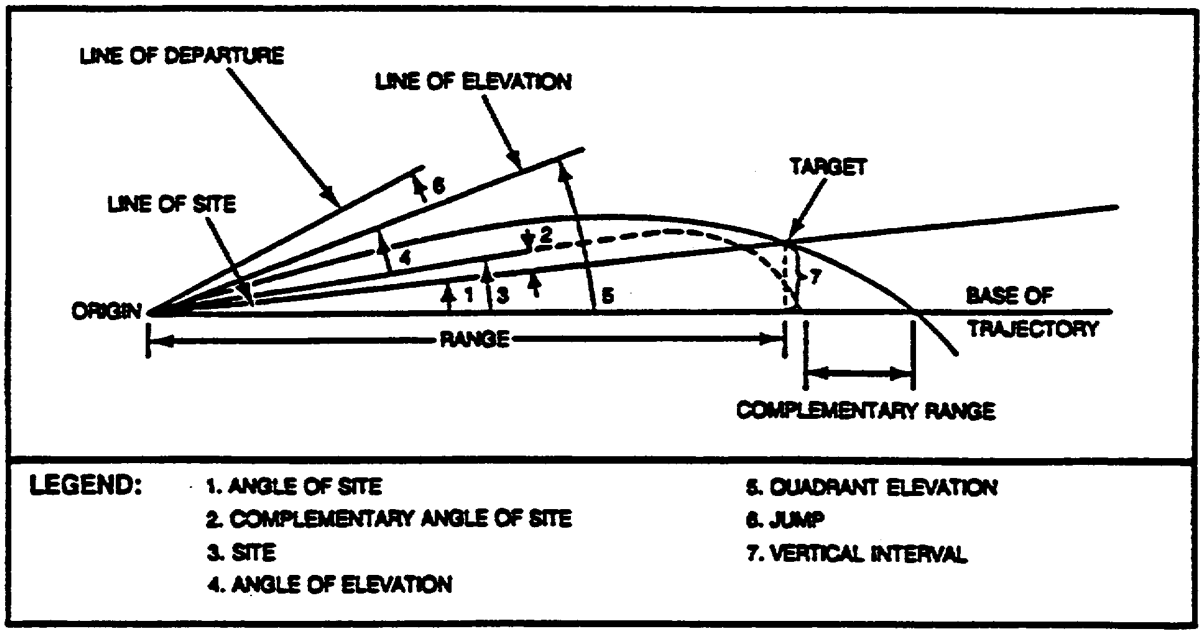
SUBCOURSE
FA9011

EDITION
A

US ARMY FIELD ARTILLERY SCHOOL

BALLISTICS



THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT
ARMY CORRESPONDENCE COURSE PROGRAM

AIPD
READINESS/PROFESSIONALISM THRU GROWTH

TABLE OF CONTENTS

GRADING AND CERTIFICATION INSTRUCTIONS

Instructions to the student. This subcourse has an examination that is performance-based, multiple-choice test covering two lessons. You must score a minimum of 70 percent on this test to meet the objectives of the subcourse.

Credit hours. Five credit hours will be awarded for successful completion of this subcourse.

INTERIOR AND EXTERIOR BALLISTICS

Subcourse FA9011

EDITION A

United States Army Field Artillery School
Fort Sill, Oklahoma, 73503

Edition Date: January 1992
Credit Hours: 5.

SUBCOURSE OVERVIEW

This subcourse is designed to teach the elements of interior and exterior ballistics and their effects on a projectile.

This subcourse reflects the doctrine which was current at the time it was prepared. In your own work situation, always refer to the latest official publication.

Unless otherwise stated, the masculine gender of singular pronouns is used to refer to both men and women.

Terminal Learning Objective:

ACTION:	Identify the elements of interior and exterior ballistics and their effects on a projectile.
CONDITION:	Given the information provided in this subcourse, you will be able to identify the elements of interior and exterior ballistics.
STANDARD:	To demonstrate competency in this task, you must achieve a minimum of 70% on the subcourse examination.

LESSON 1

IDENTIFY THE ELEMENTS OF INTERIOR BALLISTICS

TASK NO: 01-2800.00-1010

OVERVIEW

LESSON DESCRIPTION:

Upon completion of this lesson, you will be able to identify the elements of interior ballistics and their effects on the motion of a projectile.

LEARNING OBJECTIVE:

ACTION:	Identify the elements of interior ballistics and their effects on the motion of the projectile.
CONDITIONS:	Given the material contained in this lesson.
STANDARD:	Correctly answer all questions in the practical exercises contained in this lesson.
REFERENCES:	This lesson is based on TC 6-40 and other material approved for US Army field artillery instruction; however, development and progress render the text subject to continual change. Therefore, base your examination answers on material presented in this text rather than on individual unit experience.

INTRODUCTION

Ballistics is the science dealing with the motion of projectiles and the conditions affecting that motion. It is a branch of applied mechanics that is continually being investigated, and is by no means an exact science. Since 1743, when Benjamin Robinson described the first ballistic measuring device (a pendulum holding a block) the study of ballistics has developed into a considerable body of knowledge. Many accurate and useful mathematical formulas have been derived from this long investigation. This subcourse does not include a detailed examination of the mathematics involved; rather, it is concerned primarily with a description of the basic energies and motions to enable you, as artillerymen, to understand the principles of gunnery.

PART A

INTERIOR BALLISTICS

1. Interior ballistics deals with factors affecting the motion of a projectile within the tube. The total effect of all interior ballistics factors determines the velocity at which the projectile leaves the muzzle of the tube, which directly influences the range achieved by the projectile. This velocity, called MUZZLE VELOCITY (MV), is expressed in meters per second (m/s). Actual measurements of the muzzle velocities of a sample of rounds corrected for the effects of nonstandard projectile weight and propellant temperature show the performance of a specific weapon/ammunition combination. The resulting measurement(s) are compared to the standard muzzle velocity shown in the firing table(s). This comparison gives the variation from standard, called MUZZLE VELOCITY VARIATION (MVV), for that weapon/ammunition combination. Corrections to compensate for the effects of nonstandard muzzle velocity is one of the most important elements in computing accurate firing data. Tube wear, propellant efficiency, and projectile weight are items normally considered in the determination of muzzle velocity.

2. Nature of propellant and projectile movement. A propellant is a low-order explosive that burns rather than detonates. When an artillery projectile is inserted into the bore and the weapon is fired, the projectile undergoes two types of motion, FORWARD AND ROTATIONAL.

a. Forward motion is imparted to the projectile by the rapid expansion of gases from the burning propellant. As the propellant burns, it is transformed into gases, which expand and exert force in all directions. The lateral force is contained by the walls of the chamber and tube, and the longitudinal force pushes the projectile forward and the tube backward.

b. The engraved rotating band follows the lands of the rifling and imparts a rotational motion to the projectile.

3. The above effects cannot be understood without an examination of the components of a tube. (Figure 1-1).

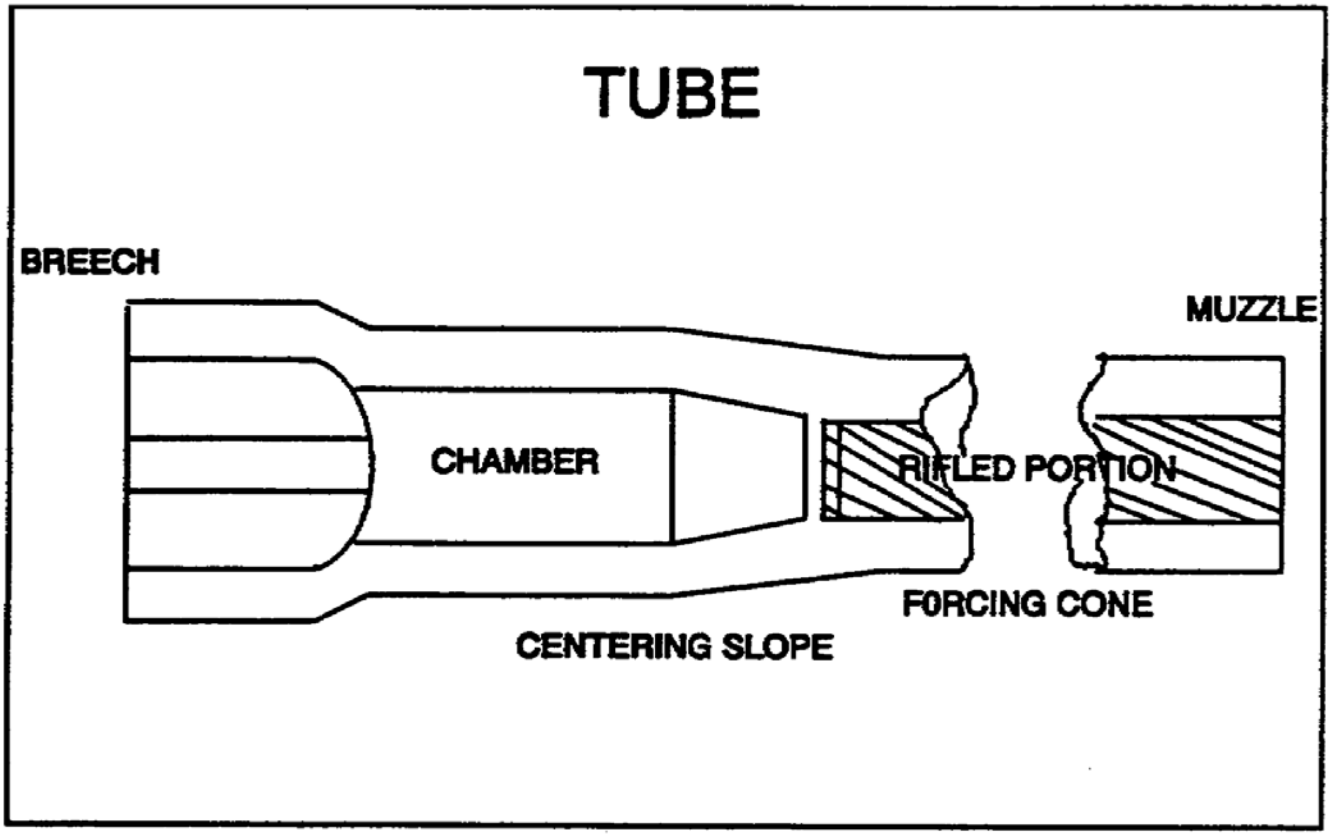


Figure 1-1. Tube.

a. The breechblock permits loading the weapons from the rear. The vertical sliding wedge (M102) and horizontal sliding wedge (M101A1) are used with semi-fixed ammunition (105mm). The stepped-thread interrupted-screw breechblock is used with separate loading ammunition on the M114A2 and M110A2. The interrupted screw breech block is used on the M109 series and the M119A1.

b. The powder chamber houses the propelling charge.

c. The centering slope is the tapered forward portion of the powder chamber which causes the projectile to center itself in the main bore.

d. The forcing cone is the rear portion of the main bore formed by tapered lands (raised rifling). The tapered lands allow the rotating band of the projectile to be engaged gradually by the rifling.

e. The obturator assembly (composed of the obturator spindle and gas check disk), seals the breech when fired, thus precluding rearward escape of the gas pressure produced by propellant ignition. Weapons firing semi-fixed ammunition do not have gas check seats since the expansion of the gas against the walls of the chamber provides a gas seal for the breech.

f. The main bore is the rifled portion of the interior of the tube and contains the lands and grooves.

g. The counter bore is at the muzzle end of the tube. The lands have been removed in order to relieve firing stress thus preventing the tube from cracking.

h. The bore evacuator removes the propellant gases after the weapon has been fired, thus preventing contamination of the fighting compartment in M109 series howitzer systems.

i. The muzzle break serves to retard the force of recoil.

j. The caliber is the inside diameter of the tube as measured between opposite lands.

k. Caliber length equals tube length divided by diameter.

4. As the projectile travels forward along the bore, it encounters spiraled lands and grooves called rifling as shown in Figure 1-2. Rifling consists of a number of grooves cut into the surface of the bore. The raised portions between the grooves are known as lands. The rifling imparts rotation to the projectile along its longitudinal axis, thereby increasing stability in flight. In most cases, the rifling in field artillery weapons of today has a uniform right-hand twist.

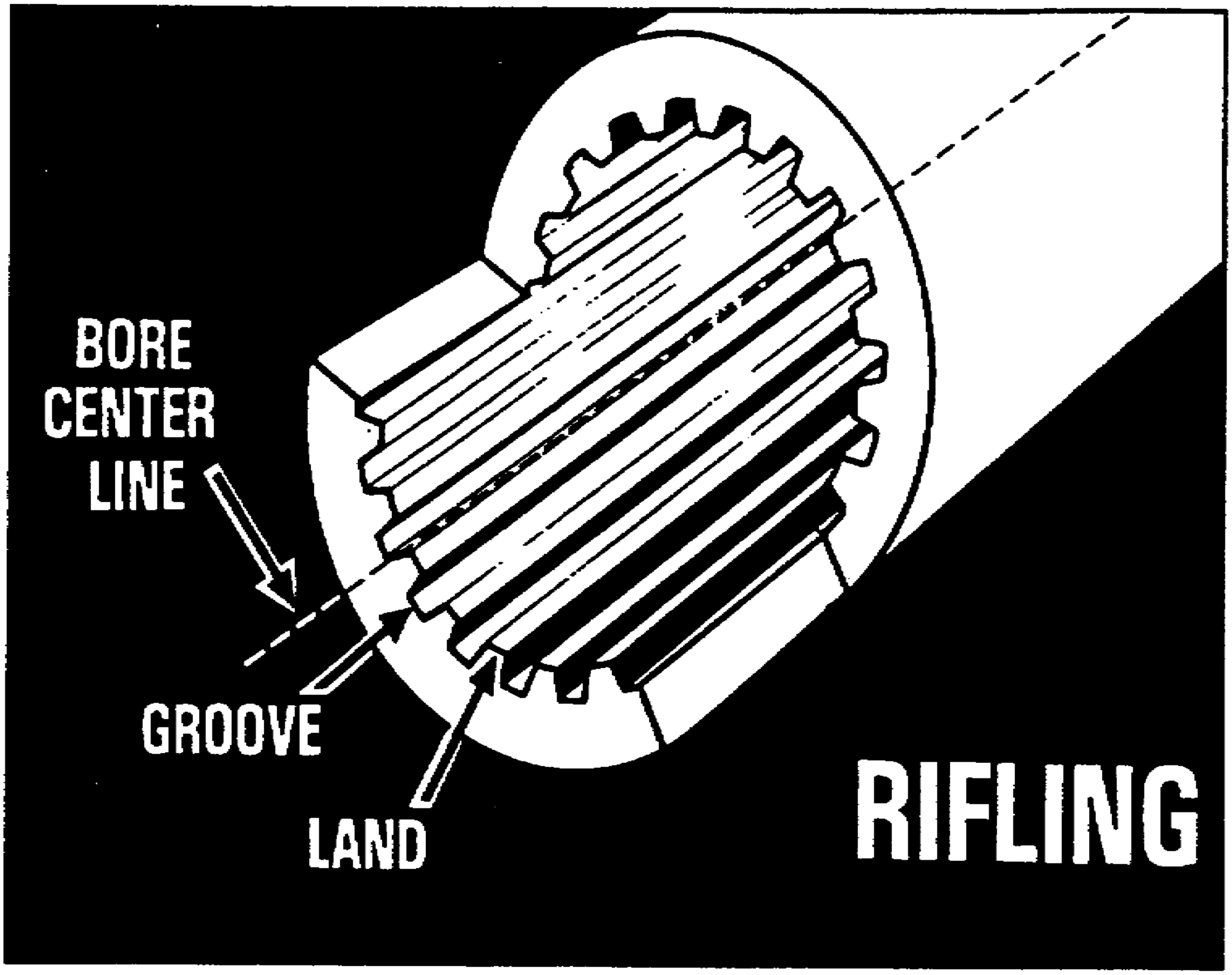


Figure 1-2. Rifling.

5. Projectile - A projectile is a bullet, shell, grenade, etc. fired from a gun or similar weapon, capable of being propelled forward. Artillery projectiles are defined in shape and exterior parts to achieve ballistic standardization, thus permitting accurate computation of firing data. Projectile components may be grouped in two broad categories: Exterior components and interior composition (filler). Internal design/composition has little effect on interior/exterior ballistics except for terminal effects and center of gravity analysis. External components vastly affect ballistics. Each unfuzed projectile consists of the lifting eyebolt, ogive, bourrelet, body, rotating band, base, and base cover, as shown in Figure 1-3.

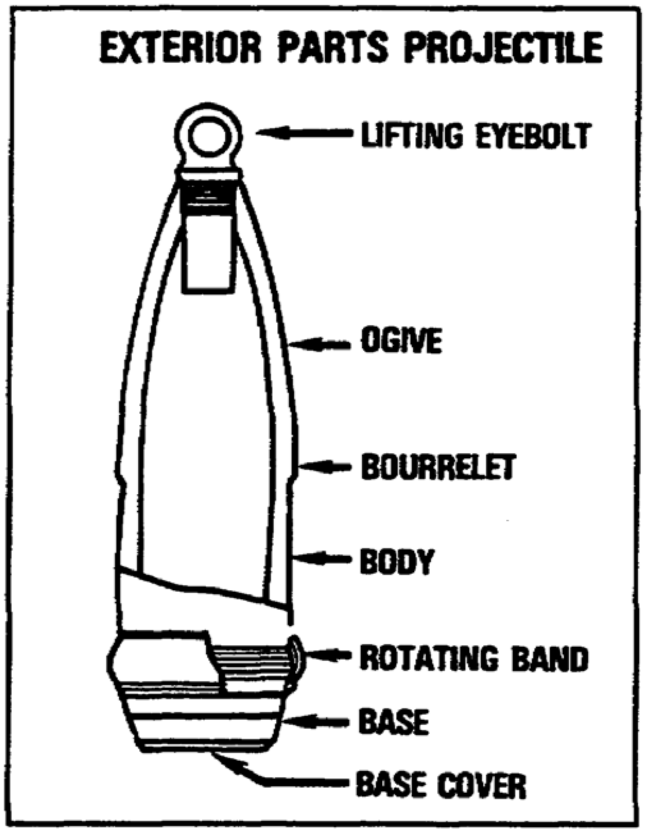


Figure 1-3. Exterior parts projectile.

PART B

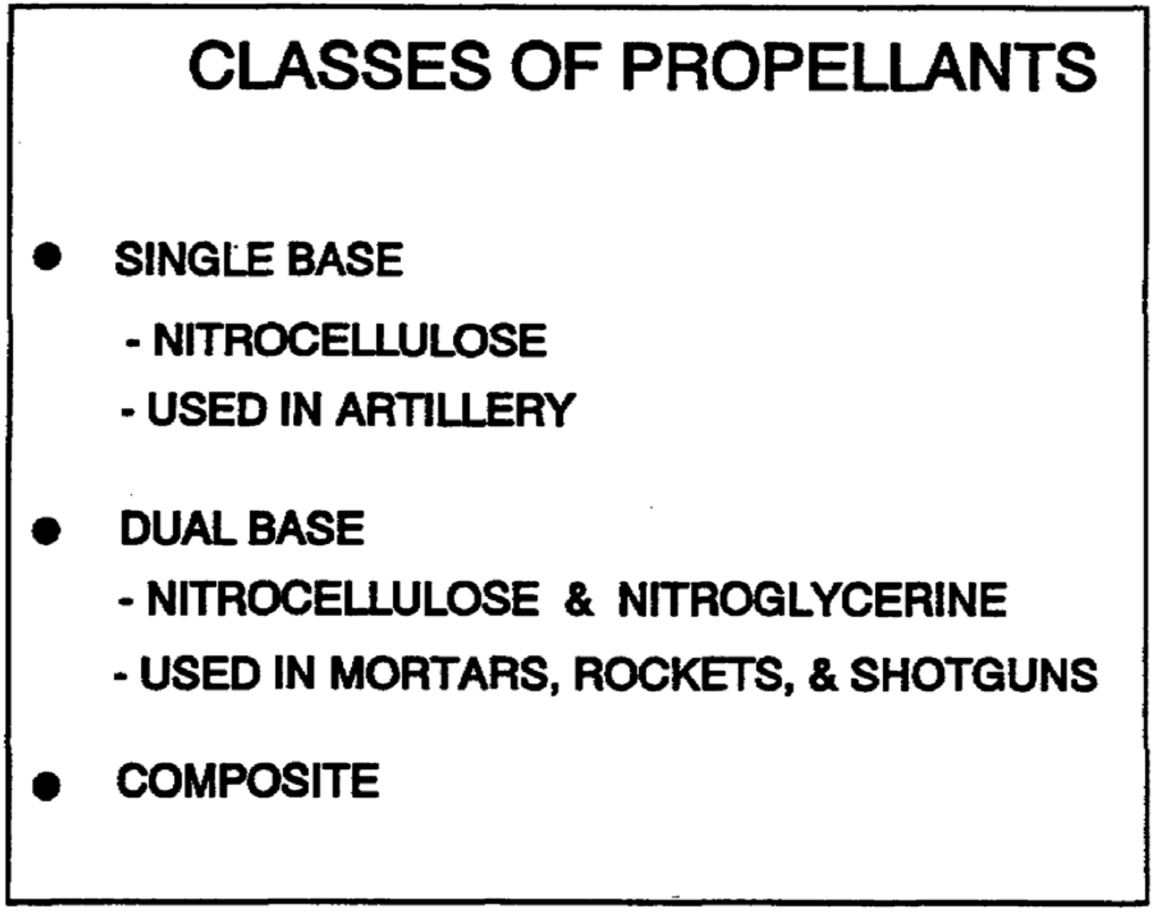
PROPELLANTS

1. A propellant is a low-order explosive material configured to burn rather than explode and that, through burning, creates rapidly expanding gases. When the expanding gases develop pressure sufficient to overcome initial bore resistance, the projectile begins to move.

a. Although propulsion of the projectile is the desired and most pronounced result of this release of energy, much of the energy is unavoidably expended in other ways. Ordinary losses include: internal energy that remains in the powder gas in the form of heat. The kinetic energy of the powder gases; potential energy in the unburned powder; energy expended in engraving the rotating band; friction between the projectile and wall of the tube; and energy expended in tube recoil. The first three types account for the majority of energy loss, while the last two represent only a small percentage of the total potential energy of the propellant.

b. The powerful disruptive action of the detonation of a high explosive precludes its use as a propellant. However, the comparatively low burning rate of the low-order explosive used in propellants permits control of the chamber pressure and, consequently, the projectile behavior. The rate of burning is determined by three factors: the composition of the propellant, the area of its exposed burning surface, and the pressure of the powder gas.

