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FM 4-110

WAR DEPARTMENT

COAST ARTILLERY FIELD MANUAL

ANTIAIRCRAFT ARTILLERY

GUNNERY, FIRE CONTROL, AND POSITION FINDING, ANTIAIRCRAFT GUNS

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CHANGES No. 2 } WAR DEPARTMENT,
WASHINGTON, May 2, 1942.

FM 4–110, August 10, 1940, is changed as follows:

■ 160. OPERATION OF DIRECTOR, M4, WHEN FIRING.

* * * * * * *

f. Procedure in case of interlock.

* * * * * * *

(2) *If the first case of locked condition occurs, restore the director to normal as follows:*

(*a*) Turn power "OFF."

(*b*) With power "OFF," turn the range handwheel to increase future horizontal range several thousand yards (if possible, 5,000 yards should be obtained).

(*c*) Set wind, target velocity, and rate dials to zero.

(*d*) With the azimuth handwheel, increase present azimuth 1,800 mils.

(*e*) Turn power "ON" and director will clear itself of the locked condition; after all prediction has settled out, the director is ready for operation.

(3) *If the second case of locked position occurs, restore the director to normal as follows:*

(*a*) Turn power "OFF."

(*b*) Remove right cover plate. (This should be done in a place free from floating particles of dust. Care must be taken to prevent dirt from entering the mechanism.)

(c) Set wind, target velocity, and rate dials to zero.

(*d*) Disconnect lead R2 on terminal block M.

(*e*) Connect a wire jumper between terminals 14 and R1 on the quadrant switch.

(*f*) With the azimuth handwheel, increase present azimuth 1,800 mils.

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(*g*) Watching the future range dial, connect a jumper between terminals 15 and 5 on terminal blocks H and L and when future range is approximately 5,000 yards, remove this jumper. This closes the circuit to the constant speed and difference motors.

(*h*) Remove wire jumper from terminals 14 and R1. Replace terminal R2.

(*i*) With the range handwheel, decrease present range about 1,500 yards. Set the range rate dial to zero.

(*j*) Turn power "ON" and director will clear itself. After prediction has settled out, replace right cover plate and director is ready for operation.

[A. G. 062.11 (1–30–42).] (C 2, May 2, 1942.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

J. A. ULIO,
Major General,
The Adjutant General.

U. S. GOVERNMENT PRINTING OFFICE: 1942

~~RESTRICTED~~

FM 4-110

COAST ARTILLERY FIELD MANUAL

ANTIAIRCRAFT ARTILLERY

GUNNERY, FIRE CONTROL, AND POSITION FINDING, ANTIAIRCRAFT GUNS

Prepared under direction of the
Chief of Coast Artillery

UNITED STATES OF AMERICA WAR OFFICE

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1940

WAR DEPARTMENT,
WASHINGTON, *August 10, 1940.*

FM 4–110, Coast Artillery Field Manual, Antiaircraft Artillery, Gunnery, Fire Control, and Position Finding, Antiaircraft Guns, is published for the information and guidance of all concerned.

[A. G. 062.11 (5–10–40).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

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E. S. ADAMS,
Major General,
The Adjutant General.

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FM 4–110

COAST ARTILLERY FIELD MANUAL

ANTIAIRCRAFT ARTILLERY

GUNNERY, FIRE CONTROL, AND POSITION FINDING

(The matter contained herein supersedes chapter 1, part two, and Tables J, K, L, and M, chapter 2, part three, Coast Artillery Field Manual, Volume II, February 1, 1933.)

CHAPTER 1

GENERAL

SECTION I

GENERAL

■ 1. SCOPE.—This manual treats of the theory and practice of gunnery, fire control, and position finding for antiaircraft artillery guns. A knowledge of the fundamentals of exterior ballistics and gunnery as covered in FM 4–10 will be helpful in understanding similar fundamentals as applied to antiaircraft gunnery. Pertinent definitions and symbols should be studied and a thorough understanding should be had of the picture in space of the various elements of data.

■ 2. BASIC ASSUMPTION.—The design of present fire-control instruments and present fire-control methods for antiaircraft artillery guns are based on the assumption that the target will fly in a straight line, at a constant speed, at a constant altitude, or with a constant change of altitude during the time required to determine and apply data, fire the gun, and during the time of flight of the projectile. This assumption is based principally on a consideration of the possible courses of action open to the individual pilot. The direction of flight is largely subject to his control, and there is no definite assurance that he will continue to fly a straight course. At any given instant the pilot has several choices of action open to him. He may turn to the right or left or continue straight ahead; he may dive, climb, or continue at the same altitude; or he may reduce or increase the speed, or continue at the same speed. He may follow any one or a combination of these courses. There is no method by which his actions may be reliably anticipated. Within limits, however, the chances of a turn to the left or to the right, a dive or a climb, or a decrease or increase in speed are about equal. It can, therefore, be assumed that the average of all choices open to the pilot is that he will follow a rectilinear course during the period indicated in the basic assumption until he is aware that he is being fired upon. This assumption is further justified by the fact that the normal targets for antiaircraft artillery guns are bombardment and observation aviation. These types of aircraft are not only less maneuverable than the smaller and lighter types, but the successful accomplishment of their missions generally requires rectilinear flight, particularly near the objective. While errors in prediction due to the basic assumption are to be expected, these errors, in the long run, will be smaller than if any other course were predicted. Furthermore, when the target does not adhere to the assumed conditions, the resulting prediction error can often be corrected by an adjustment of basic data.

