is often expressed in ampere hours (Ah). This should eventually be abandoned in favour of the kilocoulomb (kC).

Energy and Work. The joule (J) is the SI unit of all forms of energy and work. Although the watt hour (Wh) and its multiples are at present widely used as measure of electrical energy consumption, they will eventually be replaced by the joule and its multiples. Mechanical energy should be expressed in kilojoules (kJ). The joule is the SI unit of impact strength. It is the energy required to break a specimen having standard (specified) dimensions. The newton metre (Nm) is the SI unit of torque. Although 1 Nm is dimensionally equal to 1J, it is customary to express torque in the form of the Nm.

Force. The newton (N) is the SI unit of force. Buckling forces in columns are expressed in mega-newtons (MN). Forces in prestressing tendons and cables are expressed in kilonewtons (kN). Most forces applied by humans are expressed in newtons.

Hertz. The hertz is the frequency of a periodic phenomenon of which the periodic time is 1 second.

Inertia. The property of a body, by virtue of which force is required to change the state of motion of that body, is called its inertia. Mass is the numerical measure of this property.

Joule. The joule (J) is the work done when the point of application of a force of 1 N is displaced a distance of 1 m in the direction of the force.

Kilogram. The kilogram (kg) is the unit of mass (approximately 2.205 lbs).

Mass. The kilogram (kg) is the SI unit of mass. The megagram (Mg) is also known as the metric ton and tonne, both of which use the symbol t (1 t = 1 Mg). All these units may be used for expressing large masses such as those of vehicles, ships, etc.

Metre. The metre (m) is the SI unit of length (approximately 39.4 in.)

Newton. The newton (N) is the force that, when applied to a body having a mass of 1 kg gives the body an acceleration of 1 m/s

Ohm. The ohm is the electric resistance between two points of a conductor when a constant difference of potential of 1 volt (V), applied between these two points, produces in the conductor a current of 1 A and the conductor itself is not the seat of any electromotive force.

Pascal. A pascal (Pa) is the pressure (or stress) that is produced when a force of 1 N is applied to an area of 1 m^2.

Power. The watt (W) is the SI unit of power, regardless of the form of energy involved. In electric power technology, apparent power is expressed in volt amperes (VA) and reactive power in reactive volt amperes (var).

Stress and Pressure. The pascal (Pa) is the SI unit of pressure and stress, including: tensile strength; bearing pressures; modulus of elasticity (Young's modulus); shear, compressive and flexural stress; and adhesion (shear method). Stresses expressed in newtons per square millimetre (N/mm^2) are numerically equal to those expressed in megapascals (MPa). Of the two, the latter is preferred. Most pressures relating to pumps, pipelines, compressors and boilers are expressed in kilopascals (kPa), although, in high-pressure hydraulics, pressures may be expressed in MPa.

Temperature. The kelvin (K) is the SI unit of thermodynamic temperature, often used in scientific work. The degree Celsius (? C) is the SI unit of Celsius temperature, generally encountered in common, every day use. The relationship between the thermodynamic temperature (T) and the Celsius temperature (t) is defined by the equation: t = T - T? (where T? equals 273.15 K, by definition). The unit degree Celsius is equal in magnitude to the unit **kelvin** and therefore temperature intervals may be expressed in either kelvins or degrees Celsius: 1? C = 1 K.

Velocity (Speed). The metre par second (m/s) is the SI unit of velocity. The speed of land vehicles, aircraft and wind is expressed in kilometres per hour (km/h). Knots (kn) (nautical miles per hour) are used in ships and aircraft for navigational purposes.

Volt. The volt (V) is the difference of electric potential between two points of a conductor that is carrying a constant current of 1 A when the power dissipated between these points is equal to 1 W.

Volume. The cubic metre (m^3) is the SI unit of volume. It may be used for space or for a contained substance, whether solid, liquid or gas. The litre (L) is the special name for the cubic decimetre (1 L = 1 dm^3) and is used for volumes of solid, liquid or gas.

REFERENCES AND STANDARDIZATION AGREEMENTS

1. The following publications were used as references in the production of this manual:

   a. B-GL-306-004/FP-001, Field Artillery, Volume 4, Duties at Regimental Headquarters and the Gun Position;

   b. B-GL-306-008/FP-001, Field Artillery, Volume 8, Instruments;

   c. CAMT 4-3-1, Canadian Army Manual of Training, Field Gunnery, Ballistics and Ammunition 1960;

   d. AOP-1, Ballistic Standardization of Gun Ammunition;

   e. Army Code No. 71016 Artillery Training, Volume II, Field Artillery, Pamphlet No. 14, Basic Principles and Theory, Part III, Ballistics;

   f. What Happens Inside the Gun and Why;

   g. FM 6-40, Field Artillery Cannon Gunnery;

   h. Firing Tables, FT 155-AM-1;

   j. Oerlikon Pocket Book;

   k. CAN3-Z234.1-79, Canadian Metric Practice Guide; and

   m. Armies & Weapons No. 47, October 1978, The Basics of External Ballistics.

2. The following NATO Standardization Agreements (STANAGS) have been wholly or partially incorporated into this volume:

   a. STANAG 4097 (with Amendments 2 and 3), Procedures with Respect to Charge Adjustment for Velocity for Standardization Gun Ammunition;

   b. STANAG 4106, Procedure for the Determination of External Ballistic Performance of Shell;

   c. STANAG 4119 (Edition 1, Amendment 2), Adoption of a Standard Cannon Artillery Firing Table Format;

   d. STANAG 2321 (Edition 3), Ammunition Colour Code (above 20 mm);

   e. STANAG 2322 (Edition 2), Minimum Marking for Identification of Ammunition;

f. STANAG 4044 (Edition 2), Adoption of Standard Atmosphere; and

g. STANAG 4061 (Edition 3, Amendment 1), Standard Ballistic Met Message.

3. The following QSTAGS have been wholly or partially incorporated into this volume:

a. QSTAG 186 (Edition 1), Adoption of Standard Atmosphere;

b. QSTAG 220 (Edition 2), Adoption of Standard Cannon Artillery Firing Table Format; and

c. QSTAG 560, Propellant Proofing.