2. Composition of propellants. Propellants are classified according to the number of basic explosive ingredients they contain (Figure 1-4). The SINGLE-BASE propellant which contains nitrocellulose as its chief ingredient, is used in rifled artillery weapons. The DOUBLE-BASE and COMPOSITE propellant, composed primarily of nitrocellulose and nitroglycerin, is more easily ignited and has a higher burning rate and higher force than a single-base propellant. Consequently, it is used chiefly in mortars, shotguns, and rockets. For these weapons, its advantages outweigh its disadvantages.



CLASSES OF PROPELLANTS

- SINGLE BASE
  - NITROCELLULOSE
  - USED IN ARTILLERY
- DUAL BASE
  - NITROCELLULOSE & NITROGLYCERINE
  - USED IN MORTARS, ROCKETS, & SHOTGUNS
- COMPOSITE

Figure 1-4. Classes of propellant.

3. Each propellent contains certain additives which play an important part during the explosive train. DIPHENYLAMINE is used to increase stability, DIBUTYLE PHTHALATE reduces hygroscopic moisture, and DINITROTOLUENE slows the initial rate of burning.

4. Propellant grains. The exposed burning surface is governed by the geometric form or shape of the propellant grains (Figure 1-5). The four forms of grains in common use today are STRIP, CORD, SINGLE-PERFORATED, and MULTI-PERFORATED. Single-perforated and multi-perforated grains are most commonly used for artillery ammunition. Cord and strip forms are classified as having a digressive burning rate, because their surface area decreases as burn progresses. A single-perforated grain is nearly neutral in burning rate, since the outside surface decreases and the inside surface increases as the grain burns. As a result, a nearly constant total surface area is exposed to the flame during the entire burning period. Multi-perforated grains burn at a progressive burning rate due to an increase in surface. The burning rate of a propellant is important in understanding the pressure-travel relationship within the tube.

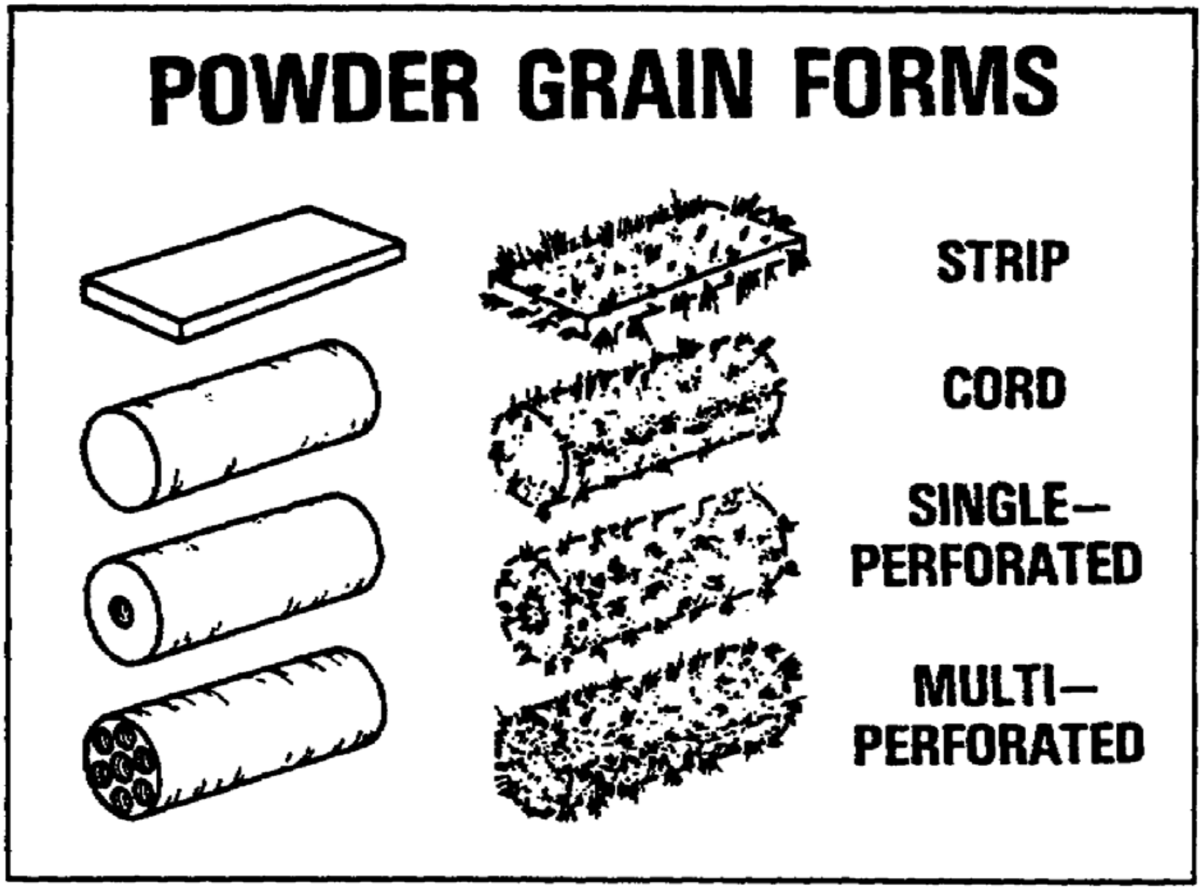


Figure 1-5. Powder grain forms.

5. Web thickness. The rate of burning depends on the form of the propellant grain. However, the time of burning depends on a less familiar but equally important characteristic of the propellant called WEB THICKNESS. Web thickness is the shortest linear dimension of the grain. For example, in multi-perforated grain, the web thickness is the distance from the perforation to the edge or to an adjacent perforation.

Web thickness has a significant effect on the pressure-travel curve: the thicker the web, the longer the grain will burn; the thinner the web, the quicker the grain will burn. We can therefore expect single perforated propellant to burn slower than multi-perforated propellants.

6. The burning propellants in the powder chamber produce gases, which exert pressure. As the pressure increases, the projectile begins to move, and the subsequent burning of the propellant causes the pressure to further increase. At the same time, however, pressure is being decreased in two ways:

a. By an increase in the space occupied by the propellant gases as a result of the forward motion of the projectile; and

b. By lowering the temperature of the propellant gases which occurs after maximum pressure. Naturally, the space occupied by the propellant gases increases as the projectile moves forward in the tube. This increase in volume lowers the pressure, since pressure and volume are inversely related. The decrease in temperature results from a loss of internal energy by the propellant gases, since energy is being used to accelerate the projectile and to overcome bore friction.

c. Energy is also lost as heat is transferred to the walls of the tube. The result is an increase in pressure until it reaches a maximum value, known as PEAK PRESSURE, and then a decrease. The PRESSURE TRAVEL CURVE (Figure 1-6) shows the relation between the pressure and the distance the projectile has traveled at a given time. This allows the projectile to leave the bore at a given rate of speed (MUZZLE VELOCITY) so that the pressure developed to accomplish this does not damage the weapon. All tubes are designed to obtain a desirable pressure-travel curve for the proposed weapon at a specific point. Since the pressure indicated by the pressure-travel curve controls the motion and speed of the projectile, it is necessary to understand the variables that affect this curve in order to understand the dynamics of interior ballistics.

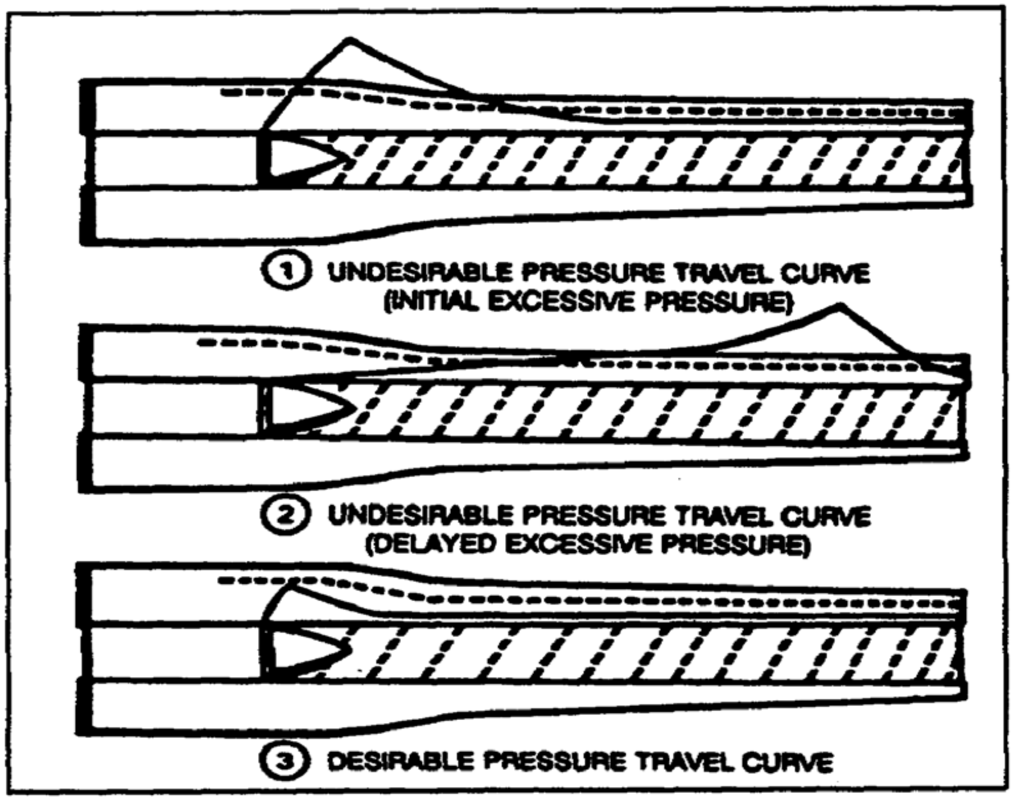


Figure 1-6. Pressure travel curve.

PART C

MUZZLE VELOCITY

There are many factors that affect the pressure-travel curve or muzzle velocity of a given weapon.

1. Type of propellant. (Ammo lots) A propellant that is digressive or that causes rapid initial burning (because of its granulation as well as its composition) creates peak pressure before the projectile has traveled as far along the bore as it would have traveled with a slower burning propellant. This initial burning causes the peak of the pressure-travel curve to appear near the breech end of the tube.

2. Rate of ignition. With either a fast or slow burning propellant, the rate of ignition naturally affects the pressure-travel curve. If the entire propellant is not ignited instantaneously, more than one pressure wave may result. This might cause the peak pressure to occur at a point where it would exceed the permissible level and rupture the tube. It is also desirable to have instantaneous ignition in order to minimize the smoke and flash at the muzzle. The slow response was prevalent in weapons employing cartridge cases with short primers and was remedied using a long igniter tube to obtain instantaneous ignition.

3. Positioning. The position of the propellant in the powder chamber is also important. The farther forward the propellant is placed in the chamber, the slower the rate of burning and the lower the subsequent velocity. To insure uniform positioning and propellant performance in weapons firing separate-loading ammunition, the base of the propellant bag should be flush against the mushroom head of the breechblock at the instant of firing. For semi-fixed ammunition, the remaining increments are reassembled in the cartridge case in their original numerical order. Associated with the positioning of the bag in the chamber are variations in the volume of the propellant, which, for the same amount of propellant, tend to change the rate of burning and resultant velocity. Loose tie straps or wrapping have the effect of increasing the diameter of the bag. Cannoneers should check the wrappings for tightness, even when the full charge is used.

4. Propellant temperature. Another variable affecting the pressure-travel curve is the temperature of the propellant. Most calculations regarding the burning rate of a particular propellant, and the resulting pressure, muzzle velocity, ranges, ect., are based on the assumption that the temperature of the propellant is 70 degrees Fahrenheit. It is unrealistic to attempt to maintain this temperature under field conditions; therefore, the ballistic characteristics and pressure-travel curve of the propellant vary. A higher temperature increases the rate of burning of the propellant, resulting in increased muzzle velocity. Sudden changes in propellant temperature can invalidate even the most recent registration; therefore, uniform propellant temperature must be maintained in order to minimize round-to-round variation. Propellant temperatures should be taken about every 30 minutes to an hour. The propellant should not be removed from the rest of the ammunition, but should be checked in place to get a true mean temperature.

5. Density of loading. The amount of propellant in a charge, as measured by its weight, governs the muzzle velocity and density of loading. This can only be varied by manufacturer's tolerances and nonuniform ramming of the projectile. Proper training of personnel can eliminate variances due to improper placement of the propellant in the chamber and nonuniform ramming of the projectile. A weak ram decreases the volume of the powder chamber and thereby increases the resultant muzzle velocity. However, this is only part of the effect. Improper seating of the projectile as a result of weak ramming, allows some of the expanding gases to escape resulting in a lower velocity. The combined effect is difficult to predict for any one round; therefore, the best solution is hard, uniform ramming for all rounds.

6. Erosion. Another variable affecting the pressure-travel curve is erosion. Erosion has a dual effect in that it decreases the muzzle velocity (decreasing range) and the rotational motion (decreasing stability and accuracy). Erosion occurs principally in three ways: GAS EROSION, SCORING, and ABRASION. The effects of erosion vary with different weapons and velocities. Erosion is more pronounced with higher velocities and is usually greatest at the origin of rifling. As wear increases and more gas leaks past the projectile, the pressure decreases, with a resulting loss in muzzle velocity. The primary cause of failure to attain proper rotation is the stripping or shearing of the rotating band by worn rifling.

a. Gas erosion. Hot gases tend to melt a thin film of metal and carry it away in a manner resembling a washing action. This wearing away affects both the lands and the grooves, and appears as a smooth enlargement of the rifling. Gas erosion is greatest with initial firing and decreased gradually with subsequent firing. Gas erosion can be minimized by careful selection of the charge and by proper cleaning of both the tube and the ammunition.

b. Scoring. Scoring is attributed to a nozzle or vent action of gas escaping past the rotating band and causing uttering at an increasing rate. It may appear as a longitudinal streak fanning out toward the muzzle or as a trough. Tool marks or land damage usually starts the scoring because of incomplete forward obturation, or sealing, by the rotating band at that point. After scoring begins, it increases in effect with each round, and usually affects the grooves more than the lands. Deep scoring reduces the strength of a cannon tube, but most tubes will fail ballistically before scoring becomes dangerous.

c. Abrasion. Abrasion is a slow, mechanical wearing away or chipping of the lands by the projectile and powder residues. It normally is more pronounced at the bottom of the bore near the origin of rifling where the weight of the projectile rests. Abrasion at this point permits a larger clearance at the top between the rotating band and the tube that permits more gas leakage, which accelerates erosion and scoring.

d. Fatigue. Fatigue is caused by the repeated application of firing pressures or high stresses from barious charges and sustained tube temperatures. Each round of ammunition fired throught a cannon reduces tube life due to metal degradation.

7. Coppering. Coppering is defined as the deposit of a thin film of copper on the bore. Coppering occurs in the tube when the velocity is high enough to develop sufficient friction to remove the outside surface of the rotating band. The amount of copper deposited varies with the velocity; therefore, copper deposits are characteristic of higher charges. Each round fired removes a part of the previous coppering. However, if a round is of a higher velocity, more copper will be deposited; a lower velocity round will produce the opposite effect. Excessive coppering causes erratic velocity performance by resistance of the bore to projectile movement. Coppering tends to increase the muzzle velocity in a new tube and decrease it in an old tube. However, no set rule can be used effectively with all weapons. Coppering can be minimized by firing lower charges that develop a lower velocity or by firing a charge that contains a decopperizing agent: i.e.; CHG 5 M1.

8. Residue. Residue from the burned powder and certain chemical agents mixed with the expanding gases, are deposited on the bore surface in a manner similar to coppering. Unless the tube is properly cleaned and cared for, these residues aggravate subsequent tube wear by causing pitting and augmenting of the abrasive action of the projectile.

9. Tube conditioning. The heat of the tube has a direct and pronounced bearing on the velocity developed. Establishing the desired heat level for a particular charge by firing warmup or conditioning rounds is known as tube conditioning. This process is influenced by many variables. The warm-up process can either increase or decrease the velocity, depending on the weapon, the charge, the oiliness of the tube, the degree of coppering, the ambient air temperature, the moisture content of the powder, the duration and charge of previous firing, and the condition of the projectile. Oil or moisture in the tube or on the rotating band tends to increase the velocity of a particular round by allowing a tighter initial gas seal and by reducing the friction of the projectile with the tube wall.

The oily condition usually occurs concurrently with a cold tube and is usually impossible to determine which of these opposing effects will dominate.

10. Charge-to-charge propellant performance. Charge-to-charge propellant performance is one of most intriguing problems in gunnery, which extends data developed from firing one propellant to all other propellants. From the viewpoint of developed muzzle velocities, there is no data available to indicate propellant-to-propellant performance will follow any convenient arithmetical ratio. Since propellants are manufactured to provide standard performance within a given propellant lot, a variation from standard in one propellant does not fit a similar or proportional variation in another propellant. Although the round-to-round probable error within each lot is about the same, the mean velocity developed by one lot may be higher or lower than that of another. The velocity level for a propellant of a particular lot can be determined only by firing. After the velocity level has been determined, its relation to other propellants of that lot remains stable.

PART D

STANDARD MUZZLE VELOCITY

1. Standard muzzle velocity. As in any situation, a starting point or standard value must be established. Applicable firing tables list the standard value of muzzle velocity for each charge. These values are based on an assumed standard tube. The values are points of departure and not absolute standards, since they cannot be reproduced in any given instance. Essentially, a given weapon-ammunition combination cannot be selected with any assurance that the combination, when fired, will produce the standard muzzle velocity for the following reasons.

a. Velocity for each charge is indirectly established by the characteristics of the weapon itself. Cannons capable of high-angle fire (howitzers) require a greater choice in the number of charges than cannons capable of only low-angle fire (guns). This choice achieves 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 weapon, the maximum elevation and charge, and the maximum permissible pressure the weapon can accommodate.

b. Manufacturing specifications for ammunition include a requirement for velocity performance within certain tolerances. Ammunition lots are subjected to firing tests, which include measuring the performance of a tested lot and comparing it to the performance of a control (reference) lot tested concurrently with the same weapon. An assumption built into the testing procedure is that both lots of ammunition will be influenced in the same manner by the performance of the tube. This assumption, although accurate in most instances, allows some error to be introduced in the assessment of the performance of the tested lot. In field conditions, variations in the performance of different projectiles or propellant lots can be expected, even though quality control has been exercised during manufacture and testing of lots. In other words, although a howitzer develops a muzzle velocity that is 3 meters per second greater (or less) than standard with propellant lot G, it will not necessarily do the same with any other propellant. The optimum method for determining ammunition performance is to measure the performance of a particular projectile family-propellant type/charge combination (calibration). However, predictions of the performance of a projectile family-propellant model combination may be inferred, only with the understanding they will not be as accurate as actual performance measurement.