■ 3. **ANTIAIRCRAFT VS. AIRCRAFT.**—Referring to the diagrammatic representation of the capabilities of present-day antiaircraft weapons (fig. 1), some conclusions may be drawn as to the normal targets for such weapons. First, as aircraft may operate at any altitude below their service ceiling, the general rules are:

a. All types of hostile aircraft within limiting range of any antiaircraft weapon are normal targets for that weapon and continue to be until they are destroyed, out of range, or a target presenting a greater threat appears.

b. Whenever different types of hostile aircraft approach simultaneously, the primary targets for all antiaircraft weapons are those types of aircraft, within limiting range, which are capable of inflicting the greatest damage upon the ground establishments being defended. It should be kept constantly in mind that the application of general rules must always be guided by common sense and in this instance by what is termed in military phraseology as the "tactical demands of the moment."

c. Pursuit airplanes are designed principally for air combat. However, they can be used to attack troops and their transportation. They are characterized by great speed and maneuverability and small vulnerability, hence they are not considered as normal targets for antiaircraft guns except when flying in large formations at a suitable altitude.

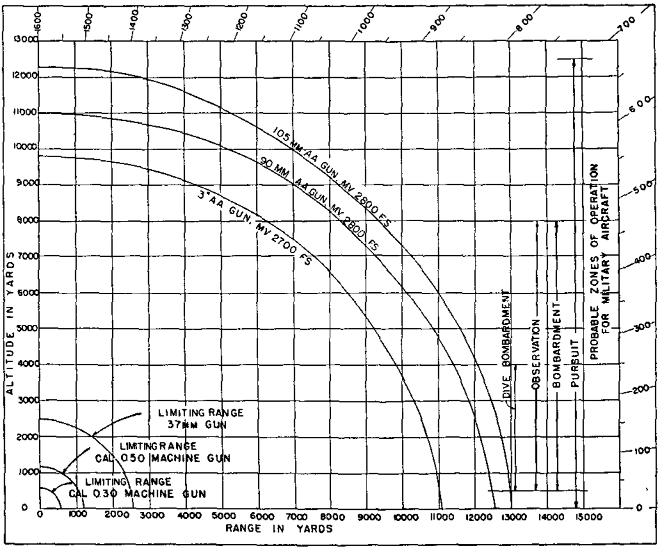


FIGURE 1.—Capabilities of antiaircraft weapons.

d. Observation airplanes are designed to conduct air reconnaissance (visual and photographic), observe artillery fire, and provide liaison. They may operate singly or in groups at altitudes best suited for the accomplishment of the mission.

e. Light bombardment airplanes are designed primarily for attacking light material objectives and troops. They will probably operate at altitudes from 1,500 to 24,000 feet.

f. Dive bombers are designed for attacking material objectives. A dive is generally made at an angle of about 70° and is started at altitudes above 12,000 feet, if possible. The bombs are released and the airplane pulled out of the dive before it enters the zone of small-arms fire—that is, 1,500 feet altitude.

g. Medium and heavy bombardment airplanes are designed primarily for attacking heavy material objectives. They may operate at altitudes from 1,500 to 24,000 feet.

h. It will therefore be concluded that normal targets for antiaircraft guns are bombardment and observation aviation. Normal targets for the automatic weapons are all types of aviation encountered at low and medium altitudes.

■ 4. **ANTIAIRCRAFT ARTILLERY DEVELOPMENT.**—Characteristics of the various types of antiaircraft weapons are:

Matériel	Type of mount	Firing table, muzzle velocity (ft/sec)	Horizontal[1] range (yds)	Vertical[1] range (yds)	Rate of fire (rds/min)
3″ AA gun	Fixed	2,700	11,100	9,800	25
3″ AA gun	Mobile	2,700	11,100	9,800	25
3″ AA gun	Trailer	2,600	7,700	7,570	15
90-mm gun	Mobile	2,800	12,600	11,000	17
105-mm gun	Fixed	2,800	13,100	12,300	15
37-mm gun	Trailer	2,700	3,500	3,500	120
.50 cal. machine gun	Tripod	2,700	1,800	1,800	500
.30-cal. machine gun	Tripod	2,600	800	800	600

[1] Range limited by maximum fuze range or tracer burn-out point.

■ 5. **GENERAL CHARACTERISTICS OF AERIAL TARGETS.**—As a logical approach to the problems of position finding, data computation, and firing which confront the antiaircraft artilleryman, a more detailed examination of the capabilities of the various types of airplanes is of interest. As a target, the characteristics of an airplane which particularly interest the artillerymen are speed, service ceiling, maneuverability, and vulnerability. From an examination of "All the World's

Aircraft" by Jane, considering all types of aircraft, it appears that the artillerymen must be prepared to fire at aerial targets whose combined capabilities will cover the following wide ranges:

a. Speed (normal), 60 to 350 miles per hour.

b. Altitude, 25 to 35,000 feet.

c. Maneuverability:

(1) Change in speed, from 50 percent to 150 percent of normal cruising speed.

(2) Climb, 100 to 2,500 feet/minute.

(3) Dive, up to 40,000 feet/minute.

(4) Change direction:
90° in less than 15 seconds.
180° in less than 30 seconds.

d. Vulnerable area, very small and normally considered to be engines, fuel tanks, and personnel.