2. Factors causing nonstandard muzzle velocities. Nonstandard muzzle velocity is expressed as a variation (plus or minus so many meters per second) from an accepted standard. Round-to-round correction for dispersion cannot be made. Each of the following factors causing nonstandard conditions is treated as a single entity, assuming no influence from related factors.

a. Velocity trends. Not all rounds of a series fired from the same weapon and using the same ammunition lot will develop the same muzzle velocity. 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 trends (or velocity dispersion). The magnitude varies with the cannon, charge, and tube condition at the time each round is fired. Velocity trends cannot be accurately predicted; thus, any attempt to correct for the effects of velocity trends is impractical.

b. Ammunition lots. Each ammunition, projectile, and propellant lot has its own mean performance level in relation to a common weapon. Although the round-to-round probable errors within a given lot are similar, the mean velocity developed by one lot may differ significantly from that of another. With separate-loading ammunition, both the projectile and propellant lots must be identified. Variations in the manufacture of projectiles (for example, the diameter and hardness of the rotating band) will affect the muzzle velocity achieved. However, this effect is so small it is not accounted for in the computation of firing data.

c. Tolerances in new weapons. All new cannons of a given caliber and model will not necessarily develop the same muzzle velocity. In a new tube, the mean factors affecting muzzle velocity are variations in the size of the powder chamber and the interior dimensions of the bore. If a battalion equipped with new cannons fired all of them using a common lot of ammunition, a variation of 4 meters per second between the cannon developing the greatest and the cannon developing the least muzzle velocity would not be unusual. Calibration of all cannons allows the firing unit to compensate for small variations in the manufacture of cannon tubes and the resulting variation in developed muzzle velocity.

d. Tube wear. Continued firing of a cannon wears away a portion of the bore by the actions of hot gases and chemicals, and by movement of the projectile within the tube. These erosive actions are more pronounced when higher charges are fired. The greater the tube wear, the more muzzle velocity decreases. Normal wear can be minimized by careful selection of the charge and by proper cleaning of both the tube and the ammunition.

e. Nonuniform ramming. Weak ramming decreases the volume of the chamber and thereby theoretically increases the pressure imparted to the projectile. This occurs because the pressure of a gas varies inversely with volume; therefore, only a partial gain in muzzle velocity might be achieved. Of greater importance is the improper seating of the projectile within the tube. Improper seating can allow some of the expanding gases to escape around the rotating band of the projectile, and thus result in decreased muzzle velocity. The combined effects of a smaller chamber and escaping gases are difficult to predict. Weak, nonuniform ramming results in an unnecessary and preventable increase in the size of the dispersion pattern (figure 1-7). Hard uniform ramming is required for all rounds. When semi-fixed ammunition is being fired, the principles of varying the size of the chamber and escape of gases still apply, particularly when ammunition is fired through worn tubes. The rear portion of the cartridge case provides rearward obturation for the projectile. Proper seating of the case is important in reducing the escape of gases.

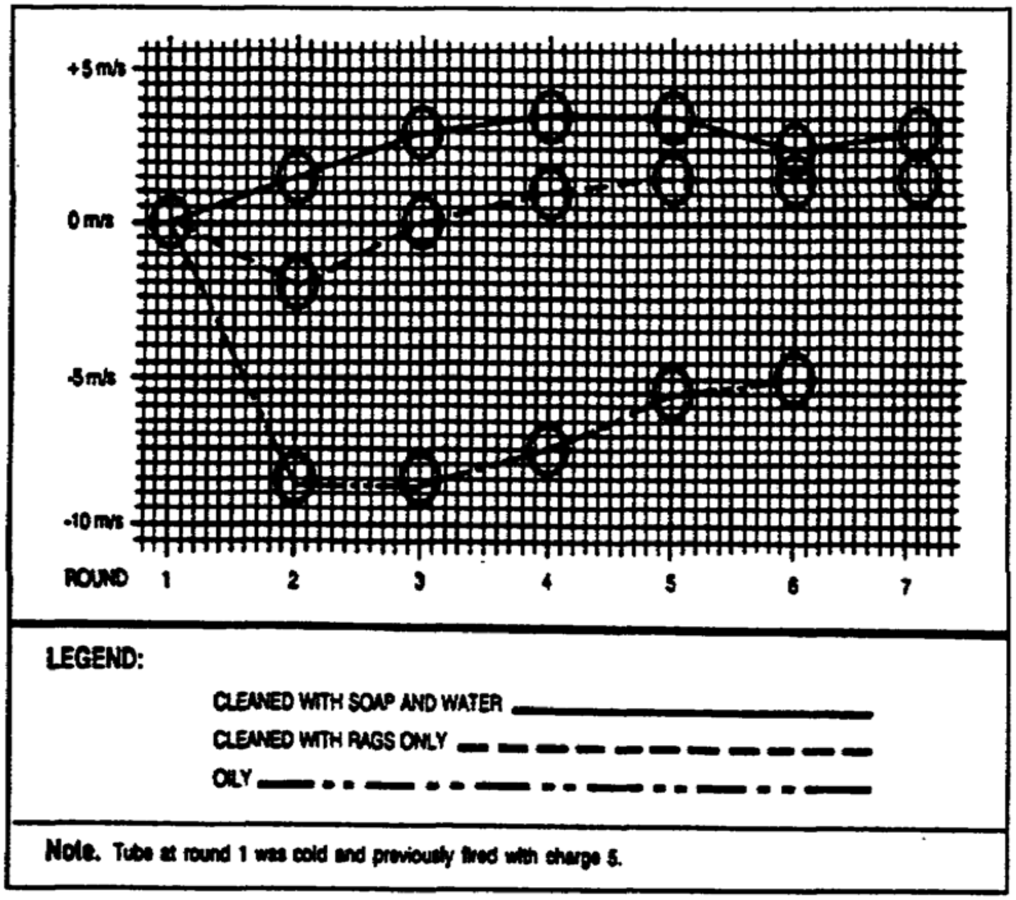


Figure 1-7. Velocity variances between rounds.

f. Rotating bands. The ideal rotating band permits proper seating of the projectile within the cannon tube. Proper seating of the projectile allows forward obturation, uniform pressure buildup, and initial resistance to projectile movement within the tube. The rotating band is also designed to provide a minimum dragging effect once the projectile overcomes initial bore resistance and starts to move. Dirt or burrs on the rotating band cause improper seating. This increases tube wear and contributes to velocity dispersion. If excessively worn, the lands may not engage the rotating band well enough to impart the proper spin to the projectile. Insufficient spin reduces projectile stability in flight, and can result in dangerously erratic round performance. When erratic rounds occur or excessive tube wear is noted, ordnance teams should be requested to determine the serviceability of each tube.

g. Propellant and projectile temperatures. Any combustible material burns more rapidly when it is heated before ignition. When a propellant burns more rapidly than expected under standard conditions, gases are produced more rapidly and the pressure imparted to the projectile is greater. As a result, the muzzle velocity will be greater than standard, and the projectile will travel farther. Table E in the firing tables lists the magnitude of change in muzzle velocity resulting from a propellant temperature greater or less than standard. Appropriate corrections can be extracted from that table; however, such corrections are valid only if they are determined to be relative to the true propellant temperature. The temperature of propellant in sealed containers remains fairly uniform, though not necessarily at the standard propellant temperature (70 degrees Fahrenheit). Once propellant has been unpacked, its temperature begins to approach the air temperature. The time and type of exposure to the weather result in temperature variations from round to round and within a firing unit. It is impractical to measure propellant temperature and apply corrections for each round fired by each cannon. Uniform projectile and propellant temperatures must therefore be maintained. Failure to do this results in erratic firing. The effects of an extreme change in projectile or propellant temperature can invalidate even the most recent corrections determined from a registration. The following precautions should be followed;

1) Ready ammunition should be kept off the ground and protected from dirt, moisture, and direct rays of the sun. There should be airspace of at least 6 inches between the ammunition and the ground. There should also be an 18 inch gap between the stack and the tarpaulin cover. This allows propellant and projectile temperatures to approach the air temperature at a uniform rate.

2) Propellant should be unpacked in advance to preclude firing freshly unpacked propellants with ammunition exposed to weather during a fire mission.

3) Ammunition should be fired in the order it was unpacked.

4) Propellant temperature should be measured from ready ammunition on a periodic basis, particularly if there has been a change in the air temperature.

h. Moisture content of propellant. Changes in the moisture content of propellant are caused by improper protection from the elements or improper handling. These changes can affect- muzzle velocity. Since the moisture content cannot be measured or corrected for, THE PROPELLANT MUST BE PROVIDED MAXIMUM PROTECTION FROM THE ELEMENTS AND FROM IMPROPER HANDLING.

i. Position of the propellant in the chamber. In fixed and semi-fixed ammunition, the propellant has a relatively fixed position with respect to the chamber, which is formed by the cartridge case. In separate-loading ammunition, however, the rate at which the propellant burns and the resulting developed muzzle velocity depends on how the cannoneer inserts the charge. To ensure proper ignition of the propellant, he must insert the charge so the base of the propellant bag is flush against the obturator spindle when the breech is closed. The farther forward the charge is inserted, the slower the burning rate and the lower the subsequent muzzle velocity. An increase in the diameter of the propellant charge can also cause an increase in muzzle velocity. Loose tie straps or wrappings have the effect of increasing the diameter of the propellant charge. PROPELLANT CHARGE WRAPPINGS SHOULD ALWAYS BE CHECKED FOR TIGHTNESS, EVEN WHEN THE FULL PROPELLANT CHARGE IS USED.

j. Weight of projectile. The weight of like projectiles varies within certain zones (normally termed square weight). The appropriate weight zone is stenciled on the projectile (in terms of so many squares). Some projectiles, such as Copperhead, are marked with the weight in pounds. In general terms, A HEAVIER-THAN-STANDARD PROJECTILE NORMALLY EXPERIENCES A DECREASE IN MUZZLE VELOCITY. This is because more of the force generated by the gases is used to overcome the initial resistance to movement. A lighter-than-standard projectile will exhibit an increase in velocity.

k. Coppering. When projectile velocity within the bore is great, sufficient friction is developed to remove the outer surface of the rotating band. The material is left as a thin film of copper within the bore and is known as coppering. This phenomenon occurs in weapons that develop a high muzzle velocity and when high charges are fired. The amount of copper deposited varies with velocity. Firing higher charges increases the amount of copper deposited on the bore surfaces, whereas firing lower charges reduces the effects of coppering. Slight coppering resulting from firing a small sample of rounds at higher charges tends to increase muzzle velocity. Erratic velocity performance is a result of excessive coppering whereby the resistance of the bore to projectile movement is effected. Excessive coppering must be removed by ordnance personnel.

l. Propellant residue. Residue from burned propellant and certain chemical agents mixed with the expanding gases is deposited on the bore surface in a manner similar to coppering. Unless the tube is properly cleaned and cared for this residue will accelerate tube wear by causing pitting and augmenting the abrasive action of the projectile.

m. Tube conditioning. The temperature of the tube has a direct bearing on the developed muzzle velocity. A cold tube offers a different resistance to projectile movement and is less susceptible to coppering, even at high velocities. IN GENERAL, A COLD TUBE YIELDS MORE RANGE DISPERSION; A HOT TUBE, LESS RANGE DISPERSION.

n. Additional effects in interior ballistics. The additional effects include tube memory and tube jump.

1) Tube memory is a phenomenon that occurs when the tube fires at a muzzle velocity similar to that of the last charge fired, even if the charge is different. For example, if the last charge fired was 5GB and the next charge to be fired is 3GB, the tube will fire at a slightly higher muzzle velocity than normal for charge 3. The tube "remembers" firing charge 5. This phenomenon is not yet fully understood.

2) Tube jump occurs as the projectile tries to maintain a straight line when exiting the muzzle. This phenomenon causes the tube to jump up when fired and may cause tube displacement.

3. Summary. Actual measurements of the muzzle velocity of a series of rounds, corrected for nonstandard conditions, depicts the performance of a certain weapon-ammunition-charge combination. The variation from standard can be obtained by comparison of the results of these measurements with the standard velocities listed in the firing tables for the charge fired. Application of corrections to compensate for nonstandard muzzle velocity is one of the most important elements in the preparation of accurate firing data.

LESSON 1

PRACTICE EXERCISE

Complete the following exercise by circling the letter preceding the correct answer, or by filling in the blanks, as appropriate. The answers follow the last exercise.

1. Muzzle velocity is expressed in _______ per second.

   a. inches
   b. feet
   c. yards
   d. meters

2. Tube wear, propellant efficiency, and _______ _______ are the items normally accounted for in determination of a muzzle velocity.

   a. projectile weight
   b. propellant temperature
   c. projectile movement
   d. powder chamber pressure

3. The bore evacuator removes the propellant ________ from the bore.

   a. residue
   b. sealant
   c. bands
   d. gases

4. The muzzle break serves to retard the force of _________.

   a. forward obturation
   b. forcing cones
   c. recoil
   d. counter bore.

5. Propellant composition normally is classified in two categories, single-base and _________.

   a. double-base
   b. multi-perforated base
   c. cord-base
   d. strip-base

LESSON 1

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback
1.	d. meters per second Muzzle velocity is, page 1-2
2.	a. projectile weight Tube wear, propellant efficiency, and projectile weight, page 1-2
3.	d. gases Bore evacuator removes the propellant gases from the bore, page 1-4
4.	c. recoil Muzzle break serves to retard the force of recoil, page 1-4.
5.	a. double-base Propellant usually are classified according to the number of basic ingredients, single-base and double-base. page 1-7

LESSON 2

EXTERIOR BALLISTICS

OVERVIEW

LESSON DESCRIPTION:

Upon completion of this lesson, you will be able to identify the elements of exterior ballistics and their effects on a projectile.

ACTION:	Identify the elements of exterior ballistics.
CONDITION:	Given the material contained in this lesson and the examination, identify the elements of exterior ballistics.
STANDARD:	Correctly answer all questions in the practice exercise contained in this lesson.
REFERENCE:	This lesson is based on information contained in TC 6-40 and other material approved for US Army field artillery instruction; however, new developments and progress render the text subject to continual change. Therefore, base your examination answers on material presented in this text rather than on individual unit experience.

INTRODUCTION

Exterior ballistics are those factors affecting the travel of a projectile after it has left the muzzle of a weapon. At the instant it leaves the tube, the projectile acquires the total effects of interior ballistics in terms of developed muzzle velocity and spin. The remainder of the projectile path, or trajectory, is influenced by the interaction of the momentum of the projectile, gravity, and atmospheric resistance. The atmospheric resistance, which is variable and complex, makes the ballistic problem intricate. Were it not for gravity and the atmosphere, the projectile would continue indefinitely at a constant velocity along the axis of the tube.

PART A

TRAJECTORY

1. Trajectory. The trajectory is the path traced by the center of gravity of a projectile in flight from the origin to the level point, as shown in Figure 2-1.

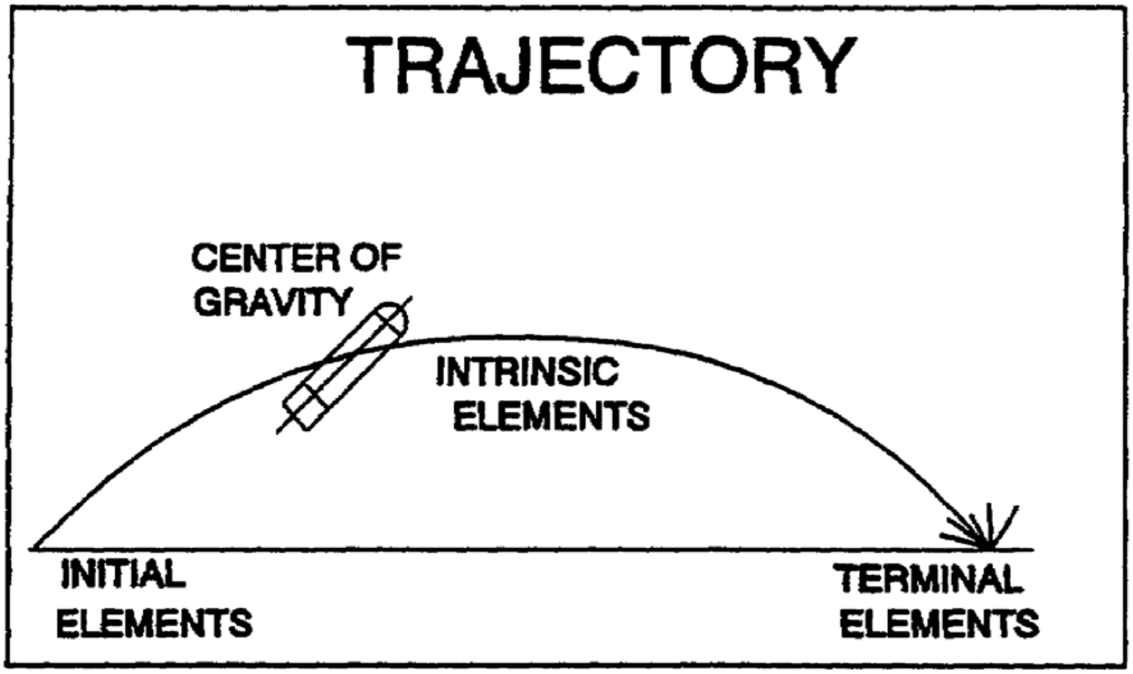


Figure 2-1. Trajectory.

2. Elements of trajectory. The elements of a trajectory are classified into three groups: INTRINSIC ELEMENTS, INITIAL ELEMENTS, AND TERMINAL ELEMENTS.

a. Intrinsic elements. Intrinsic elements are those elements that are characteristics of any trajectory by its very nature as indicated in Figure 2-2.

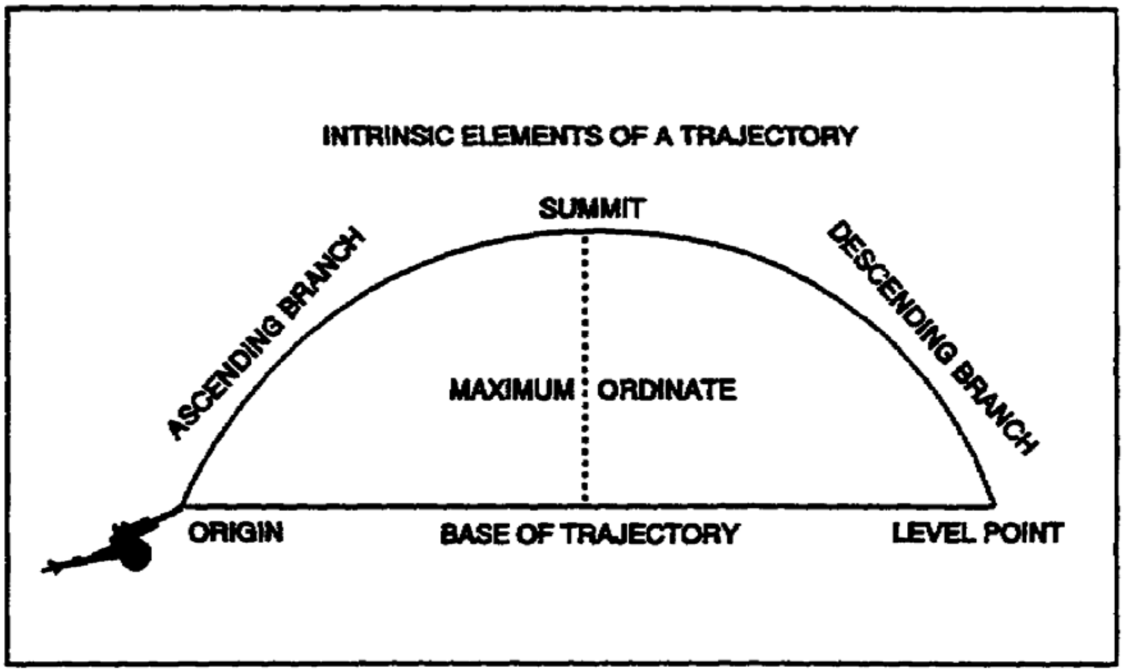


Figure 2-2. Intrinsic elements.

1) Origin. The origin of the trajectory is the location of the center of gravity of the projectile at the time it leaves the muzzle of the piece. Throughout the remaining definitions relating to the elements of trajectory, the word ORIGIN will designate the center of gravity of the projectile at the muzzle.

2) Ascending branch. The ascending branch is that portion of the trajectory traced while the projectile is rising from the origin.

3) Summit. The summit is the highest point of the trajectory. It is the end of the ascending branch and the beginning of the descending branch.

4) Descending branch. The descending branch is that portion of the trajectory traced while the projectile is falling.

5) Maximum ordinate. The maximum ordinate is the difference in altitude between the origin and the- summit.

6) Level point. The level point is the point on the descending branch of the trajectory that is at the same altitude as the origin.

7) Base of the trajectory. The base of the trajectory is the straight line from the origin to the level point.

b. Initial elements. The initial elements are those that are characteristic at the origin of the trajectory as shown in Figure 2-3.

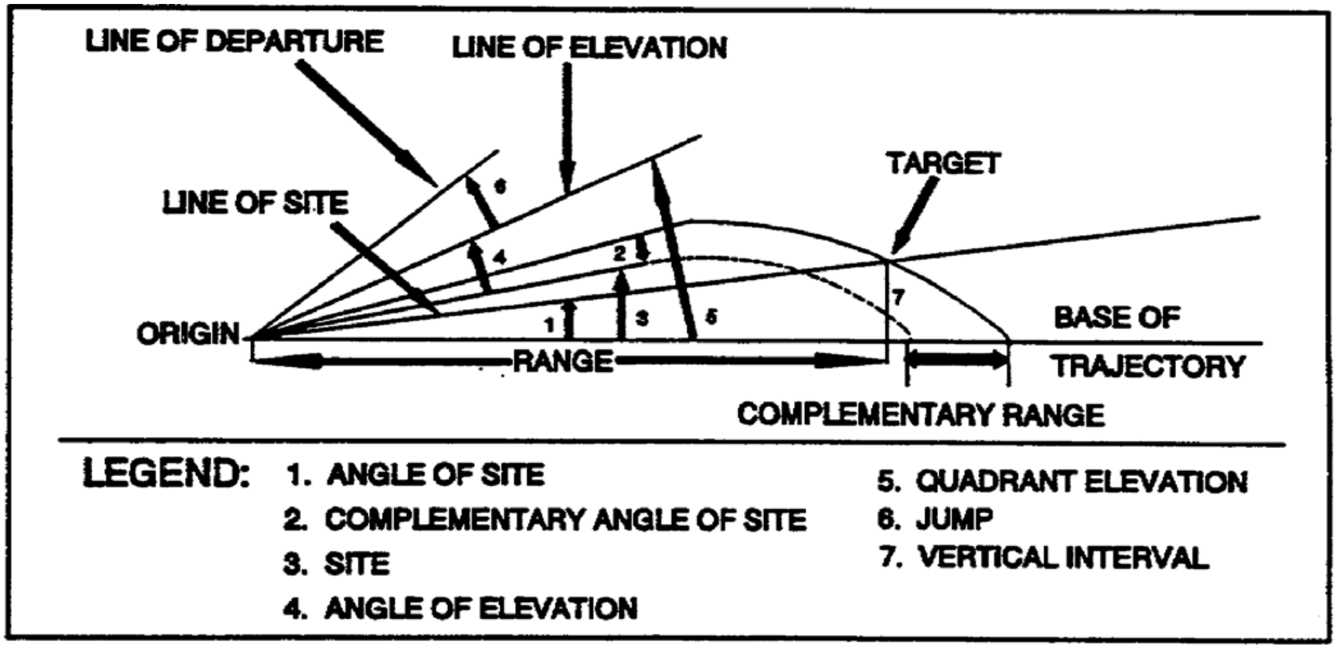


Figure 2-3. Initial elements.

1) Line of elevation. When the piece has been laid, the line of elevation is the axis of the tube extended.

2) Line of departure. The line of departure is tangent to the trajectory at the instant the projectile leaves the tube.

3) Jump. Jump is the displacement of the line of departure from the line of elevation that exists at the instant the projectile leaves the tube.

4) Angle of site. The angle of site is the angle between the base of trajectory and the straight line joining the origin and the target, with the vertex at the origin. The angle of site is plus when the target is above the base of the trajectory and minus when the target is below the base of the trajectory. The angle of site compensates for the vertical interval (VI).

5) Complementary angle of site (CAS). The complementary angle of site is an angle that is algebraically applied to the angle of site to compensate for the non-rigidity of the trajectory. When large angles of site or longer ranges for any one charge are involved, significant error is introduced because the shape of the trajectory changes. The sign and value of the complementary angle of site depend on the angle of site, the range, the shape of the trajectory (low or high angle fire), and the muzzle velocity.

6) Complementary range. Complementary range is the range correction corresponding to the complementary angle of site.

7) Site. Site is the algebraic sum of the angle of mite and the complementary angle of site.

8) Line of site. The line of site is the straight line from the origin that, together with the base of the trajectory, represents the angle called site.

9) Angle of elevation. The angle of elevation is the interior angle at the origin in a vertical plane from the line of site to the line of elevation (when site exists). If site is 0, line of site will be the base of the trajectory.

10) Quadrant elevation. Quadrant elevation is the algebraic sum of site plus the angle of elevation. It is the angle at the origin in a vertical plane from the base of the trajectory to the line of elevation. It is the angle to which the tube must be elevated to cause the trajectory to pass through the target.

c. Terminal elements. The terminal elements, are those that are characteristic of a trajectory at the point of impact as shown in Figure 2-4.

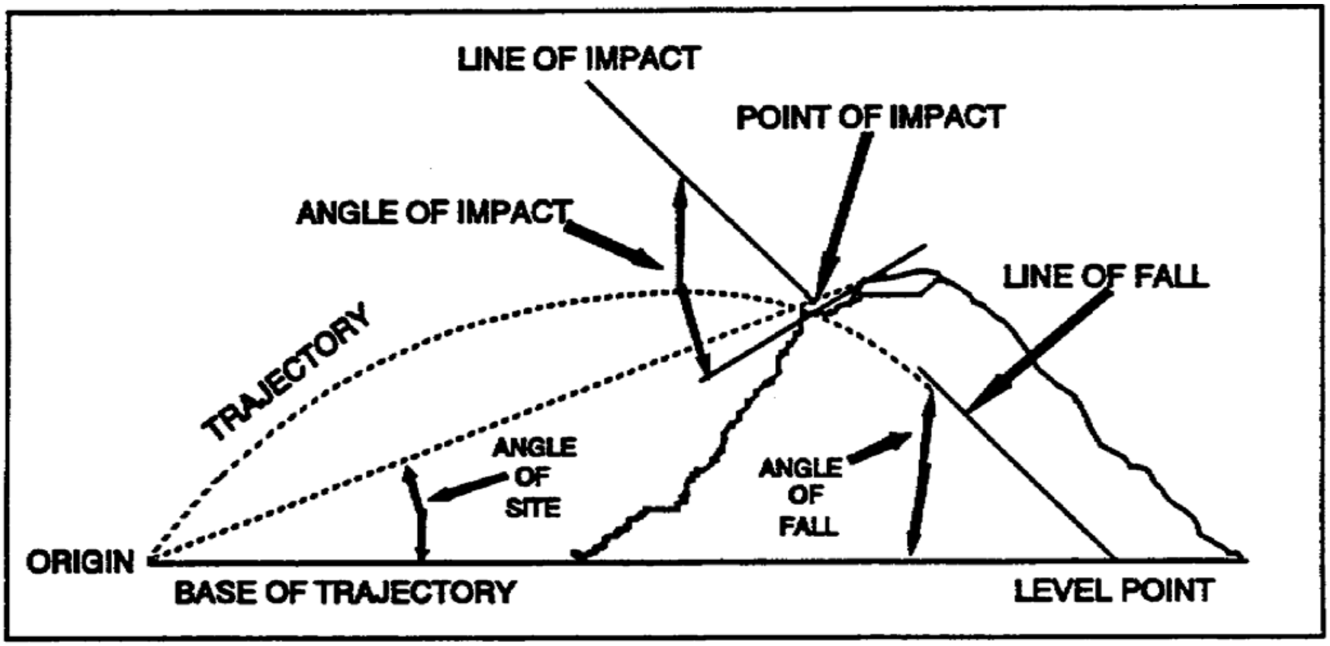


Figure 2-4. Terminal elements.

1) Point of impact. The point of impact is the point at which the projectile first strikes the target area. (The point of burst is the point at which a projectile bursts in the air).

2) Line of fall. The line of fall is line tangent to the trajectory at the level point.

3) Angle of fall. The angle of fall is the vertical angle at the level point, between the line of fall and the base of trajectory.

3. Trajectory in a vacuum. At the instant a projectile leaves the muzzle of a weapon, the total effect of interior ballistics in terms of developed muzzle velocity and spin will have been imparted to the projectile. If the only force acting on the projectile were gravity, the trajectory would be rigid in shape or a parabola in an atmosphere.

4. Trajectory in a standard atmosphere. The most apparent difference between the trajectory in a vacuum and the trajectory in a standard atmosphere is the reduction of the range. This reduction occurs because the horizontal velocity component is not constant, but continually decreased by the retarding effect of the resistance of the air. The vertical velocity component is likewise affected by air resistance. The characteristics of a trajectory in a standard atmosphere differ from the characteristics of a trajectory in a vacuum, as shown in Figure 2-5.

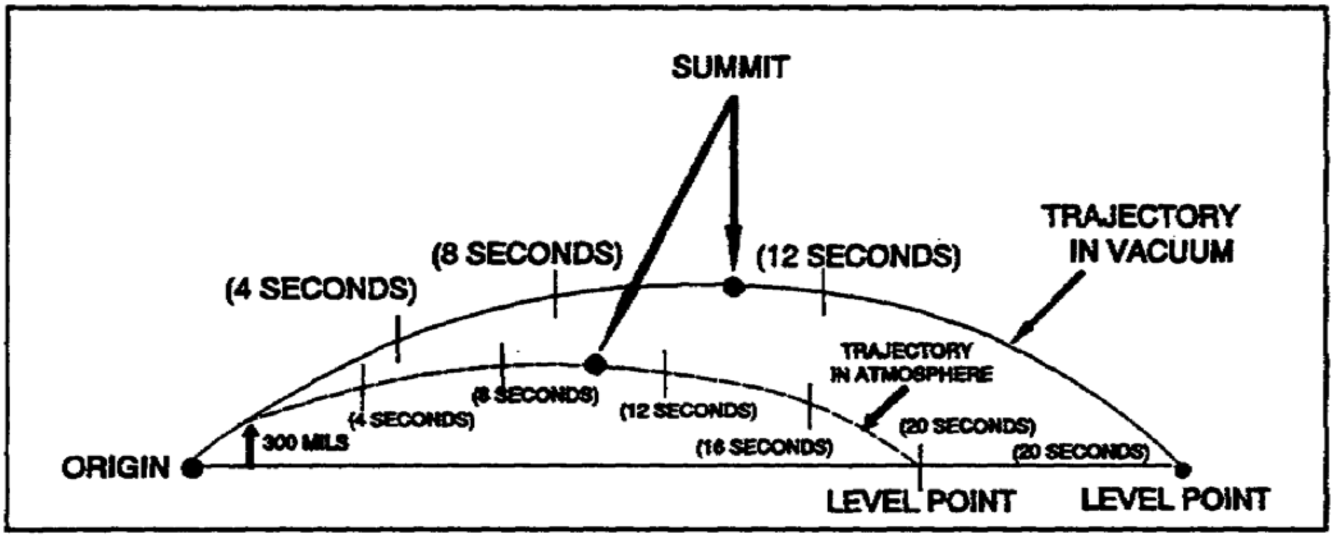


Figure 2-5. Trajectories.

a. The velocity at the level point is less than the velocity at the origin. The mean horizontal velocity of the projectile beyond the summit is less than the mean horizontal velocity before the summit; therefore, the projectile travels a shorter horizontal distance, the descending branch is shorter than the ascending branch, and the angle of fall is greater than the angle of elevation. Also, since the mean vertical velocity is less beyond the summit than it is before the summit, the time of descent is greater than the time of ascent.

b. Because of air resistance, the spin or rotational motion initially imparted causes the projectile to respond differently in direction in a standard atmosphere than it would in a vacuum. This phenomenon is known as drift.

c. A trajectory in a standard atmosphere is shorter and lower than a trajectory in a vacuum after any specific time of flight for several reasons as follows.

1) Horizontal velocity is not a constant, but decreases with each succeeding time interval.

2) Vertical velocity is affected not only by gravity, but also by the additional retardation effect of the atmosphere.

3) In a vacuum, the summit would be midway between the origin and the level point; in an atmosphere, it is nearer the level point as shown in Figure 2-6.

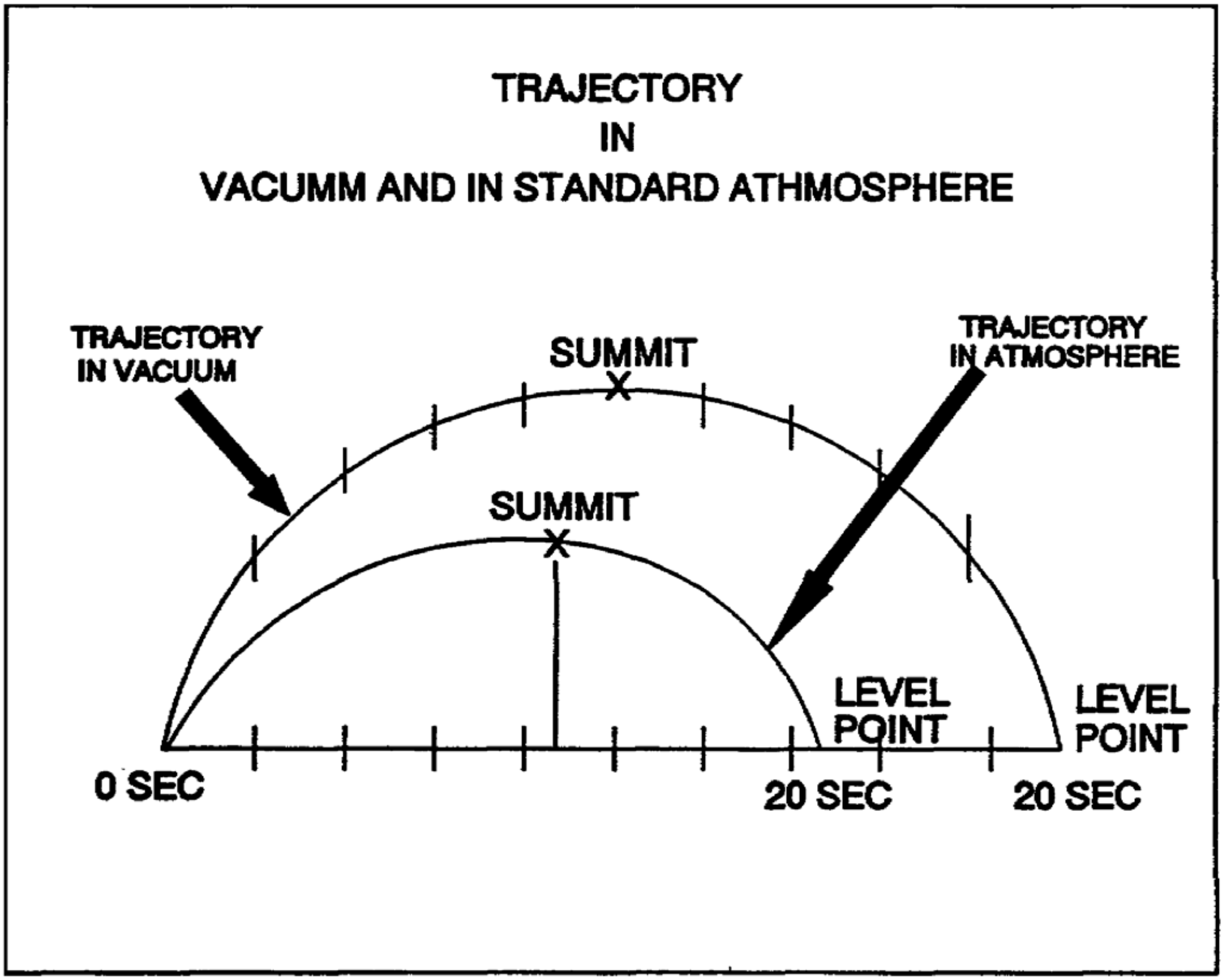


Figure 2-6. Trajectory in a vacuum.

5. Relation of air resistance and projectile efficiency to standard range is based on the three elements; BALLISTIC COEFFICIENT, BALLISTIC COEFFICIENT CHANGE, and DRAG.

a. Ballistic coefficient. The ballistic coefficient is the measure of the ability of a projectile to overcome air resistance in relation to an assumed standard. The ballistic coefficients of various projectiles vary with the muzzle velocity, the angle fired, and the form, finish diameter, and mass of the projectile concerned.

b. Ballistic coefficient change. The ballistic coefficient change (BCC) is the difference in efficiency between any given projectile lot and the specific lot used for construction of firing tables. The BCC is expressed as a percentage change in air density.

c. Drag. Air resistance affects the flight of the projectile. The component of air resistance that resists the forward motion (RANGE) of the projectile is called drag. Because of drag, both the horizontal and vertical components of velocity are less at any given time of flight than they would be if drag were zero, as it would be in a vacuum.

d. To compensate for the effects of ballistics, firing tables were developed based on standard conditions. The standard conditions are contained in tabular firing tables, as outlined in Part B.

PART B

FIRING TABLES

1. Firing tables are based on actual firing of the weapon and its ammunition under, or correlated to, a set of conditions defined and accepted as standard. These standards are points of departure used to compensate for variables in the weapon-weather-ammunition combination known to exist at a given instant and location. The atmospheric standards accepted in the United States firing tables reflect the conditions of the International Civil Aviation Organization (ICAO) Standard Atmosphere. Since firing tables are based on assumed standards, large variations from standard or combinations of large variations are not readily corrected by the use of firing table. The firing tables are sufficiently accurate for variations from standard that do not exceed:

AIR DENSITY	+/- 10 PERCENT
AIR TEMPERATURE	+/- 10 PERCENT
WIND	50-KNOT RANGE OR CROSS WIND COMPONENT
MUZZLE VELOCITY	+/- 10 METERS PER SECOND
ANGLE SITE	+/- 50 MIL
PROJECTILE WEIGHT	+/- 1 SQUARE (APPROXIMATE)

If these variations are exceeded, a degradation in accuracy of computations results.

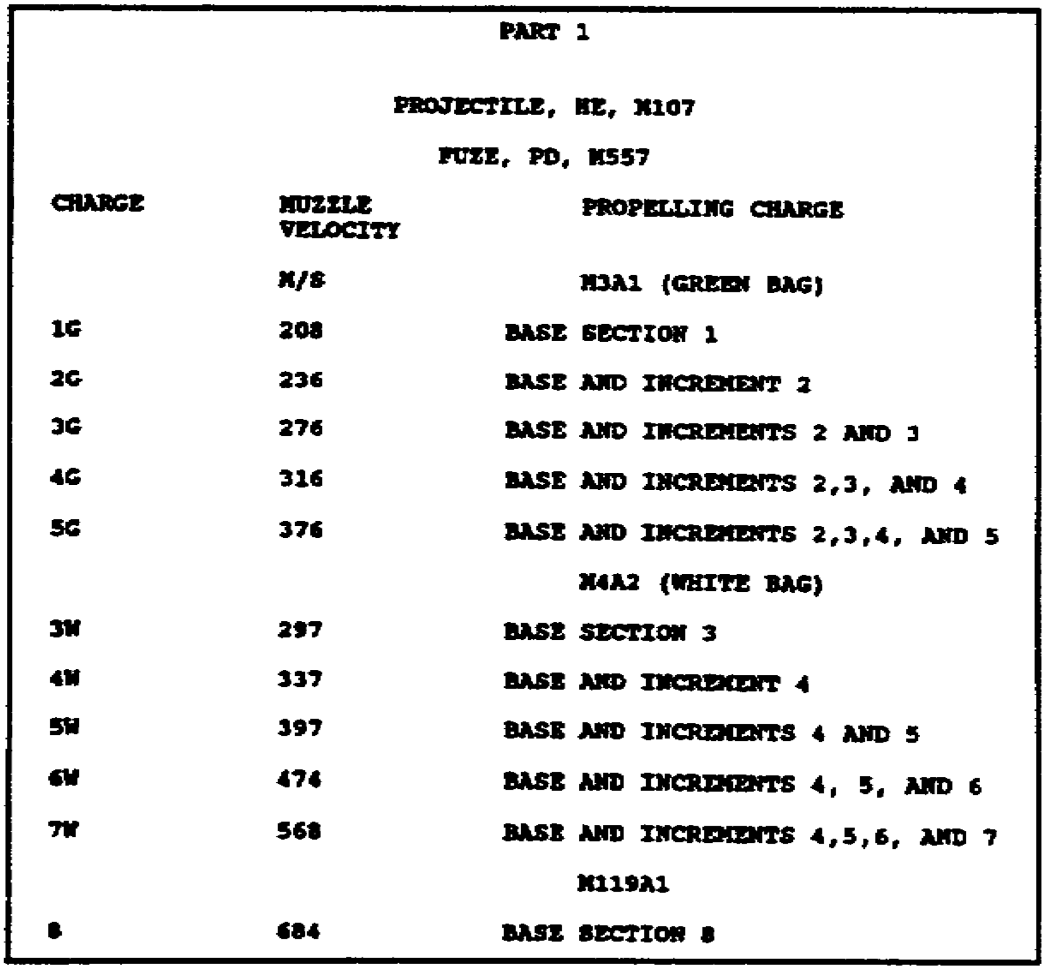
2. The principal elements measured in experimental firings include angle of elevation, angle of departure, muzzle velocity, achieved range, drift, and concurrent atmospheric condition.