■ 6. ANTIAIRCRAFT GUNNERY PROBLEM.—*a.* From the capabilities of military aircraft listed in paragraph 5, it may be concluded that time is the basis of the antiaircraft gunnery problem. Consideration of a few specific examples will strengthen this conclusion. The results of the following computations are approximate:

(1) A bombing airplane flying a straight line course at a constant altitude of 15,000 feet with a constant speed of 250 miles per hour will enter the field of fire of a 3" antiaircraft gun at a horizontal range of 9,350 yards. If the airplane proceeds directly over the battery, it will remain in the field of fire for 2.5 minutes.

(2) The same airplane flying at a constant altitude of 3,000 feet directly over the battery will remain in the field of fire of the 37-mm gun for 0.91 minute.

(3) If the airplane is flying at an altitude of 1,500 feet or less directly over the battery it will remain in the field of fire for the 37-mm gun for 0.94 minute and in the field of fire of the caliber .50 machine gun for 0.46 minute.

(4) A dive bomber commencing its dive at 12,000 feet and leveling off at 1,500 feet altitude will remain in the field of fire of a 37-mm gun for 0.61 minute and in the field of fire of the caliber .50 machine gun for 0.28 minute.

(5) The above times are the optimum and will rarely be realized, as such factors as increase in speed and altitude, multiple targets, and displacement of guns from the defended area will tend to decrease the time available to fire.

b. Reviewing briefly the cycles of operation in firing a gun at a moving naval target, it will be recalled that a "dead time" of from 20 to 40 seconds can be tolerated without material loss in accuracy for position finding and data calculation, due to the comparatively slow movement of the target. Manifestly, such a "dead time" interval cannot be tolerated in firing at a moving aerial target. It must be reduced or entirely eliminated. Ideally, the operations of position finding and data calculation should be instantaneous and continuous.

c. The time factor also exerts a marked influence upon the methods of solving the problem. Referring to the specific examples given in *a* above, a simple calculation will show that in (1) the airplane will pass through a vertical angle of about 2,200 mils measured at the gun in 2.5 minutes, or an average angular travel of about 14 mils per second, with a maximum rate of about 25 mils per second; in (2) the average angular travel rate is about 48 mils per second and the maximum rate about 124 mils per second; in (3) the average angular travel rate is about 51 mils per second with a maximum of 244 mils per second for the 37-mm gun and 95 mils per second average rate with a maximum of 244 mils per second for the caliber .50 machine gun.

d. A consideration of the mechanical principles involved will demonstrate that none of the current fire-control equipment for antiaircraft guns is mechanically capable of operating when the angular travel of the target varies between such wide limits. (The rate varies between 0 mil and 250 mils or more per second.) In addition, the relatively heavy guns are not flexible enough to use the data, if such data were calculated. The 37-mm gun and the caliber .50 machine gun, which have sufficient flexibility to operate at high angular velocities, have been developed to fire on the low-altitude, high-speed airplanes using different methods of computing and applying the firing data.

■ 7. **GENERAL DOCTRINES OF ANTIAIRCRAFT FIRE.**—*a.* Consideration of the relative capabilities of aircraft and antiaircraft artillery leads to some definite conclusions regarding the solution of the antiaircraft artillery gunnery problem.

(1) The relatively high speed of airplanes and the "fleeting moments" available for firing dictate that position finding and data computation must be rapid, approaching as an ideal, the instantaneous and continuous application of firing data to the weapons employed, with a projectile meeting a target the instant it comes within limiting range.

(2) The small vulnerable area presented by an airplane target dictates first that position finding and data computation be accurate, and second, since a great many shots fired in a minimum time increase the probability of hitting, that weapons be fired at the maximum practicable rate.

(3) The wide variation of angular travel rate, coupled with the mechanical limitations of both the fire-control equipment and guns, necessitates that a different solution of the problem be used for low-altitude, high-speed aircraft.

b. In its essential features, the problem of firing at an airplane is the same as firing at any moving land or water target. In its details, it is more complex, due to the greater speed of the airplane and its ability to move in three dimensions. In all cases it is desired to make the projectile meet the target at some point in space. In antiaircraft-gun firing, the small vulnerable area presented by an airplane target makes it desirable to cause the projectile to burst, not upon impact as with seacoast artillery, but on or just short of the expected position of the target in order to increase the probability of hitting. The elementary problem consists of predicting the future location of the target on the basis of its behavior during some interval of time just prior to the prediction, and calculating data necessary to pass a trajectory through this point.

SECTION II

ELEMENTS OF DATA

■ 8. METHODS OF COMPUTING FIRING DATA.—*a.* Firing data may be computed by two different methods—the linear speed method and the angular travel method. At present the linear speed method has superseded the angular travel method. However, at some future date it is entirely possible

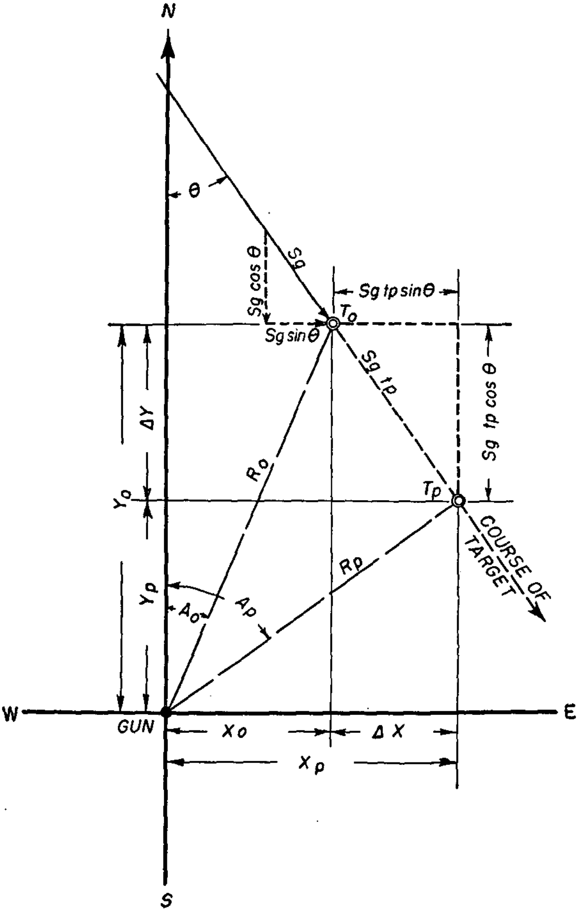


FIGURE 2.—Elements of data, linear speed method (horizontal projection).

A_o	Azimuth of target at present position (T_o).
A_p	Azimuth of target at future position (T_p).
ΔX or $S_g \times t_p \sin \Theta$	East–west component of travel of target during time of flight of projectile.
ΔY or $S_g \times t_p \cos \Theta$	North–south component of travel of target during time of flight of projectile.
R_o	Horizontal range to target at present position (T_o).
R_p	Horizontal range to target at future position (T_p).
S_g	Ground speed of target.
$S_g \cos \Theta$ or N–S rate	North–south component of ground speed of target.
$S_g \sin \Theta$ or E–W rate	East–west component of ground speed of target.
$S_g \times t_p$	Linear travel of target in horizontal plane during time of flight.
Θ	Angle between vertical planes containing course of target and north–south axis of data computor. (Never greater than 90°.)
T_o	Present position of target at instant of firing.
T_p	Future or predicted position of target.
t_p	Time of flight to future position of target.
X_o	East–west component of horizontal range to present position.
X_p	East–west component of horizontal range to future position.
Y_o	North–south component of horizontal range to present position.
Y_p	North–south component of horizontal range to future position.

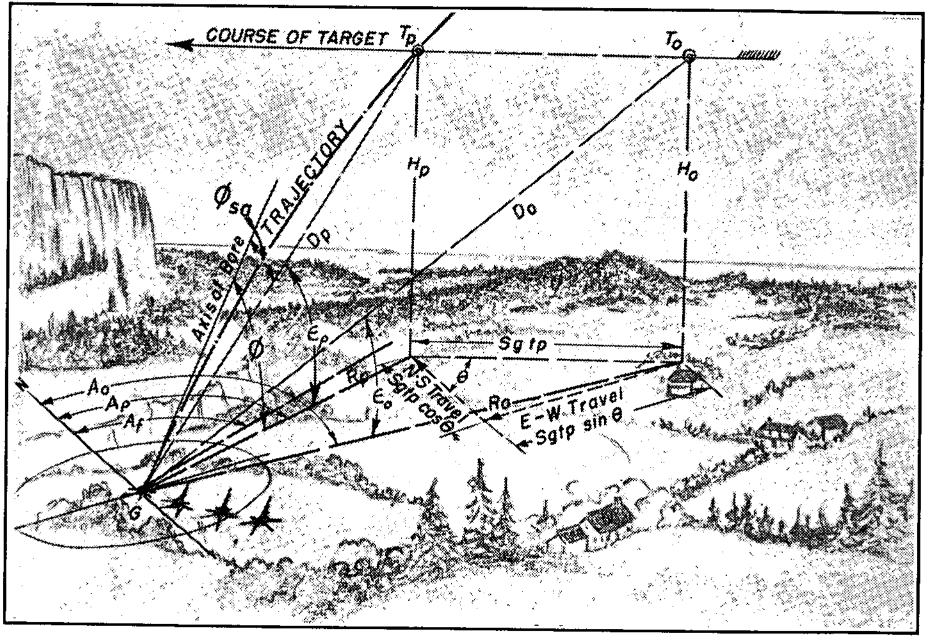


Figure 3.—Elements of data, linear speed method (oblique projection).

A_o	Azimuth of target at present position (T_o).
A_p	Azimuth of target at future position (T_p).
A_j	Firing azimuth, angle of train of gun.
D_o	Slant range to present position of target.
D_p	Slant range to future position of target.
ϵ_o	Angular height of target at present position.
ϵ_p	Angular height of target at future position.
H_o	Altitude of present position of target.
H_p	Altitude of future position of target.
ϕ	Quadrant elevation.
ϕsa	Superelevation under existing conditions.
R_o	Horizontal range to present position of target.
R_p	Horizontal range to future position of target.
S_g	Ground speed of target.
$S_g \times t_p$	Linear travel of target in horizontal plane during time of flight.
$S_g t_p \cos \Theta$ or N–S travel	North–south component of travel of target during time of flight of projectile.
$S_g t_p \sin \Theta$ or E–W travel	East-west component of travel of target during time of flight of projectile.
Θ	Angle between vertical plane containing course of target and vertical plane containing north–south axis of the computor. (Never greater than 90°.)
T_o	Present position of target at instant of firing.
T_p	Future or predicted position of target.
t_p	Time of flight to future position of target.

that the angular travel method may replace or supplement the linear speed method, and for this reason the angular travel method is included in this manual.

b. The basic elements of firing data and the corresponding symbols for each of the two methods are defined and discussed in sections III and IV. Certain elements of data are applicable to both methods, even though they are discussed under the section heading of either linear speed method or angular travel method. A consolidated list of symbols, with definitions, is located for convenience in paragraph 247.