3. The main purpose of a firing table is to provide the data required for bringing effective fire on a target under any set of conditions. To obtain data for firing tables, firings are conducted with the weapon at various quadrant elevations. Computed trajectories, based on the equations of motion, are compared with the data obtained from the firing. The data for elevations not fired are determined by interpolation. The firing table data define the performance of known properties under conditions of standard muzzle velocity and weather and a motionless earth.

4. Contents of the tabular firing tables. For instructional purposes, we will use Firing Table FT 155-AM-2 as an example, comparing charge 4 Green Bag.

a. The introduction contains a list of symbols and abbreviations, general information about the firing tables, an explanation of the ballistic MET message and several types of problems, probability table, a table of natural functions of angles, a charge selection table, and a table of conversion factors (refer to Appendix A, Glossary of Terms).

b. Part 1 contains information applicable to the indicated projectile for charges 1 through 8. For each charge, part 1 contains all necessary tables, as indicated in Figure 2-7.



PART 1

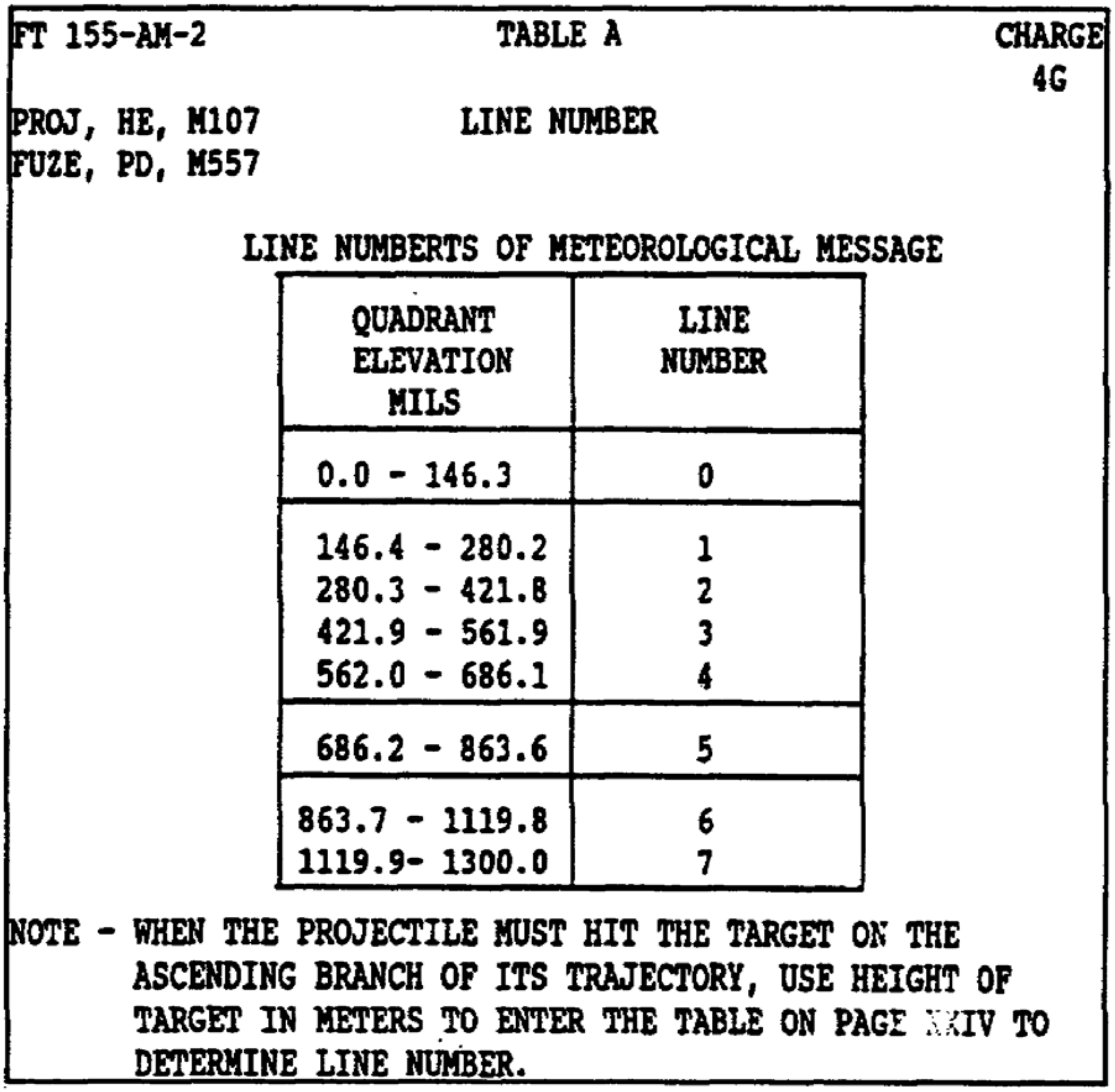
PROJECTILE, HE, M107

FUZE, PD, M557

CHARGE	MUZZLE VELOCITY	PROPELLING CHARGE
	M/S	M3A1 (GREEN BAG)
1G	208	BASE SECTION 1
2G	236	BASE AND INCREMENT 2
3G	276	BASE AND INCREMENTS 2 AND 3
4G	316	BASE AND INCREMENTS 2,3, AND 4
5G	376	BASE AND INCREMENTS 2,3,4, AND 5
		M4A2 (WHITE BAG)
3W	297	BASE SECTION 3
4W	337	BASE AND INCREMENT 4
5W	397	BASE AND INCREMENTS 4 AND 5
6W	474	BASE AND INCREMENTS 4, 5, AND 6
7W	568	BASE AND INCREMENTS 4,5,6, AND 7
		M119A1
8	684	BASE SECTION 8

Figure 2-7. Part 1.

1) Table A, Line Number. Table A is entered in the left column, with quadrant elevation to a target. From the right column, the line number of the meteorological message is extracted. The ballistic met message divides the atmosphere into zones that are "stacked" on top of each other. Table A (Figure 2-8) translates the height of the zones' lower and upper boundaries into the quadrant elevations. These quadrant elevations (if fired under standard conditions) cause the summit of the trajectory to be at the boundary of the zone. By entering with the adjusted quadrant between listed values; table A shows the highest zone through which the trajectory passed.



FT 155-AM-2 TABLE A CHARGE 4G

PROJ, HE, M107 LINE NUMBER
FUZE, PD, M557

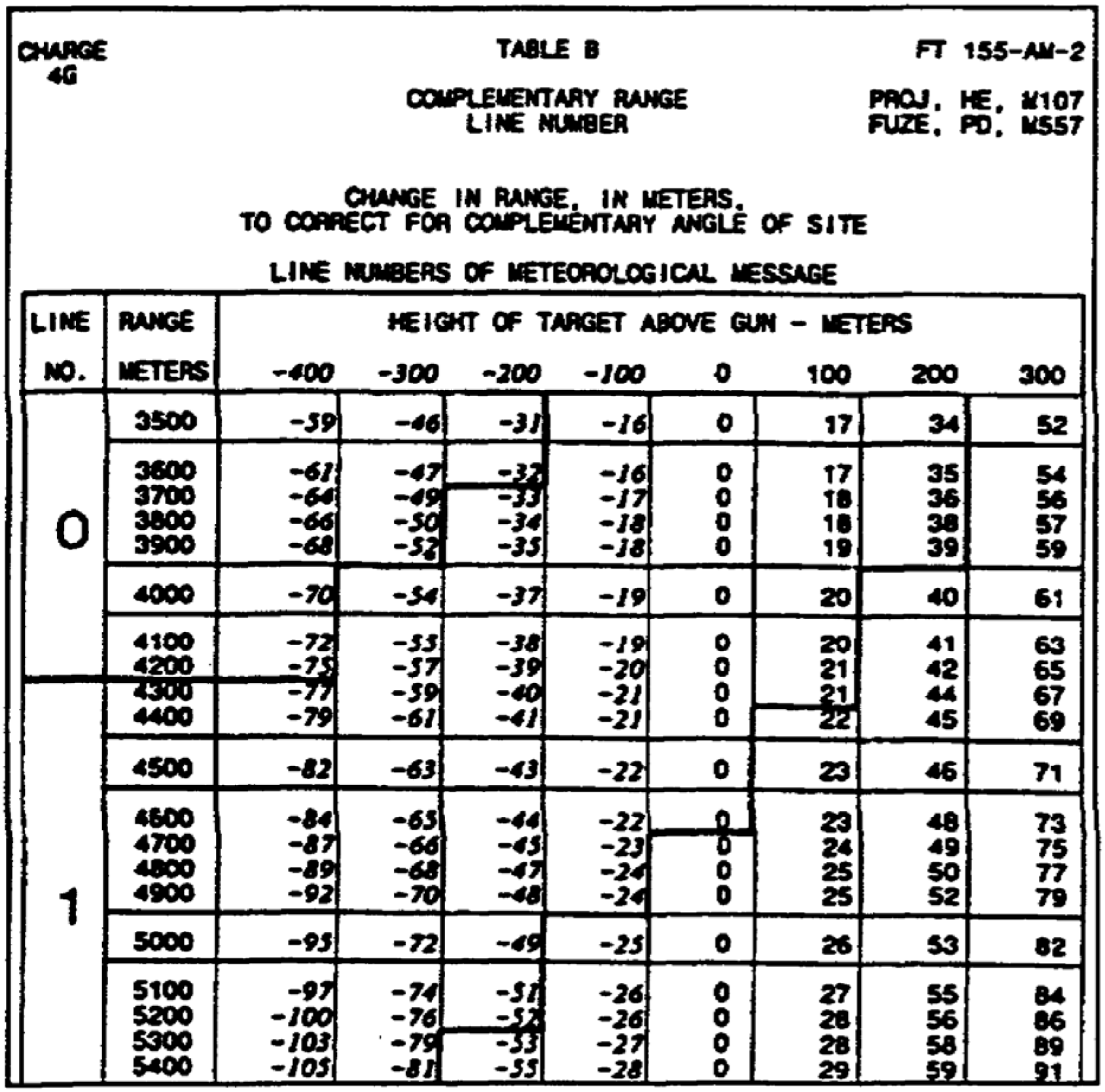
LINE NUMBERTS OF METEOROLOGICAL MESSAGE

QUADRANT ELEVATION MILS	LINE NUMBER
0.0 - 146.3	0
146.4 - 280.2	1
280.3 - 421.8	2
421.9 - 561.9	3
562.0 - 686.1	4
686.2 - 863.6	5
863.7 - 1119.8	6
1119.9- 1300.0	7

NOTE - WHEN THE PROJECTILE MUST HIT THE TARGET ON THE ASCENDING BRANCH OF ITS TRAJECTORY, USE HEIGHT OF TARGET IN METERS TO ENTER THE TABLE ON PAGE XXIV TO DETERMINE LINE NUMBER.

Figure 2-8. Table A.

2) Table B, Complementary Range Line Number. Table B is entered from the range column along the left side, with the chart range to a target expressed to the nearest 100 meters. The top of the table with the height of target above gun (vertical interval) is expressed to the nearest 100 meters (cross indexing, complementary range is extracted). The complementary range is the number of meters of range correction that corresponds to the complementary angle of site. The range correction is measured at the base of the trajectory. The sum of the complementary range and the chart range, expressed to the nearest 10 meters, equals the entry range, which is the most accurate range for entry into Table F, to extract firing data and range corrections. Another use of Table B is to determine the line number from the ballistic MET message for use in subsequent met applications. The table is divided by heavy black lines. These lines form the boundaries of which the complementary range is extracted to the outer edge of the table. The bold number in the margin is the MET line number (Figure 2-9).



CHARGE
4G

TABLE B

COMPLEMENTARY RANGE
LINE NUMBER

FT 155-AM-2

PROJ. HE. M107
FUZE. PD. M557

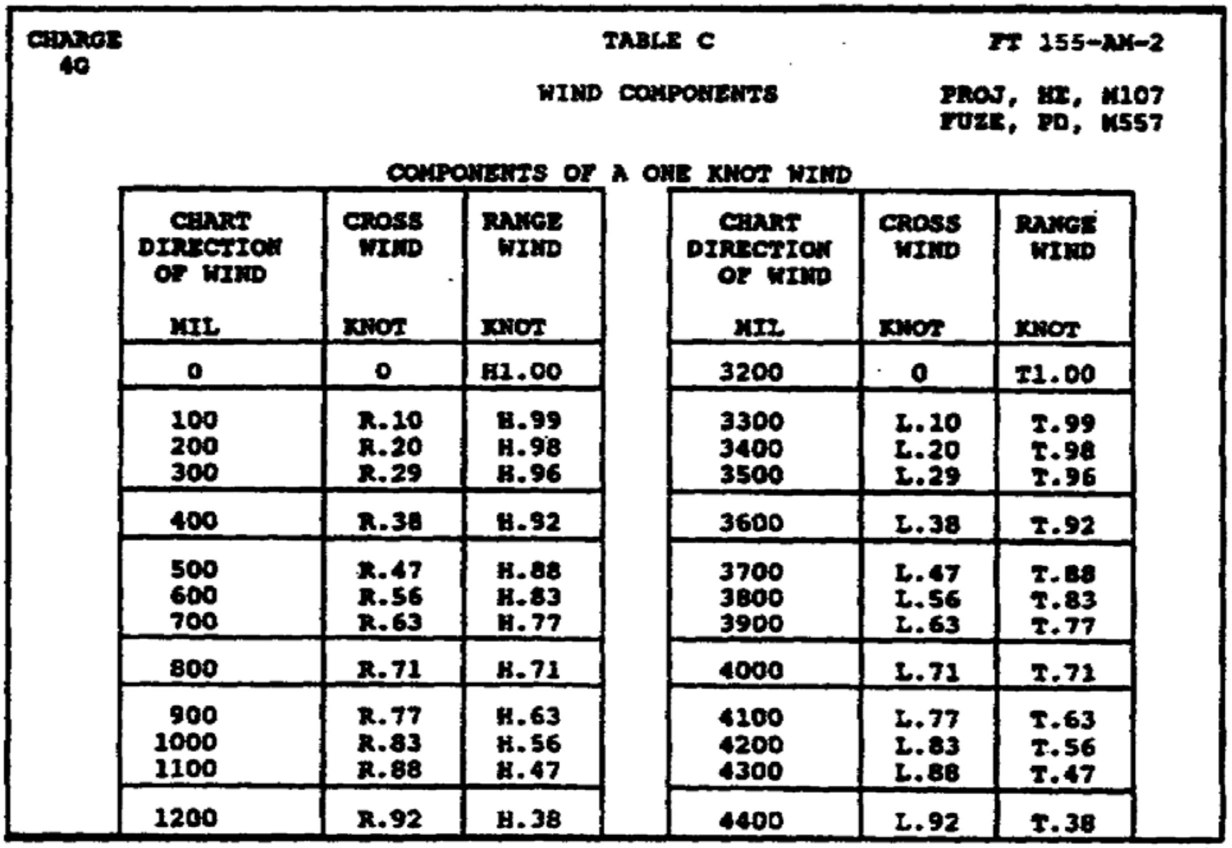
CHANGE IN RANGE, IN METERS.
TO CORRECT FOR COMPLEMENTARY ANGLE OF SITE

LINE NUMBERS OF METEOROLOGICAL MESSAGE

LINE	RANGE	HEIGHT OF TARGET ABOVE GUN - METERS							
NO.	METERS	-400	-300	-200	-100	0	100	200	300
0	3500	-59	-46	-31	-16	0	17	34	52
	3600	-61	-47	-32	-16	0	17	35	54
	3700	-64	-49	-33	-17	0	18	36	56
	3800	-66	-50	-34	-18	0	18	38	57
	3900	-68	-52	-35	-18	0	19	39	59
	4000	-70	-54	-37	-19	0	20	40	61
	4100	-72	-55	-38	-19	0	20	41	63
	4200	-75	-57	-39	-20	0	21	42	65
1	4300	-77	-59	-40	-21	0	21	44	67
	4400	-79	-61	-41	-21	0	22	45	69
	4500	-82	-63	-43	-22	0	23	46	71
	4600	-84	-65	-44	-22	0	23	48	73
	4700	-87	-66	-45	-23	0	24	49	75
	4800	-89	-68	-47	-24	0	25	50	77
	4900	-92	-70	-48	-24	0	25	52	79
	5000	-95	-72	-49	-25	0	26	53	82
	5100	-97	-74	-51	-26	0	27	55	84
	5200	-100	-76	-52	-26	0	28	56	86
	5300	-103	-79	-53	-27	0	28	58	89
	5400	-105	-81	-55	-28	0	29	59	91

Figure 2-9. Table B.

3) Table C, Wind Components is entered with the chart direction of wind. The extracted values are described as the components of a one knot wind. This table vectors the winds force into its effects on the projectile with regard to cross wind and range wind. The chart direction of wind is the angle formed by the intersection of the direction of the wind from the met message and the direction of fire. The range wind component is the percentage of the wind speed that acted as a range factor. The cross wind component is the percentage of the wind's force that acts to blow the projectile laterally and is translated into a lateral correction factor (Table C is based on chart direction of wind and thus is the same for all charges and all weapons) Figure 2-10.



CHARGE
4G

TABLE C

FT 155-AM-2

WIND COMPONENTS

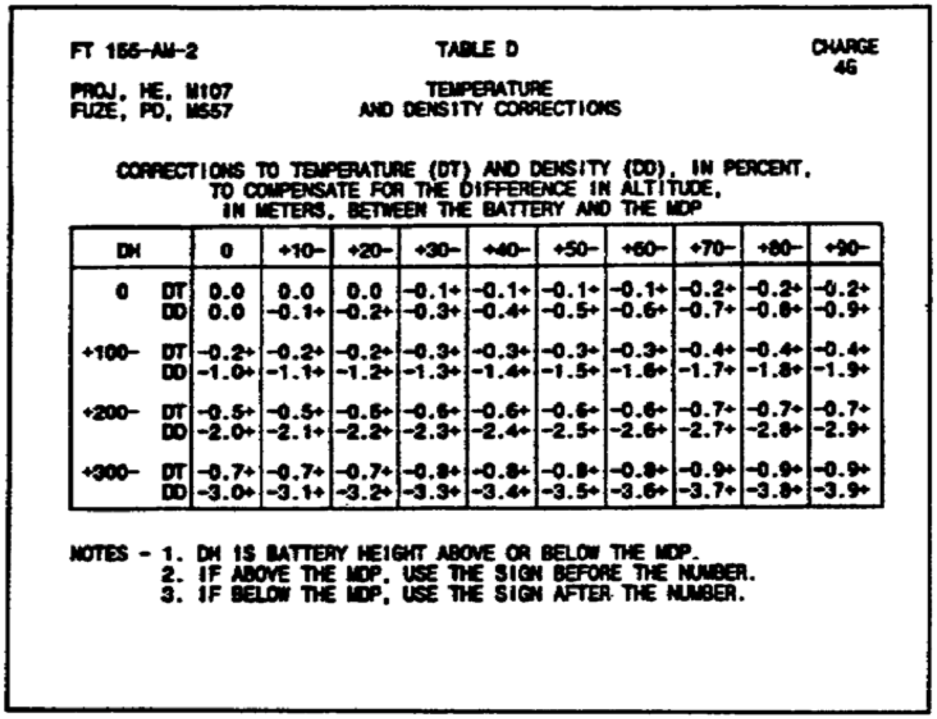
PROJ, HE, M107
FUZE, PD, M557

COMPONENTS OF A ONE KNOT WIND

CHART DIRECTION OF WIND MIL	CROSS WIND KNOT	RANGE WIND KNOT	CHART DIRECTION OF WIND MIL	CROSS WIND KNOT	RANGE WIND KNOT
0	0	H1.00	3200	0	T1.00
100	R.10	H.99	3300	L.10	T.99
200	R.20	H.98	3400	L.20	T.98
300	R.29	H.96	3500	L.29	T.96
400	R.38	H.92	3600	L.38	T.92
500	R.47	H.88	3700	L.47	T.88
600	R.56	H.83	3800	L.56	T.83
700	R.63	H.77	3900	L.63	T.77
800	R.71	H.71	4000	L.71	T.71
900	R.77	H.63	4100	L.77	T.63
1000	R.83	H.56	4200	L.83	T.56
1100	R.88	H.47	4300	L.88	T.47
1200	R.92	H.38	4400	L.92	T.38

Figure 2-10. Table C.

4) Table D, Temperature and Density Corrections is entered with the height of the battery above or below the meteorological datum plane (MDP) or met station. The difference in height is entered on the left side in hundreds of meters, and along the top of the table in tens of meters. By cross indexing, the corrections to the density and temperature are extracted. This table provides a correction based on a standard departure, to correct the temperature and density in the message (which is measured at altitudes beginning at the MDP) to values as they would be if measured initially from the battery altitude (Figure 2-11).