SECTION III

LINEAR SPEED METHOD

■ 9. GENERAL.—Figures 2 and 3 show graphically the elements of data for the linear speed method.

■ 10. LOCATION OF POINT IN SPACE (*T*).—*a.* A point in space (*T*), without reference to its direction from an observer on the ground, may be located by the solution of a right triangle in which one acute angle and one side, or any two sides, are known. Thus in figure 4, if any two of the four elements of the triangle shown are given, the point *T* may be located.

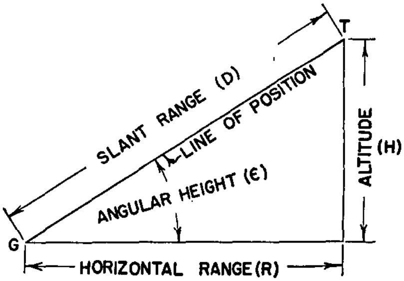


FIGURE 4.—Right triangle in space.

b. Altitude is used as the basic linear measurement for reasons enumerated in paragraph 37.

c. The sights on the gun or the position-finding instruments are directed on the point in space. The vertical angle thus obtained (angular height) combined with the measured altitude of the point will determine the horizontal range to the point (T). In practice this is done by some type of mechanical calculating device.

d. T_o and T_p are, respectively, the present position of the target (at instant of firing) and the future (predicted) position of the target.

■ 11. ANGULAR HEIGHT.—(ϵ).—There is an angular height corresponding to each of the two positions of the target (T_o and T_p). It is obvious that, considering an airplane moving in space with reference to a point on the ground, the angular height of the airplane will vary from instant to instant for nearly all conditions of flight. The most notable exceptions are those when the target flies at a constant altitude on the circumference of a circle whose center is directly above the observer, or dives or climbs along the line of position.

a. Present angular height (ϵ_o).—This is the angular height of the target at the instant the gun is fired.

b. Future angular height (ϵ_p).—This is the angular height of the target in its future position; that is, the point where it is predicted to be at the end of the time of flight.

■ 12. ALTITUDE OF TARGET (H).—Corresponding to each of the positions of the target T_o and T_p are the altitudes of these points (all altitudes are based on a horizontal plane which passes through the data computor) called H_o and H_p, respectively. Unless the target is executing a dive or a climb, these two quantities are equal.

a. Present altitude (H_o).—Data computors are supplied with the altitude obtained from one of three sources: estimation, two-station altimeter system, or self-contained range finder or height finder.

b. Future altitude (H_p).—Originally the problem of determining future altitude (H_p) was ignored by the assumption that the airplane did not change altitude during the time of flight of the projectile. The latest data computors, however, have made provision for shallow dives and climbs by the airplane. Based on a rate of change of altitude obtained either by estimation or by use of some mechanical device, the data computor predicts the future altitude (H_p) and calculates firing data for this altitude.

■ 13. **SUPERELEVATION** (ϕ_{sa}).—*a. Definition.*—A projectile does not move in a straight line in the direction and elevation in which it is fired, but describes a curve. Superelevation is that part of the quadrant elevation which allows for the curvature of the trajectory and represents the combined effect of ballistic conditions and gravity in deflecting the projectile downward from its line of departure.

b. Factors affecting superelevation.—(1) The curvature of the trajectory is dependent upon the initial direction of the projectile, for the forces which act upon it exert their effect according to the relation between the direction of motion of the projectile and the direction in which the resultant force acts. Thus a projectile fired straight up meets with forces acting in a direction different from the direction of the forces which will act on a projectile fired at a comparatively low angle of departure.

(2) The superelevation necessary to cause a trajectory to pass through a particular point in space is dependent also upon the muzzle velocity of the projectile. If the muzzle velocity developed is less than the assumed (firing table) muzzle velocity, then for a given quadrant elevation, the range and altitude attained at the end of a given time of flight will be less than those shown by the firing table. Thus for a particular horizontal range and altitude, if the muzzle velocity were less than the firing table muzzle velocity, the superelevation necessary to cause a trajectory to pass through the predicted position would be greater than if the assumed muzzle velocity were developed.

(3) For a given point, atmospheric conditions will affect the amount of superelevation which must be given to the gun. The wind which is blowing may accelerate or retard the projectile. The existing density may increase or decrease the range, as may also the temperature elasticity effect of the atmosphere.

(4) Furthermore, the condition of the matériel will directly affect the superelevation which must be given to the gun. A new gun will fire with a greater velocity than an old one, and as the gun wears, in order to obtain the same range, a greater elevation must be given to the gun.

(5) Summarized, the superelevation which must be applied to the gun is dependent upon—

(*a*) The position of the target.