FT 155-AM-2

TABLE D

CHARGE
4G

PROJ, HE, M107
FUZE, PD, M557

TEMPERATURE
AND DENSITY CORRECTIONS

CORRECTIONS TO TEMPERATURE (DT) AND DENSITY (DD), IN PERCENT,
TO COMPENSATE FOR THE DIFFERENCE IN ALTITUDE,
IN METERS, BETWEEN THE BATTERY AND THE MDP

DH		0	+10-	+20-	+30-	+40-	+50-	+60-	+70-	+80-	+90-
0	DT	0.0	0.0	0.0	-0.1+	-0.1+	-0.1+	-0.1+	-0.2+	-0.2+	-0.2+
	DD	0.0	-0.1+	-0.2+	-0.3+	-0.4+	-0.5+	-0.6+	-0.7+	-0.8+	-0.9+
+100-	DT	-0.2+	-0.2+	-0.2+	-0.3+	-0.3+	-0.3+	-0.3+	-0.4+	-0.4+	-0.4+
	DD	-1.0+	-1.1+	-1.2+	-1.3+	-1.4+	-1.5+	-1.6+	-1.7+	-1.8+	-1.9+
+200-	DT	-0.5+	-0.5+	-0.6+	-0.6+	-0.6+	-0.6+	-0.6+	-0.7+	-0.7+	-0.7+
	DD	-2.0+	-2.1+	-2.2+	-2.3+	-2.4+	-2.5+	-2.6+	-2.7+	-2.8+	-2.9+
+300-	DT	-0.7+	-0.7+	-0.7+	-0.8+	-0.8+	-0.8+	-0.8+	-0.9+	-0.9+	-0.9+
	DD	-3.0+	-3.1+	-3.2+	-3.3+	-3.4+	-3.5+	-3.6+	-3.7+	-3.8+	-3.9+

NOTES - 1. DH IS BATTERY HEIGHT ABOVE OR BELOW THE MDP.
2. IF ABOVE THE MDP, USE THE SIGN BEFORE THE NUMBER.
3. IF BELOW THE MDP, USE THE SIGN AFTER THE NUMBER.

Figure 2-11. Table D.

5) Table E, Propellant Temperature is entered with the temperature of the propellant in degrees fahrenheit (left column) or celsius (right column). A correction in meters per second is extracted from the center column. This is the change in muzzle velocity due to the temperature of the propellant (Figure 2-12).

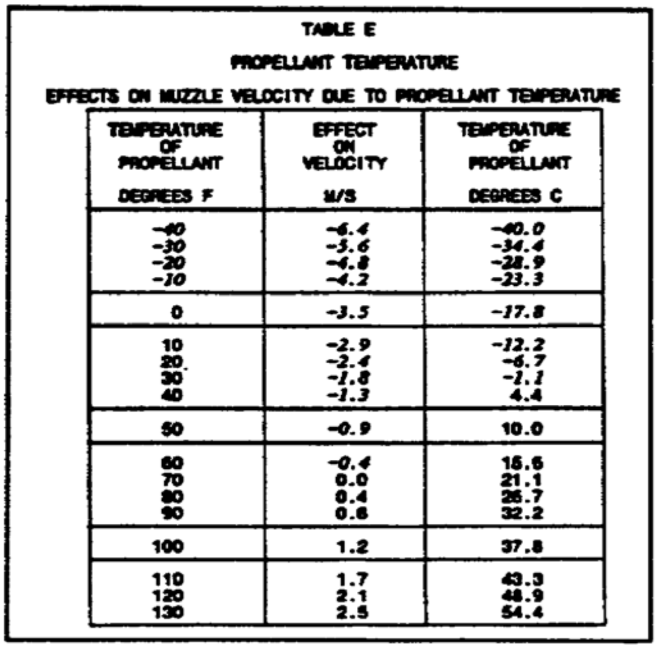


TABLE E

PROPELLANT TEMPERATURE

EFFECTS ON MUZZLE VELOCITY DUE TO PROPELLANT TEMPERATURE

TEMPERATURE OF PROPELLANT DEGREES F	EFFECT ON VELOCITY M/S	TEMPERATURE OF PROPELLANT DEGREES C
-40	-6.4	-40.0
-30	-5.6	-34.4
-20	-4.8	-28.9
-10	-4.2	-23.3
0	-3.5	-17.8
10	-2.9	-12.2
20	-2.4	-6.7
30	-1.8	-1.1
40	-1.3	4.4
50	-0.9	10.0
60	-0.4	15.6
70	0.0	21.1
80	0.4	26.7
90	0.8	32.2
100	1.2	37.8
110	1.7	43.3
120	2.1	48.9
130	2.5	54.4

Figure 2-12. Table E.

6) Table F, Ground Data and Correction Factors. Table F is comprised of 19 columns. Columns 2 through 8 provide information for the computation of basic firing data. The remaining columns provide corrections to range and deflection for non-standard conditions (Figures 2-13 & 2-13A).

- COLUMN 1. RANGE - the straight line distance measured from the battery to the target.

- COLUMN 2. ELEVATION - the angle the tube must be elevated from the horizontal to cause the round to reach the ranges listed in column 1.

- COLUM 3. FS FOR A GRAZE BURST - the increments of fuze settings to cause the fuze to function on the ground at the given range under standard conditions.

- COLUMN 4. DFS PER 10 M DEC HOB - the change that must be applied to fuze setting to cause a 10 meter change in HOB for fuze time.

- COLUMN 5. DR PER 1 MIL D ELEV - the number of meters change in the range from column 1 (along the gun target line) that would result from a 1 mil change to the elevation listed in column 2.

- COLUMN 6. FORK - the change in elevation necessary to move the mean point of impact four probable errors for a specific charge and range.

- COLUMN 7. TIME OF FLIGHT - the number of seconds (real time) necessary for the round to travel from the muzzle to the level point at the given elevation.

- COLUMN 8. AZIMUTH CORRECTION FOR DRIFT - the number of mils that must be added to deflection to compensate for the rightward drift of the projectile.

- COLUMN 9. AZIMUTH CORRECTION FOR A CROSS WIND OF 1 KNOT - the correction, (in mils) necessary to correct for a 1 knot cross wind. The correction is made into the wind.

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TABLE F

BASIC DATA

FT 155-AM-2

PROJ, HE, M109
FUZE, PD, M557

1	2	3	4	5	6	7	8	9
RANGE	ELEV	FS FOR GRAZE BURST FUZE M564	DFS PER 10 M DEC HOB	DR PER 1 MIL DEC ELEV	FORK	TIME OF FLIGHT	AZIMUTH CORRECTION DRIFT (CORR TO L)	CW OF 1KNOT
M	MIL			M	MIL	SEC	MIL	MIL
0	0.0			20	1	0.0	0.0	0.00
100	5.1			20	1	0.3	0.0	0.01
200	10.1			20	1	0.6	0.0	0.01
300	15.2			20	1	1.0	0.1	0.01
400	20.3			20	1	1.3	0.1	0.02
500	25.4			19	1	1.6	0.2	0.02
600	30.6	1.9	1.06	19	1	1.9	0.3	0.03
700	35.8	2.2	0.91	19	1	2.3	0.4	0.03
800	41.1	2.5	0.79	19	1	2.6	0.5	0.04
900	46.4	2.8	0.71	19	1	2.9	0.6	0.04
1000	51.7	3.2	0.63	19	1	3.2	0.7	0.04
1100	57.1	3.5	0.57	19	1	3.6	0.8	0.05
1200	62.5	3.8	0.53	18	1	3.9	0.8	0.05
1300	67.9	4.2	0.48	18	1	4.3	0.9	0.05
1400	73.4	4.5	0.45	18	1	4.6	1.0	0.06
1500	78.9	4.9	0.42	18	1	4.9	1.1	0.06
1600	84.4	5.2	0.39	18	2	5.3	1.2	0.07
1700	90.0	5.5	0.37	18	2	5.6	1.3	0.07
1800	95.6	5.9	0.35	18	2	6.0	1.4	0.07
1900	101.3	6.2	0.33	18	2	6.3	1.6	0.08
2000	107.0	6.6	0.31	17	2	6.7	1.7	0.08
2100	112.8	6.9	0.30	17	2	7.0	1.8	0.08
2200	118.6	7.3	0.28	17	2	7.4	1.9	0.09
2300	124.4	7.6	0.27	17	2	7.7	2.0	0.09
2400	130.3	8.0	0.26	17	2	8.1	2.1	0.09
2500	136.2	8.3	0.25	17	2	8.4	2.2	0.10
2600	142.2	8.7	0.24	17	2	8.8	2.3	0.10
2700	148.2	9.1	0.23	17	2	9.2	2.5	0.10

Figure 2-13. Table F, Columns 1 - 9.

- COLUMN 10. CORRECTION FOR A 1 M/S DEC IN MUZZLE VELOCITY - the correction to range to compensate for a decrease in muzzle velocity of 1 m/s.

- COLUMN 11. CORRECTION FOR A 1 M/S INC IN MUZZLE VELOCITY - the correction to range to compensate for an increase in muzzle velocity of 1 m/s.

- COLUMN 12. CORRECTION FOR A HEAD WIND OF 1 KNOT - the correction to range to compensate for a head wind of 1 knot.

- COLUMN 13. CORRECTION FOR TAIL WIND OF 1 KNOT - the correction to range to compensate for a tail wind of 1 knot.

- COLUMN 14. CORRECTION FOR A 1% DEC IN AIR TEMP - the correction to range to compensate for a decrease of 1% of standard.

- COLUMN 15. CORRECTION FOR A 1% INC IN AIR TEMP- the correction to range to compensate for an increase of 1% of standard.

- COLUMN 16. CORRECTION FOR A 1% DEC IN AIR DENSITY - the correction to range to compensate for a decrease in air density of 1% of standard.

- COLUMN 17. CORRECTION FOR 1% INC IN AIR DENSITY - the correction to range to compensate for an increase in air density of 1%t of standard.

- COLUMN 18. CORRECTION FOR A 1 SQ DEC IN PROJ WT - the correction to range to compensate for a decrease of one square in projectile weight.

- COLUMN 19. CORRECTION FOR A 1 SQ INC IN PROJ WT - the correction to range to compensate for a increase of one square in projectile weight.

FT 155-AM-2
TABLE F
CHARGE 4G

PROJ, HE, M107
CORRECTION FACTORS
FUZE, PD, M557

1	10	11	12	13	14	15	16	17	18	19
RANGE	RANGE CORRECTIONS FOR									
	MUZZLE VELOCITY 1 M/S		RANGE WIND 1 KNOT		AIR TEMP 1 PCT		AIR DENSITY 1 PCT		PROJ WT OF 1 SQ 4 SQ STD	
	DEC	INC	HEAD	TAIL	DEC	INC	DEC	INC	DEC	INC
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
100	0.6	−0.6	0.0	0.0	0.0	0.0	0.0	0.0	−1	1
200	1.3	−1.2	0.0	0.0	0.1	−0.1	0.0	0.0	−2	2
300	1.9	−1.7	0.1	0.0	0.2	−0.1	0.0	0.0	−3	3
400	2.5	−2.2	0.1	−0.1	0.3	−0.2	−0.1	0.1	−4	4
500	3.1	−2.7	0.2	−0.1	0.5	−0.2	−0.1	0.1	−5	5
600	3.6	−3.2	0.3	−0.1	0.6	−0.3	−0.1	0.1	−6	6
700	4.2	−3.7	0.4	−0.2	0.9	−0.4	−0.2	0.2	−7	7
800	4.7	−4.1	0.5	−0.2	1.1	−0.5	−0.2	0.2	−7	8
900	5.3	−4.5	0.6	−0.2	1.4	−0.6	−0.3	0.3	−8	8
1000	5.8	−5.0	0.7	−0.3	1.7	−0.8	−0.3	0.3	−9	9
1100	6.3	−5.4	0.8	−0.3	2.0	−0.9	−0.4	0.4	−10	10
1200	6.8	−5.8	0.9	−0.4	2.3	−1.0	−0.4	0.4	−10	11
1300	7.3	−6.2	1.1	−0.4	2.6	−1.1	−0.5	0.5	−11	11
1400	7.9	−6.6	1.2	−0.5	2.9	−1.3	−0.6	0.6	−11	12
1500	8.4	−7.0	1.4	−0.5	3.3	−1.4	−0.7	0.6	−13	13
1600	8.8	−7.3	1.5	−0.6	3.6	−1.6	−0.7	0.7	−13	14
1700	9.3	−7.7	1.7	−0.6	4.0	−1.7	−0.8	0.8	−14	14
1800	9.8	−8.1	1.8	−0.7	4.4	−1.8	−0.9	0.9	−14	15
1900	10.3	−8.4	2.0	−0.8	4.7	−2.0	−1.0	1.0	−15	16
2000	10.8	−8.8	2.2	−0.8	5.1	−2.1	−1.1	1.1	−16	16
2100	11.3	−9.2	2.3	−0.9	5.5	−2.3	−1.2	1.2	−16	17
2200	11.7	−9.5	2.5	−1.0	5.8	−2.4	−1.3	2.3	−17	17
2300	12.2	−9.9	2.7	−1.0	6.2	−2.6	−1.4	1.4	−17	18
2400	12.7	−10.2	2.8	−1.1	6.6	−2.7	−1.5	1.5	−18	19
2500	13.1	−10.6	3.0	−1.2	6.9	−2.9	−1.7	1.6	−19	19
2600	13.6	−10.9	3.2	−1.3	7.3	−3.0	−1.8	1.8	−19	20
2700	14.1	−11.3	3.4	−1.3	7.6	−3.2	−1.9	1.9	−20	20

Figure 2-13A. Table F, Columns 10 - 19

7) Table G, Supplementary Data. A table of supplementary data containing probable error information and certain trajectory elements (Figure 2-14).

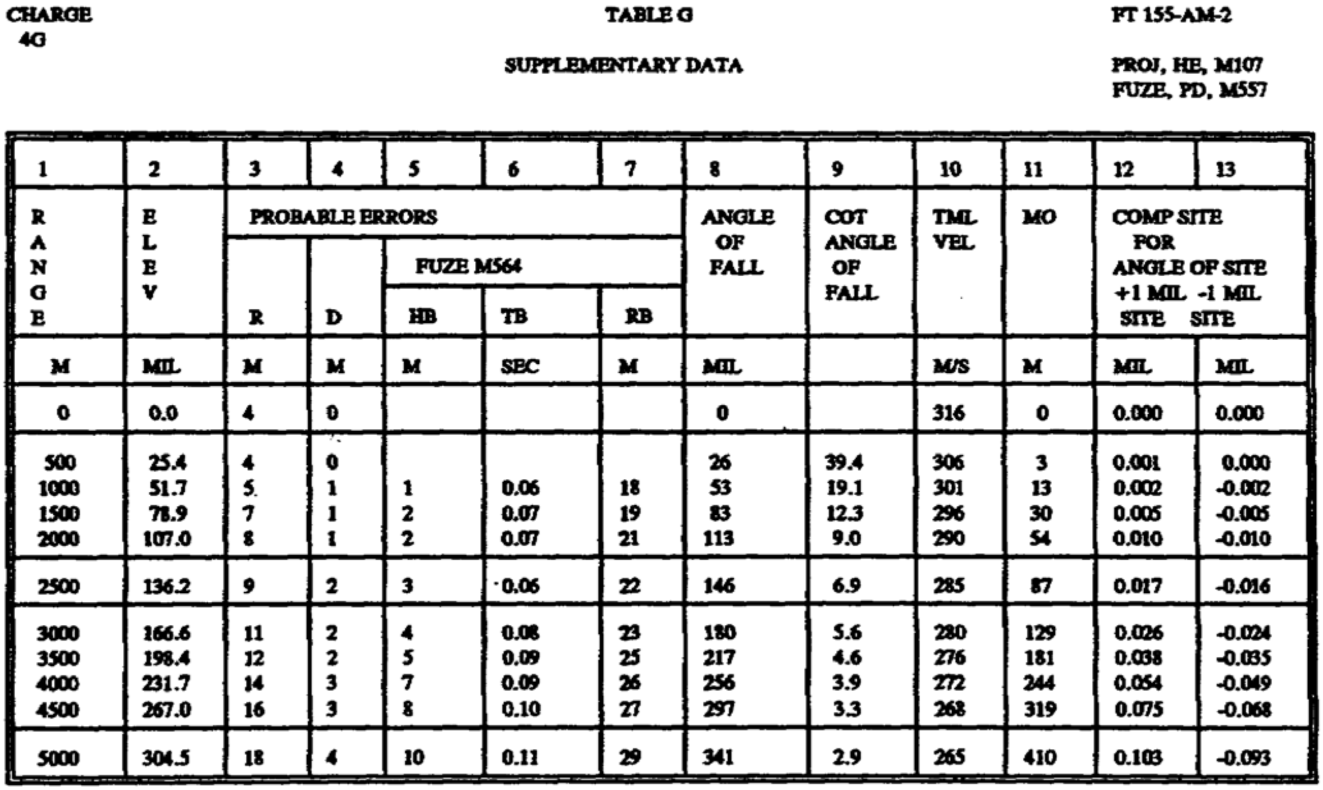
- COLUMN 1. RANGE - the horizontal distance measured from the battery to the target.
- COLUMN 2. ELEVATION - the angle the cannon tube must be elevated from level to cause the round to reach the ranges listed in column 1.
- COLUMN 3. PROBABLE ERROR R - This value, when added to and subtracted from the range, will produce an interval that should contain 50 percent of all rounds fired.
- COLUMN 4. PROBABLE ERROR D - the number of meters left or right of the direction of fire at the given range that may be expected to contain 25% of the bursting rounds. This is a measure of the inherent inaccuracy of the weapon.
- COLUMN 5. PROBABLE ERROR HB - the number of meters that, when added or subtracted from the HOB, may be expected to contain 25% of the bursting rounds. This is a measure of the inherent inaccuracy of the weapon.
- COLUMN 6. PROBABLE ERROR TB - the number of increments of fuze setting when, added or subtracted from the fuze setting fired, may be expected to contain 25% of the bursting rounds. This is a measure of the inherent inaccuracy of the fuze for which data is tabulated and weapon.
- COLUMN 7. PROBABLE ERROR RB - the number of meters that the range may be expected to change for a change of 1 probable error in fuze setting. This is a measure of the inherent inaccuracy of the fuze and weapon.
- COLUMN 8. ANGLE OF FALL - the value (in mils) of the angle formed by the base of the trajectory and line tangent to the trajectory at the level point.
- COLUMN 9. COT ANGLE OF FALL - the trigonometric function of the angle of fall. When the probable error in range is divided by this factor, the quotient is the vertical probable error - the number of meters above or below the center of impact that may be expected to contain 25% of the impacts when firing into a vertical face.

- COLUMN 10. TML VEL - the velocity (speed) of the projectile at the level point under standard conditions.

- COLUMN 11. MO - maximum ordinate, the highest point along the trajectory of a projectile. The difference in altitude between the origin and the summit.

- COLUMN 12. COMP SITE FOR ANGLE OF SITE +1 SITE - the value of the complementary angle of site for every +1 mil of angle of site. When this factor is multiplied by the absolute value of the angle of site, the product is the complementary angle of site.

- COLUMN 13. COMP SITE FOR ANGLE OF SITE -1 SITE - the value of the complementary angle of site for every -1 mil of angle of site. When this factor is multiplied by the absolute value of the angle of site, the product is the complementary angle of site.