(*b*) The existing atmospheric and ballistic conditions.

c. Superelevation value.—If the atmospheric and ballistic conditions enumerated in *b* above were constant, then for any particular horizontal range and altitude, superelevation would be a constant value. But for varying atmospheric and ballistic conditions, superelevation will have different values. In order to distinguish between these two, the symbol ϕ_s is used to designate the superelevation under firing table conditions, and the symbol ϕ_{sa} to designate the superelevation under conditions actually existing.

d. Firing table superelevation (ϕ_s).—(1) Firing tables give the superelevation in table B using fuze setting and quadrant elevation as arguments. In table A, which uses time of flight and quadrant elevation as arguments, the superelevation can be obtained by subtracting angular height from quadrant elevation. Extracts of tables A and B from Firing Tables 3 AA–J–2a and 3 AA–O–1 are found in paragraph 257.

(2) This value of ϕ_s is used for the purpose of constructing curves or cams or graduating drums in data computors. It is subject to correction for the variation between existing conditions and the firing table conditions.

e. Superelevation under nonstandard conditions (ϕ_{sa}).—(1) When conditions existing at the time of firing vary from firing table conditions, then the firing table data must be corrected. The correction depends upon the effects of the variations in conditions.

(2) The vertical pointing correction (σ_2) is a correction of the superelevation made necessary by variations between standard and actual conditions. The factors affecting σ_2 are discussed in paragraph 29*b*.

Thus, under actual conditions—

$$\phi = \epsilon_p + \phi_s \pm \sigma_2,$$

and since

$$\phi_{sa} = \phi_s \pm \sigma_2,$$

$$\phi = \epsilon_p \pm \phi_{sa}$$

■ 14. FUZE RANGE (*F*).—*a*. From an examination of trajectory chart (fig. 23 or 24), it is evident that by changing the quadrant elevation (ϕ) the trajectory can be passed through any point in space within range. All that remains to be done is to burst the projectile at some definite position along the trajectory. This is done by means of the time fuze. In other words, by varying the quadrant elevation (ϕ) and the fuze range (F), the projectile can be made to burst at any particular point in space within range. Fuze range can therefore be defined as the fuze setting necessary to burst the projectile at a particular point along the trajectory. Fuze range for any particular point can be ascertained by reference to either the trajectory chart or firing tables for the particular gun and ammunition used. The data computor calculates the fuze range to the future position (T_p).

b. Nonstandard atmospheric and ballistic conditions affect the shape of the trajectory (due to changes in superelevation, see par. 13*c*) passing through a particular point in space. Therefore the time of flight and consequently the fuze range to the particular point will vary with the atmospheric and ballistic conditions. Certain ammunition now in general use in antiaircraft artillery is equipped with a 21-second powder train time fuze. The fuze is graduated in terms of fuze range from 0 to 21.2. Theoretically each of the whole divisions represents 1 second time of burning, but actually it does not. As a result of experimental tests and firings, the time of fuze burning (which is actually the time of flight (t_p)) for different fuze ranges and quadrant elevations has been computed and tabulated. These same data are also shown graphically on the trajectory chart. These tests have also demonstrated that at least three physical factors affect the burning of a powder train time fuze.

(1) *Pressure under which it burns.*—Since the air pressure decreases as the altitude increases, the time of burning will vary with the altitude attained by the projectile. (It will also vary with the atmospheric density. This effect of density on fuze burning is discussed in paragraph 86*c*.) A specific example from the firing tables will show how much of a difference altitude makes on the time of burning of the fuze. Referring to table XIX, paragraph 257, using as arguments $F=13$, and $\phi=700$ mils; $t_p=12.68$ seconds, and the altitude of the burst is 3,223 yards. Using as arguments $F=13$, and

ϕ=1,500 mils; t_p=14.96 seconds and H=6,189 yards. A difference of 2,966 yards in altitude has increased the time of burning of the fuze for the same fuze setting 2.28 seconds.

(2) *Temperature of the fuze.*—While the temperature of the fuze affects its rate of burning, the magnitude of this effect has not been determined satisfactorily.

(3) *Speed of rotation of the projectile.*—The speed of rotation, or spin of the projectile, has an effect on the rate of burning of the fuze. It has been found by experiment that there are limits of rate of spin beyond which powder-train fuzes may not be expected to function except with extreme inaccuracy and unreliability.

c. From the above discussion it will be seen that the fuze range varies according to the ballistic and atmospheric conditions of the moment, with the altitude of the burst, and with the quadrant elevation of the gun. If we assume certain values for H and ϕ, we select a certain point in space. This same point can be identified equally as well by a combination of (H_p and R_p), or (ϵ_p and t_p). H_p and R_p are used in the M4 director to determine the fuze range (F).

d. Mechanical time fuzes will ultimately replace the powder train time fuze. They are graduated in terms of fuze range from 0 to 30 seconds. The factors which affect the functioning of the powder train time fuze do not have any effect on the mechanical time fuze. Consequently, F equals t_p in the mechanical time fuze.

■ 15. AZIMUTH OF TARGET (A).—For each position of the target, there is a horizontal angle called the azimuth of target (A). This angle is measured in a clockwise direction from a reference axis to the horizontal projection of the target. The reference axis is usually made to coincide with either grid north or true north. The azimuths of the target at each of the two positions of the target T_o and T_p are called, respectively, A_o and A_p.

a. Azimuth of target at present position (A_o).—A_o is the azimuth of the target at the instant the gun is fired.

b. Azimuth of target at future position (A_p).—A_p is the azimuth of T_p. It is the azimuth at which the burst should meet the target.

■ 16. FIRING AZIMUTH (A_f).—A_f is the azimuth at which the gun is laid in order that the burst will occur at T_p. $A_f=A_p\pm\delta_2$. The factors affecting δ_2 are discussed in paragraph 28*b*.

■ 17. HORIZONTAL RANGE (R).—For each of the positions of the target, there is a corresponding horizontal range. The horizontal ranges to T_o and T_p are called, respectively, R_o and R_p.

■ 18. GROUND SPEED OF TARGET (S_g).—Ground speed of target is the velocity of the target expressed in distance per interval of time, usually yards per second. The distance is measured in the horizontal plane.

■ 19. TIME OF FLIGHT (t_p).—t_p is the time in seconds that it will take the projectile to reach the future position (T_p). For the same point, it will vary depending upon the combination of gun and ammunition and the atmospheric and ballistic conditions of the moment.

■ 20. SLANT RANGE TO TARGET (D).—For each position of the target in space, the distance measured from gun to target in the inclined plane is called the slant range to target. For each position of the target T_o and T_p, there is a corresponding slant range called D_o and D_p, respectively.

■ 21. QUADRANT ELEVATION (ϕ).—ϕ is the elevation at which the gun is laid in order that the trajectory will pass through the future position. ϕ is a function of H_p and R_p.

■ 22. X_o AND Y_o.—The horizontal range to the present position of the target is resolved into a component in the E–W direction (called X_o) and a component in the N–S direction (called Y_o). It will be seen that X_o and Y_o are the coordinates of the present position of the target using as reference axes, the E–W and N–S directions. The gun is considered as being at the origin.

■ 23. E–W AND N–S RATES.—The continuous tracking of the target establishes an instantaneous rate S_g. This rate is resolved into a component in the E–W direction (called E–W rate$=S_g \sin \Theta$), and a component in the N–S direction (called N–S rate$=S_g \cos \Theta$). These rates are the instantaneous rates of change of X_o and Y_o.

■ 24. E–W AND N–S TRAVEL (ΔX AND ΔY).—The E–W and N–S rates multiplied by the time of flight, give the travel of the target in the E–W and N–S directions during the time of flight of the projectile.

$$\Delta X = \text{E–W rate} \times t_p = S_g \sin \theta \times t_p$$
$$\Delta Y = \text{N–S rate} \times t_p = S_g \cos \theta \times t_p$$

■ 25. X_p AND Y_p.—If the E–W and N–S travel of the target are added algebraically to the coordinates of the present position of the target, we have the coordinates of the future position of the target X_p and Y_p.

$$X_p = X_o \pm \Delta X$$
$$Y_p = Y_o \pm \Delta Y$$

SECTION IV

ANGULAR TRAVEL METHOD

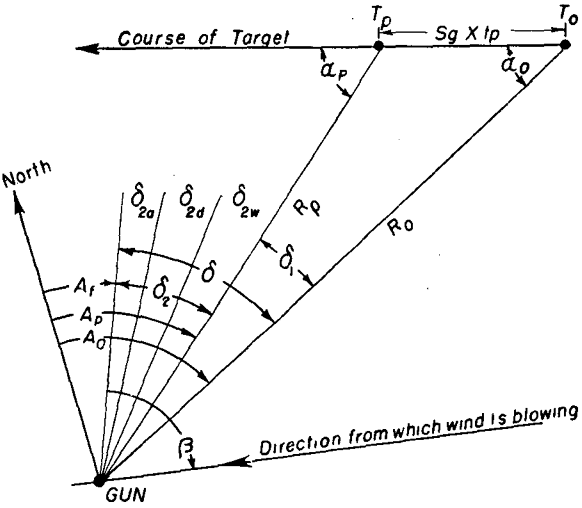
■ 26. GENERAL.—Figures 5, 6, and 7 show graphically the basic elements of data for the angular travel method.

■ 27. LOCATION OF A POINT IN SPACE.—The method of locating a point in space is the same as in the linear speed method. However, the data computor determines the slant range (D_o) instead of the horizontal range (R_o).

■ 28. LATERAL DEFLECTION ANGLE (δ).—The lateral deflection angle is the angle by which the gun must lead the airplane laterally in order that the projectile meet the target at the predicted point (T_p). δ is the difference between the firing azimuth (A_f) and the present azimuth (A_o). It consists of the algebraic sum of the components, principal lateral deflection (δ_1) and the lateral pointing correction (δ_2).

a. Principal lateral deflection (δ_1).—δ_1 is the lateral lead necessary to compensate for the travel of the target during time of flight of the projectile. It is a variable whose value is dependent upon direction of course of target, speed of target, time of flight of the projectile, ϵ_o and ϵ_p, and the value of the principal vertical deflection angle (σ_1).

b. Lateral pointing correction (δ_2).—δ_2 is the lateral lead necessary to compensate for effects other than travel of the target. It is the algebraic sum of three variable quantities, the lateral arbitrary adjustment correction (δ_{2a}), lateral



HORIZONTAL PROJECTION

FIGURE 5.—Elements of data, angular travel method (horizontal projection).