CHARGE
4G

TABLE G

SUPPLEMENTARY DATA

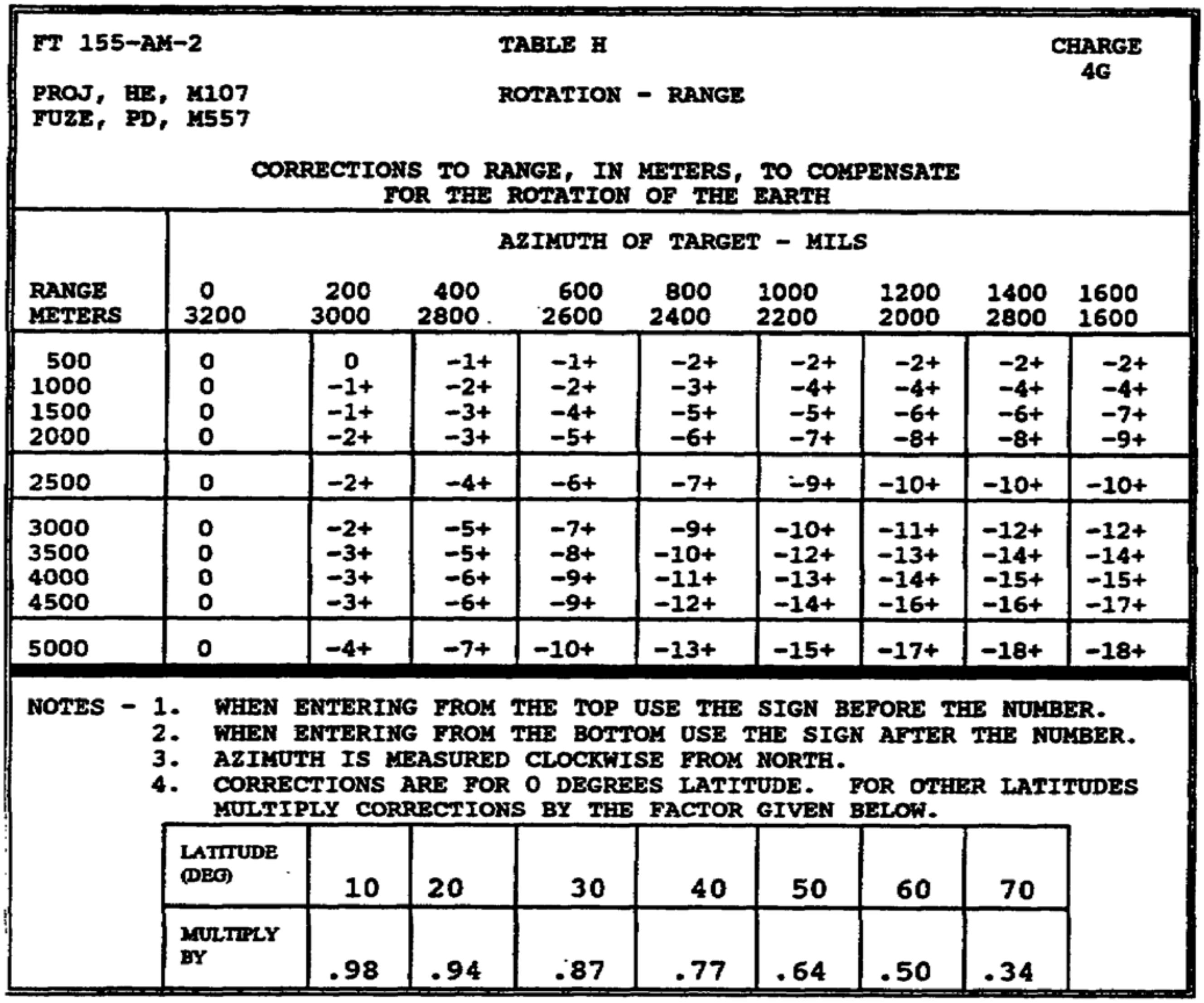
FT 155-AM-2

PROJ, HE, M107
FUZE, PD, M557

1	2	3	4	5	6	7	8	9	10	11	12	13
RANGE	ELEV	PROBABLE ERRORS					ANGLE OF FALL	COT ANGLE OF FALL	TML VEL	MO	COMP SITE FOR ANGLE OF SITE	
				FUZE M564							+1 MIL SITE	-1 MIL SITE
		R	D	HB	TB	RB						
M	MIL	M	M	M	SEC	M	MIL		M/S	M	MIL	MIL
0	0.0	4	0				0		316	0	0.000	0.000
500	25.4	4	0				26	39.4	306	3	0.001	0.000
1000	51.7	5	1	1	0.06	18	53	19.1	301	13	0.002	-0.002
1500	78.9	7	1	2	0.07	19	83	12.3	296	30	0.005	-0.005
2000	107.0	8	1	2	0.07	21	113	9.0	290	54	0.010	-0.010
2500	136.2	9	2	3	0.06	22	146	6.9	285	87	0.017	-0.016
3000	166.6	11	2	4	0.08	23	180	5.6	280	129	0.026	-0.024
3500	198.4	12	2	5	0.09	25	217	4.6	276	181	0.038	-0.035
4000	231.7	14	3	7	0.09	26	256	3.9	272	244	0.054	-0.049
4500	267.0	16	3	8	0.10	27	297	3.3	268	319	0.075	-0.068
5000	304.5	18	4	10	0.11	29	341	2.9	265	410	0.103	-0.093

Figure 2-14. Table G.

8) Table H, rotation (corrections to range) is entered along the left side with the entry range expressed to the nearest listed value., and along the top with the azimuth to the target (direction of fire) to the nearest listed value. The extracted value, is the correction to range, in meters, for the rotation of the earth at 0 degrees latitude. A correction for any other latitude is extracted from the from Table H, and must be multiplied by the correction factor from the table located at the bottom of Table H (Figure 2-15).



FT 155-AM-2 TABLE H CHARGE 4G

PROJ, HE, M107 ROTATION - RANGE
FUZE, PD, M557

CORRECTIONS TO RANGE, IN METERS, TO COMPENSATE
FOR THE ROTATION OF THE EARTH

RANGE METERS	AZIMUTH OF TARGET - MILS								
	0 3200	200 3000	400 2800	600 2600	800 2400	1000 2200	1200 2000	1400 2800	1600 1600
500	0	0	-1+	-1+	-2+	-2+	-2+	-2+	-2+
1000	0	-1+	-2+	-2+	-3+	-4+	-4+	-4+	-4+
1500	0	-1+	-3+	-4+	-5+	-5+	-6+	-6+	-7+
2000	0	-2+	-3+	-5+	-6+	-7+	-8+	-8+	-9+
2500	0	-2+	-4+	-6+	-7+	-9+	-10+	-10+	-10+
3000	0	-2+	-5+	-7+	-9+	-10+	-11+	-12+	-12+
3500	0	-3+	-5+	-8+	-10+	-12+	-13+	-14+	-14+
4000	0	-3+	-6+	-9+	-11+	-13+	-14+	-15+	-15+
4500	0	-3+	-6+	-9+	-12+	-14+	-16+	-16+	-17+
5000	0	-4+	-7+	-10+	-13+	-15+	-17+	-18+	-18+

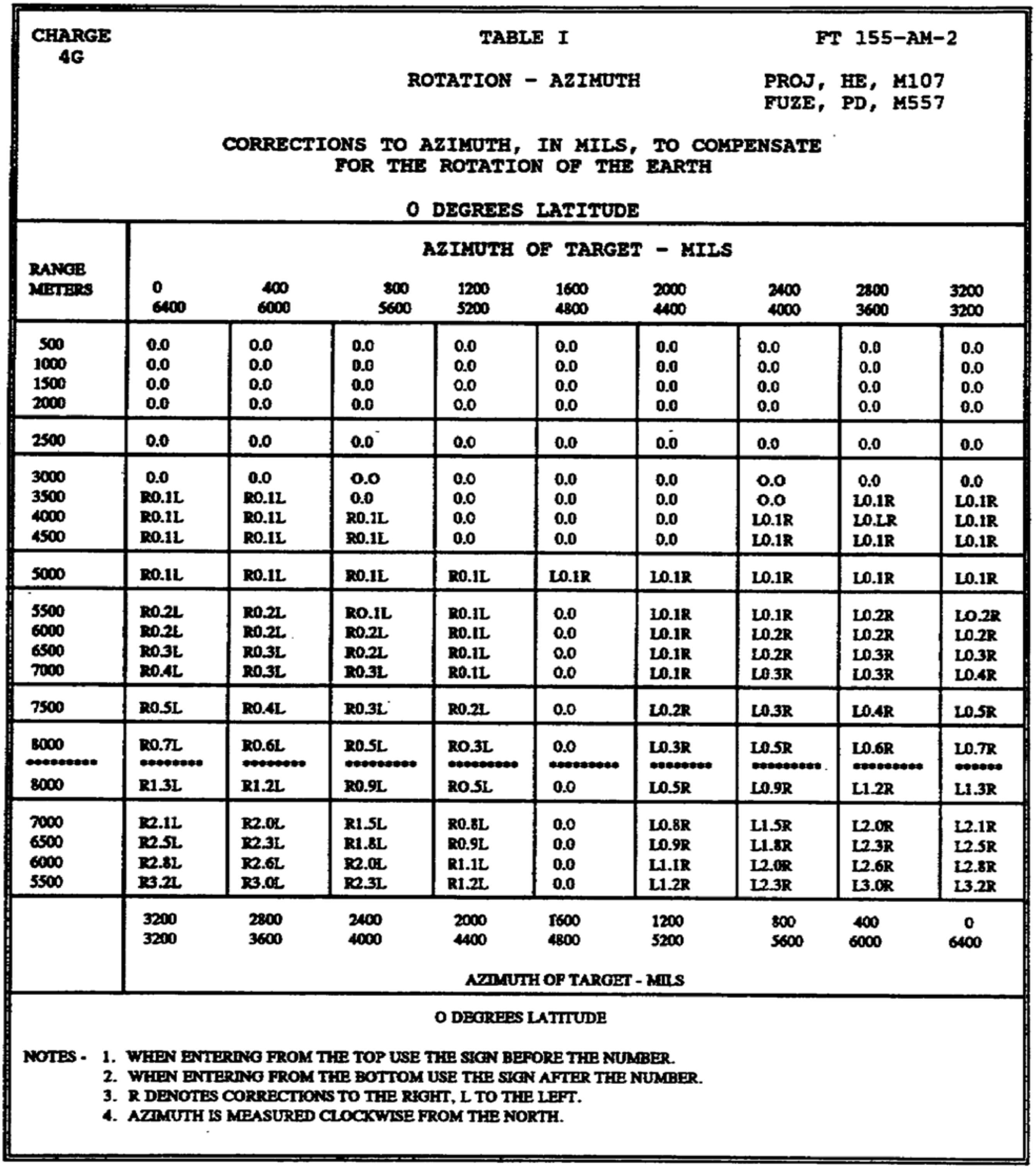
NOTES - 1. WHEN ENTERING FROM THE TOP USE THE SIGN BEFORE THE NUMBER.
2. WHEN ENTERING FROM THE BOTTOM USE THE SIGN AFTER THE NUMBER.
3. AZIMUTH IS MEASURED CLOCKWISE FROM NORTH.
4. CORRECTIONS ARE FOR 0 DEGREES LATITUDE. FOR OTHER LATITUDES MULTIPLY CORRECTIONS BY THE FACTOR GIVEN BELOW.

LATITUDE (DEG)	10	20	30	40	50	60	70
MULTIPLY BY	.98	.94	.87	.77	.64	.50	.34

Figure 2-15. Table H.

9) Table I, rotation (correction to azimuth) is entered along the left side with the entry range expressed to the nearest listed value, and along the top with the azimuth to the target (direction of fire) to the nearest listed value. The extracted value is the correction to deflection in mils, for the rotation of the earth. The table is produced in a series for

latitudes from 0 to 70 degrees latitude at 10 degree intervals (Figure 2-16).



CHARGE 4G

TABLE I

FT 155-AM-2

ROTATION - AZIMUTH

PROJ, HE, M107
FUZE, PD, M557

CORRECTIONS TO AZIMUTH, IN MILS, TO COMPENSATE FOR THE ROTATION OF THE EARTH

0 DEGREES LATITUDE

RANGE METERS	AZIMUTH OF TARGET - MILS								
	0 6400	400 6000	800 5600	1200 5200	1600 4800	2000 4400	2400 4000	2800 3600	3200 3200
500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3500	R0.1L	R0.1L	0.0	0.0	0.0	0.0	0.0	L0.1R	L0.1R
4000	R0.1L	R0.1L	R0.1L	0.0	0.0	0.0	L0.1R	L0.LR	L0.1R
4500	R0.1L	R0.1L	R0.1L	0.0	0.0	0.0	L0.1R	L0.1R	L0.1R
5000	R0.1L	R0.1L	R0.1L	R0.1L	L0.1R	L0.1R	L0.1R	L0.1R	L0.1R
5500	R0.2L	R0.2L	R0.1L	R0.1L	0.0	L0.1R	L0.1R	L0.2R	L0.2R
6000	R0.2L	R0.2L	R0.2L	R0.1L	0.0	L0.1R	L0.2R	L0.2R	L0.2R
6500	R0.3L	R0.3L	R0.2L	R0.1L	0.0	L0.1R	L0.2R	L0.3R	L0.3R
7000	R0.4L	R0.3L	R0.3L	R0.1L	0.0	L0.1R	L0.3R	L0.3R	L0.4R
7500	R0.5L	R0.4L	R0.3L	R0.2L	0.0	L0.2R	L0.3R	L0.4R	L0.5R
8000	R0.7L	R0.6L	R0.5L	R0.3L	0.0	L0.3R	L0.5R	L0.6R	L0.7R
•••••••••	••••••••	••••••••	•••••••••	•••••••••	•••••••••	••••••••	•••••••••	•••••••••	••••••
8000	R1.3L	R1.2L	R0.9L	R0.5L	0.0	L0.5R	L0.9R	L1.2R	L1.3R
7000	R2.1L	R2.0L	R1.5L	R0.8L	0.0	L0.8R	L1.5R	L2.0R	L2.1R
6500	R2.5L	R2.3L	R1.8L	R0.9L	0.0	L0.9R	L1.8R	L2.3R	L2.5R
6000	R2.8L	R2.6L	R2.0L	R1.1L	0.0	L1.1R	L2.0R	L2.6R	L2.8R
5500	R3.2L	R3.0L	R2.3L	R1.2L	0.0	L1.2R	L2.3R	L3.0R	L3.2R
	3200 3200	2800 3600	2400 4000	2000 4400	1600 4800	1200 5200	800 5600	400 6000	0 6400

AZIMUTH OF TARGET - MILS

0 DEGREES LATITUDE

NOTES -
1. WHEN ENTERING FROM THE TOP USE THE SIGN BEFORE THE NUMBER.
2. WHEN ENTERING FROM THE BOTTOM USE THE SIGN AFTER THE NUMBER.
3. R DENOTES CORRECTIONS TO THE RIGHT, L TO THE LEFT.
4. AZIMUTH IS MEASURED CLOCKWISE FROM THE NORTH.

Figure 2-16. Table I.

10) Table J, Fuze Setting (FS) factors - provides corrections to fuze setting for nonstandard conditions (Figure 2-17).

- COLUMN 1. FUZE SETTING - the FS corresponding to adjusted elevation, expressed to the nearest whole increment.

- COLUMN 2. CORRECTIONS FOR A 1 M/S DEC IN MUZZLE VELOCITY - the correction to FS to compensate for a decrease in muzzle velocity of 1 m/s.

- COLUMN 3. CORRECTIONS FOR A 1 M/S INC IN MUZZLE VELOCITY - the correction to FS to compensate for an increase in muzzle velocity of 1 m/s.

- COLUMN 4. CORRECTION FOR A HEAD WIND OF 1 KNOT - the correction to FS to compensate for a head wind of 1 knot.

- COLUMN 5. -CORRECTION FOR A TAIL WIND OF 1 KNOT - the correction to FS to compensate for a tail wind of 1 Knot.

- COLUMN 6. CORRECTION FOR A 1% DEC IN AIR TEMP - the correction to FS to compensate for a decrease of 1% of standard.

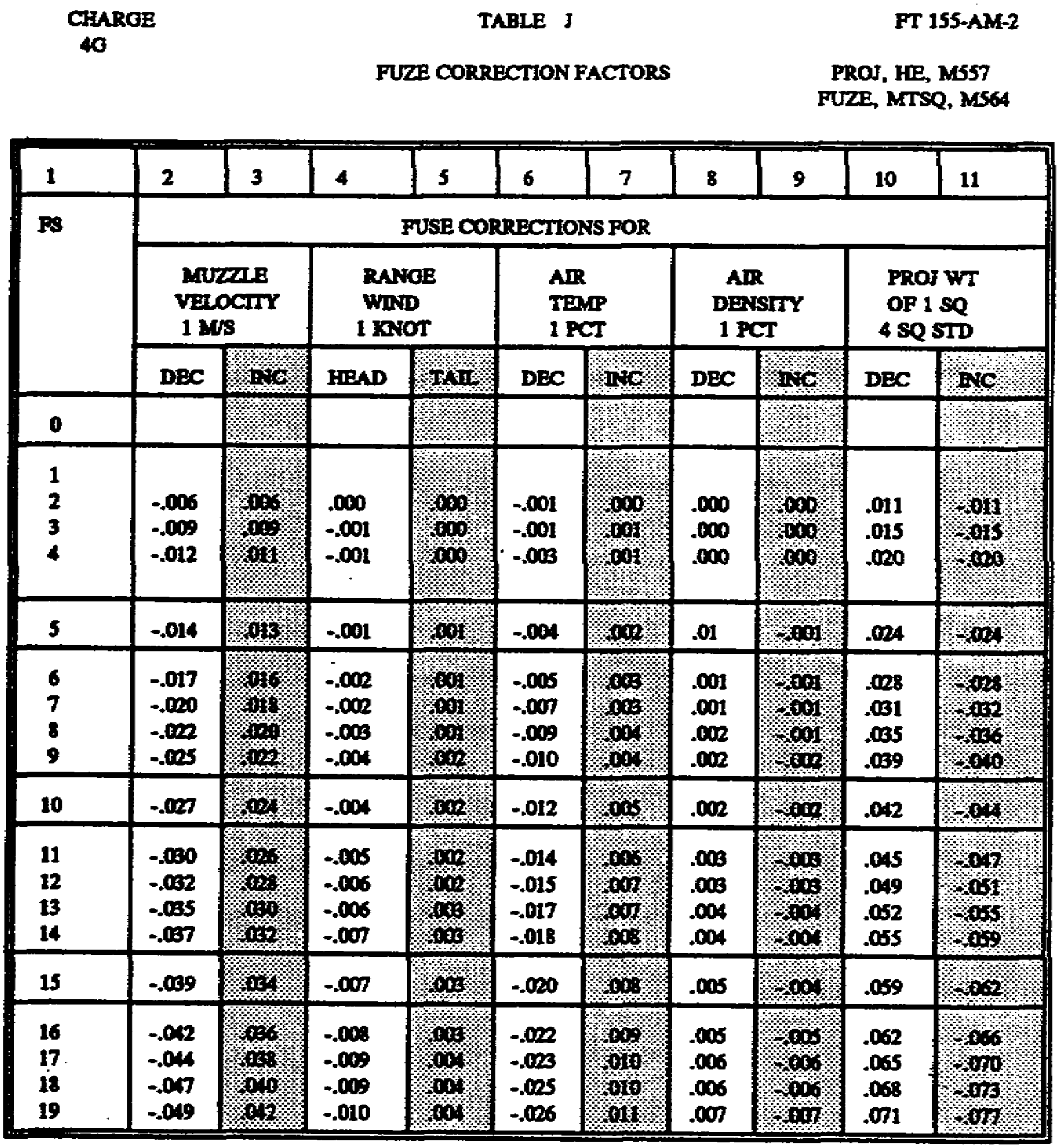
- COLUMN 7. CORRECTION FOR A 1% INC IN AIR TEMP - the correction to FS to compensate for an increase of 1% of standard.

- COLUMN 8. CORRECTION FOR A 1% DEC IN AIR DENSITY - the correction to FS to compensate for a decrease in air density of 1% of standard.

- COLUMN 9. CORRECTION FOR A 1% INC IN AIR DENSITY - the correction to FS to compensate for an increase in air density of 1% of standard.

- COLUMN 10. CORRECTION FOR A 1 SQ DEC IN PROJ WT - the correction to FS to compensate for a decrease of one square in projectile weight.

- COLUMN 11. CORRECTION FOR A 1 SQ INC IN PROJ WT - the correction to FS to compensate for an increase of one square in projectile weight.



CHARGE
4G

TABLE J

FT 155-AM-2

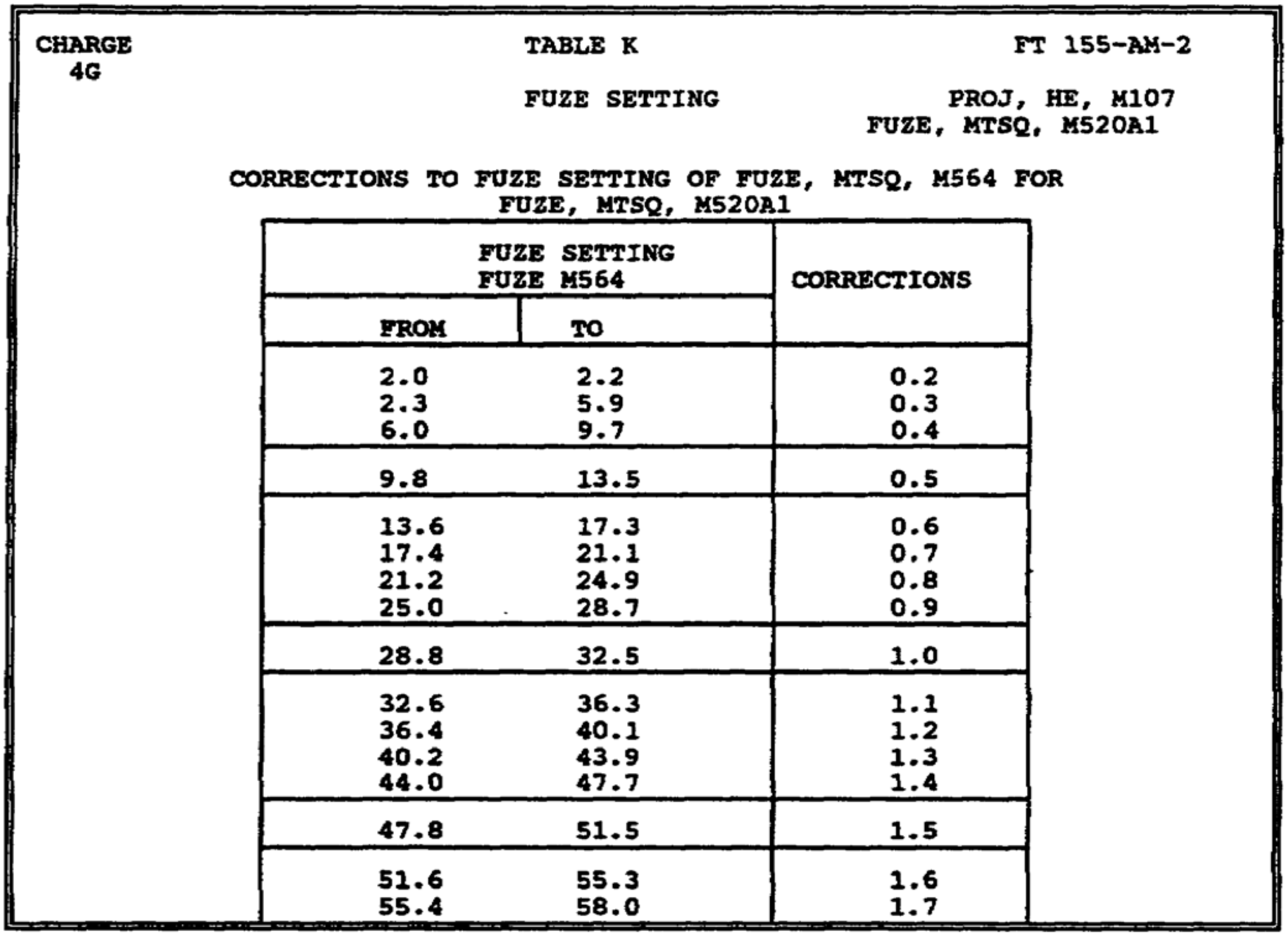
FUZE CORRECTION FACTORS

PROJ, HE, M557
FUZE, MTSQ, M564

1	2	3	4	5	6	7	8	9	10	11
FS	FUSE CORRECTIONS FOR									
	MUZZLE VELOCITY 1 M/S		RANGE WIND 1 KNOT		AIR TEMP 1 PCT		AIR DENSITY 1 PCT		PROJ WT OF 1 SQ 4 SQ STD	
	DEC	INC	HEAD	TAIL	DEC	INC	DEC	INC	DEC	INC
0										
1										
2	-.006	.006	.000	.000	-.001	.000	.000	.000	.011	-.011
3	-.009	.009	-.001	.000	-.001	.001	.000	.000	.015	-.015
4	-.012	.011	-.001	.000	-.003	.001	.000	.000	.020	-.020
5	-.014	.013	-.001	.001	-.004	.002	.01	-.001	.024	-.024
6	-.017	.016	-.002	.001	-.005	.003	.001	-.001	.028	-.028
7	-.020	.018	-.002	.001	-.007	.003	.001	-.001	.031	-.032
8	-.022	.020	-.003	.001	-.009	.004	.002	-.001	.035	-.036
9	-.025	.022	-.004	.002	-.010	.004	.002	-.002	.039	-.040
10	-.027	.024	-.004	.002	-.012	.005	.002	-.002	.042	-.044
11	-.030	.026	-.005	.002	-.014	.006	.003	-.003	.045	-.047
12	-.032	.028	-.006	.002	-.015	.007	.003	-.003	.049	-.051
13	-.035	.030	-.006	.003	-.017	.007	.004	-.004	.052	-.055
14	-.037	.032	-.007	.003	-.018	.008	.004	-.004	.055	-.059
15	-.039	.034	-.007	.003	-.020	.008	.005	-.004	.059	-.062
16	-.042	.036	-.008	.003	-.022	.009	.005	-.005	.062	-.066
17	-.044	.038	-.009	.004	-.023	.010	.006	-.006	.065	-.070
18	-.047	.040	-.009	.004	-.025	.010	.006	-.006	.068	-.073
19	-.049	.042	-.010	.004	-.026	.011	.007	-.007	.071	-.077

Figure 2-17. Table J.

11) Table K, Fuse Setting - lists the corrections to be applied to M564 fuze setting when time fuze M520A1 is being fired (Figure 2-18).



CHARGE
4G

TABLE K

FUZE SETTING

FT 155-AM-2

PROJ, HE, M107
FUZE, MTSQ, M520A1

CORRECTIONS TO FUZE SETTING OF FUZE, MTSQ, M564 FOR FUZE, MTSQ, M520A1

FUZE SETTING FUZE M564		CORRECTIONS
FROM	TO	
2.0	2.2	0.2
2.3	5.9	0.3
6.0	9.7	0.4
9.8	13.5	0.5
13.6	17.3	0.6
17.4	21.1	0.7
21.2	24.9	0.8
25.0	28.7	0.9
28.8	32.5	1.0
32.6	36.3	1.1
36.4	40.1	1.2
40.2	43.9	1.3
44.0	47.7	1.4
47.8	51.5	1.5
51.6	55.3	1.6
55.4	58.0	1.7

Figure 2-18. Table K.

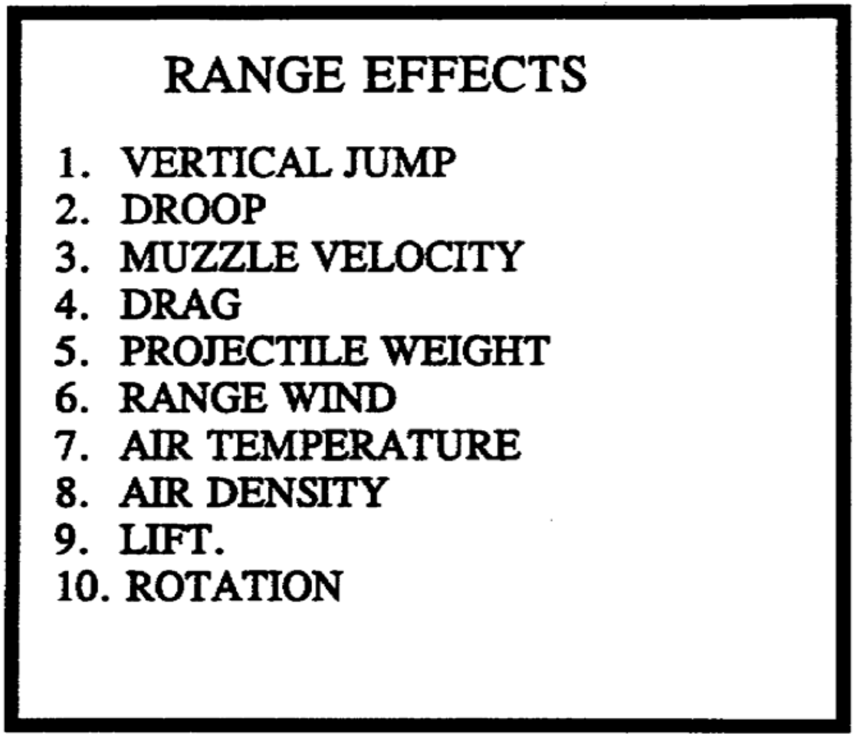
c. Part 2 of the TFT contains information and firing data applicable to M485 illumination projectiles for charges 1 through 8.

d. The appendix lists the trajectory charts for each charge.

PART C

EFFECTS OF NONSTANDARD CONDITIONS

1. Deviations from standard conditions, if not corrected in the computation of firing data, will cause the projectile to impact or burst at some point other than desired. Corrections for nonstandard conditions are made to improve accuracy. The accuracy of artillery fires depends on the accuracy and completeness of the data available, the computational procedures used, and the care exercised in laying the pieces (Figure 2-19).



RANGE EFFECTS

1. VERTICAL JUMP
2. DROOP
3. MUZZLE VELOCITY
4. DRAG
5. PROJECTILE WEIGHT
6. RANGE WIND
7. AIR TEMPERATURE
8. AIR DENSITY
9. LIFT.
10. ROTATION

Figure 2-19. Range effects.

a. Vertical jump. The shock of firing causes a momentary vertical and rotational movement of the tube called vertical jump, prior to the ejection of the projectile. Vertical jump has the effect of a small change in elevation, and depends on the extent of change in the center of gravity of the recoiling parts with respect to the axis of the bore. Vertical jump is not considered separately in the gunnery problem because the angles of elevation in Column 2 of Table F are actually angles of departure. Vertical jump is only a minor factor contributing to range dispersion.

b. Droop. Droop is the algebraic sum of barrel curvature, untrueness of the breech quadrant seats, and untrueness in the assembly of the tube to the breech. The magnitude of droop is the difference between the elevation measured at the muzzle and the elevation measured-on the breech quadrant seats. Firing tables are constructed on the basis of measurements at the muzzle. Droop is absorbed into the basis of measurements at the muzzle and into the computed velocity error. In reality, droop is an elevation error.

c. Muzzle velocity. The velocity of a projectile with respect to the muzzle at the instant the projectile leaves the muzzle of the tube. Applicable firing tables list the standard value of muzzle velocity for each charge. These standards are based on an assumed standard tube.

d. Drag. The resistance of the atmosphere to movement of a projectile. Drag is directly proportional to the diameter and velocity of the projectile and density of the air.

e. Projectile weight. The weight of the projectile affects muzzle velocity. Two opposing factors affect the flight of a projectile of nonstandard weight. A heavier projectile is more efficient in overcoming air resistance; however, because such a projectile is more difficult to push through the tube, its muzzle velocity is lower. An increase in projectile efficiency increases range, and a decrease in muzzle velocity decreases range. In firing tables, corrections for these two opposing factors are combined into a single correction. The change in muzzle velocity predominates at shorter times of flight; the change in projectile efficiency predominates at longer times of flight. Hence, for heavier than standard projectiles, the correction is plus at the shorter times of flight and minus at the longer times of flight. The reverse is true for a lighter than standard projectile.

f. Range winds. The component of the ballistic wind blowing parallel to the direction of fire and in the plane of fire. The plane of fire 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 to the projectile and a longer range results; air moving against the projectile (head wind) has the opposite effect.

g. Air temperature. The effects of nonstandard air temperature may appear inconsistent and puzzling at first. For example, a decrease in air temperature decreases the velocity of sound, which in turn, increases the MACH number (the ratio of the velocity of the projectile to the speed of sound). As this occurs, the drag coefficient decreases. This relationship changes abruptly in the vicinity of MACH 0.8 to MACH 1.2, where an increase in MACH number causes a rapid increase in the drag coefficient. A decrease in MACH number (increase in temperature) will at times lead to an increase in drag. At other times it will lead to decrease in drag, depending on the terminal velocity at the range being considered.

h. Air density. Air density effects are directly related to the drag coefficient. Air that is more dense offers greater resistance; less dense air offers less resistance.

i. Rotation. Although the earth rotates at a constant rate, the correction for rotation varies with a number of factors. Therefore, rotation is more readily considered a nonstandard condition. Factors influencing the effect of rotation of the earth on the travel of a projectile are the direction of fire, angle of departure, velocity of projectile, range to the target, and latitude of the gun. Corrections for these factors are presented in firing tables. The correction tables provide all the data needed for determining corrections to compensate for rotation. However, some background theory of rotational effects may assist you in gaining an understanding of ballistics.

1) Curvature effects exist because we use a map range for which the surface of the earth is assumed to be flat, whereas 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 will still be above the curved surface of the earth and will continue to drop. This is of little significance except at very long ranges. It is disregarded when firing tables are used, since firing table ranges include the curvature effect.

2) A final rotational effect is that of latitude. When the gun and target are at different latitudes, the eastward rotational velocity effects imparted to the projectile are different from those imparted to the target. For example, if the gun is nearer the equator, the projectile will travel faster and therefore, farther to the east than the target (the effect left or right will depend on the hemisphere). When the gun and target are at the same latitude, the projectile will be deflected away from the target. The projectile tends to travel in the plane of the great circle containing the gun and target at the time of firing. Because of the rotation of the earth, the great circle plane is continuously changing. When the latitude is other than that at the equator, the projectile will be pulled out of its original vertical plane by the force of gravity, which operates from the center of the earth and not perpendicular to the axis of the earth. For example, if a gun was placed at the North or South pole, and a projectile was fired due South or North respectably, towards the equator, the projectile will impact west of the target due to the rotation of the earth.

2. Effects of nonstandard conditions of deflection and the factors which effect lateral deviation (Figure 2-20).

FACTORS WHICH EFFECT LATERAL DEVIATION

1. DRIFT
   - A. EQUILIBRIUM YAW (RIGHT) →
   - B. MAGNUS EFFECT (LEFT) ←
2. ROTATION OF EARTH
3. LATERAL WINDS
4. LATERAL JUMP

Figure 2-20. Effects of lateral deviation

a. Drift. Drift is the departure of the projectile from standard direction because of the combined action of air resistance, projectile spin, yaw, and gravity.

1) Equilibrium yaw. In order to fully understand the forces that cause drift, it is necessary to understand the angle of yaw, which is the angle between the tangent to the trajectory and the axis of the projectile. The direction of this angle is constantly changing in a spinning projectile--right, down, left, and up. This initial yaw is at a maximum near the muzzle and gradually subsides as the projectile stabilizes. The atmosphere offers greater resistance to yawing projectiles; therefore, it is fundamental to the design of projectiles that yaw be kept to a minimum and be quickly damped out in flight. At the summit, where the descending branch of the trajectory begins, summital yaw is introduced. This effect on the projectile keeps the nose pointed slightly toward the direction of spin. Therefore, since artillery shells have a clockwise spin, they drift to the right in the descending branch of the trajectory. The magnitude of drift (expressed as lateral angle) depends on the time of flight, rotational speed of the projectile, and the curvature of the trajectory.

2) Magnus effect. The magnus force is generated by the interaction of the boundary layer, which is a thin, viscous film of air that forms around the projectile's surface and the air stream. The intersection is very complex and depends upon the shape of the projectile, its spin rate, its angle of yaw and the atmospheric conditions. The process involved in this interaction can be roughly described as follows: When a non-spinning projectile flies with some yaw, the boundary layer will be thicker on the leeward side than on the windward side. When spin is added, the projectile will try to pull the boundary layer around with it. The combined effect of the shell's spin and airflow on the boundary layer will be to rotate the thicker portion slightly in the direction of spin.

b. Lateral winds. The crosswind is that component of the ballistic wind blowing across the direction of fire. Crosswind causes a deviation from the direction of fire. However, wind component tables reduce the ballistic wind into its two components with respect to the direction of fire.

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

3. Effects of nonstandard conditions on time of flight. Nonstandard conditions that affect range also effect time of flight. Also, the setting for current time fuzes which approximate time of flight, are not interchangeable with time of flight. In the firing tables, corrections to fuze setting are computed separately from correction to elevation.

4. Summary. Although the artilleryman cannot make corrections for normal round-to-round variations in velocity, he can take positive steps to eliminate certain extraneous factors that magnify and distort the normal variations. The following procedures should be followed whenever possible:

a. Segregation of ammunition by lots.

b. Uniform ramming and positioning of propellant bags.

c. Maintenance of uniform propellant temperature.

d. General care and cleanliness of ammunition.

e. Proper cleaning of the tube.

f. Judicious selection of the charge to minimize tube wear.

LESSON 2

PRACTICE EXERCISE

1. The elements of a trajectory are classified into three groups: Intrinsic, Initial, and _______.

   a. Enteral
   b. Terminal
   c. External
   d. Positive

2. The summit is the ______ point of the trajectory.

   a. lowest
   b. mid
   c. intermittent
   d. highest

3. Maximum ordinate is the difference in altitude between the origin and ___________.

   a. level point
   b. summit
   c. target
   d. battery

4. Site is the algebraic sum of the angle of site and the _________.

   a. complementary angle of site
   b. vertical angle
   c. vertical interval
   d. comp site factor

5. When using Part 1 of the tabular firing tables, you will extract what components from Table C?

   a. air temperature
   b. density
   c. wind
   d. propellant

6. When using Part 1 of the tabular firing tables you would extract what factors from Table J?

   a. rotation corrections
   b. fuze setting
   c. comp site factor
   d. angle of fall

LESSON 2
PRACTICAL EXERCISE
ANSWER KEY AND FEEDBACK

Item Correct Answer and Feedback

1. b. Terminal
classified into three groups; Intrinsic, Initial, and Terminal. Page 2-2.

2. d. Highest
The summit is the highest point. Page 2-3

3. b. Summit
altitude between the origin and summit. Page 2-3

4. a. Complementary angle of site
sum of angle of site and complementary angle of site. Page 2-4.

5. c. wind
wind components will be extracted from table C. Page 2-12.

6. b. Fuzing setting
fuze setting factor are extracted from table J. Page 2-20.

EXAMINATION

Edition A

BALLISTICS

Material needed to take the examination:

Subcourse booklet; a number 2 pencil; and ACCP Examination Response Sheet.

Instructions:

There is only one correct answer for each item. Mark the correct answer for each item, then transfer your answers to the ACCP Examination Response Sheet, completely blacking out the lettered oval which corresponds to your selection (A,B,C, or D). Use a number 2 lead pencil to mark your responses. Mail your response sheet in the preaddressed envelope you received with this subcourse.

1. The total effect of all interior ballistic factors determines the velocity of the projectile as it leaves the tube. This velocity is referred to as ________.

   a. interior velocity
   b. exterior velocity
   c. chamber velocity
   d. muzzle velocity

2. The centering slope is the tapered forward portion of the powder chamber which causes the projectile to ________ itself in the main bore.

   a. lock
   b. center
   c. seat
   d. retract

3. The forcing cone is the rear portion of the main bore formed by the ________________.

   a. tapered grooves
   b. powder chamber
   c. tapered lands
   d. breech assembly

4. The main purpose of the counter bore is to prevent the tube from __________.

   a. cracking
   b. jumping
   c. drooping
   d. smoking

5. When measuring the caliber of the tube, the measurement is taken from the ________ diameter.

   a. outside
   b. powder chamber
   c. inside
   d. breech

6. Propellants are classified into three classes: single base, dual base, and _____________.

   a. multi base
   b. composite base-
   c. action base
   d. reaction base

7. The four forms of grains in common use today are strip, cord, multi and _______ perforated.

   a. single
   b. composite
   c. dual
   d. line

8. Three elements principally cause erosion within a tube; they are erosion, scoring, and ___________.

   a. heat
   b. recoil
   c. expansion
   d. abrasion

9. Velocity for each charge is indirectly established by the characteristics of the __________.

   a. projectile
   b. propellant
   c. weapon
   d. pressure travel

10. The elements of a trajectory are classified into three groups: Intrinsic, Initial and __________.

a. Terminal
b. Interior
c. Exterior
d. Base

11. The base of the trajectory is the straight line from the origin to the ___________.

a. vertical interval
b. vertical base
c. target
d. level point

12. The level point is the point on the descending branch of the trajectory that is at the same altitude as the ____________.

a. target
b. origin
c. summit
d. base

13. Initial elements are those characteristic at the _________ of the trajectory.

a. summit
b. descending branch
c. origin
d. ascending branch

14. The angle of site is the angle between the base of trajectory, the straight line joining the origin and the ________.

a. line of elevation
b. level point
c. summit
d. target

15. Complementary angle of site is an angle algebraically applied to the _______.

a. site
b. angle of site
c. angle of elevation
d. angle of fall

16. Site is the algebraic sum of the angle of site and the _________.

a. complementary angle of site
b. angle of elevation
c. angle of departure
d. line of site

17. Quadrant elevation is the algebraic sum of site and ___________.

a. line of site
b. vertical angle
c. angle of site
d. angle of elevation

18. The line of fall is the line tangent to the trajectory at the ___________.

a. point of impact
b. angle of impact
c. level point
d. base

19. The atmospheric standards accepted in the United States firing tables reflect the conditions of the ____________ organization.

a. International Meteorological Organization
b. International Civil Aviation Organization
c. United States Meteorological Organization
d. United States Civil Aviation Organization

20. What component(s) are extracted from Table C of the tabular firing tables?

a. cross and range wind corrections
b. temperature and density corrections
c. correction for muzzle velocity
d. rotation corrections

21. What correction(s) are extracted from Table D of the tabular firing tables?

a. cross and range wind correction
b. temperature and density correction
c. correction for muzzle velocity
d. rotation correction

22. What element(s) are extracted from Table E of the tabular firing tables?

a. rotation correction
b. corrections for muzzle velocity
c. correction for the rotation of the earth
d. fuze setting corrections

23. When using Table F, ___________ is extracted from Columns 2 through 8?

a. corrections for air temperature
b. supplementary data for probable errors
c. rotations corrections
d. basic firing data

24. Which of the following does not have an effect on range?

a. vertical jump
b. muzzle velocity
c. projectile weight
d. lateral winds.