A_p	Azimuth of target at future position (T_p).
A_o	Azimuth of target at present position (T_o).
A_f	Firing azimuth.
αp	Angle of approach at future position (T_p).
αo	Angle of approach at present position (T_o).
β	Wind-fire angle.
δ	Lateral deflection angle.
δ_1	Principal lateral deflection angle.
δ_2	Lateral pointing correction.
δ_{2a}	Lateral adjustment correction (arbitrary).
δ_{2d}	Lateral pointing correction due to drift.
δ_{2w}	Lateral pointing correction due to cross wind.
R_p	Horizontal range to target at future position (T_p).
R_o	Horizontal range to target at present position (T_o).
S_g	Ground speed of target.
$S_g \times t_p$	Linear travel of target in horizontal plane during time of flight.
T_p	Predicted position of target (future position).
T_o	Present position of target (instant of firing).
t_p	Time of flight to future position of target (T_p).

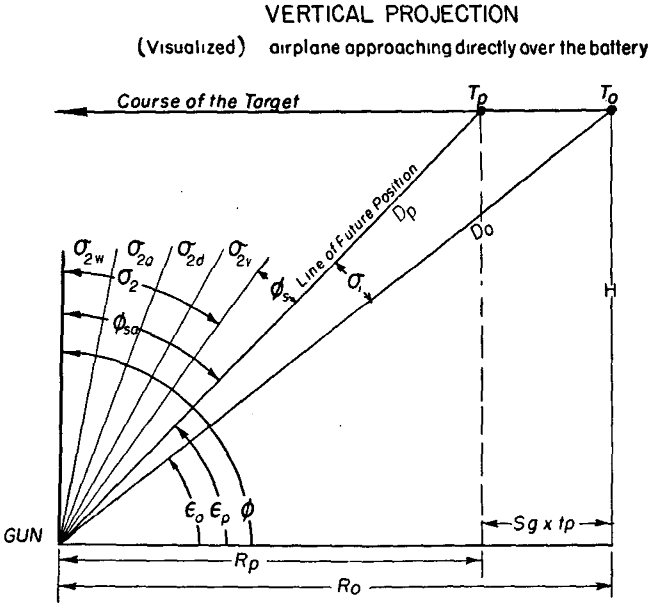


FIGURE 6.—Elements of data, angular travel method (vertical projection).

D_p	Slant range to target at future position (T_p).
D_o	Slant range to target at present position (T_o).
ϵp	Angular height of target at future position (T_p).
ϵo	Angular height of target at present position (T_o).
H	Altitude of target.
ϕ	Quadrant elevation.
ϕs	Superelevation under firing table conditions.
ϕsa	Superelevation under actual conditions.
R_p	Horizontal range to target at future position (T_p).
R_o	Horizontal range to target at present position (T_o).
S_g	Ground speed of target.
$S_g \times t_p$	Linear travel of target in horizontal plane during time of flight.
$\sigma 1$	Principal vertical deflection angle.
$\sigma 2$	Vertical pointing correction.
$\sigma 2a$	Vertical adjustment correction (arbitrary).
σ_{2d}	Vertical pointing correction due to density.
$\sigma 2v$	Vertical pointing correction due to muzzle velocity.
σ_{2w}	Vertical pointing correction due to range wind.
T_p	Predicted position of target (future position).
T_o	Present position of target (instant of firing).
t_p	Time of flight to future position of target (T_p).

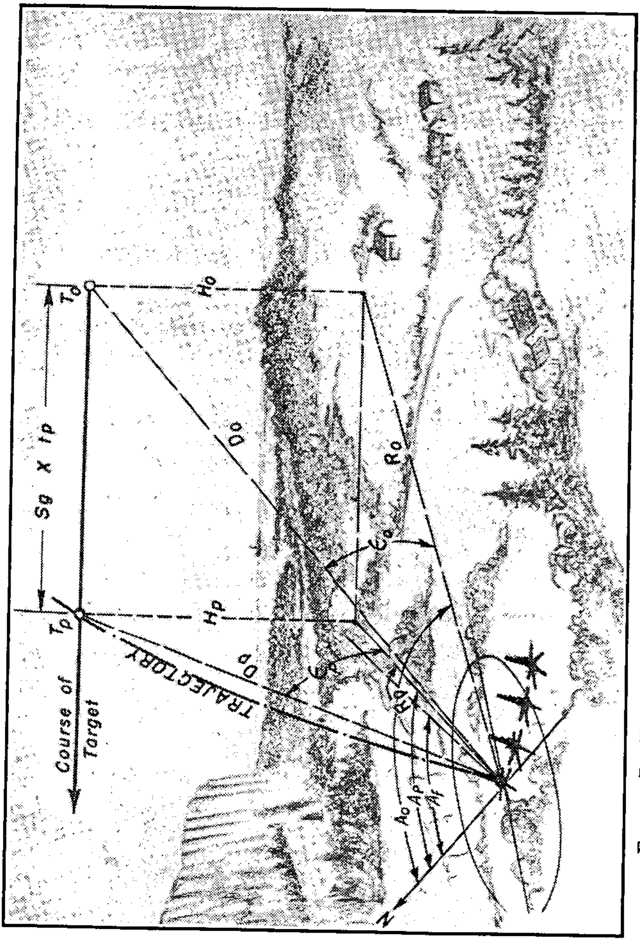


FIGURE 7.—Elements of data, angular travel method (oblique projection).

pointing correction due to cross wind (δ_{2w}), and lateral pointing correction due to drift (δ_{2d}).

■ 29. VERTICAL DEFLECTION ANGLE (σ).—The vertical deflection angle is the angle (exclusive of superelevation) by which the gun must lead the target vertically in order that the projectile meet the target at the predicted point (T_p). It is the algebraic sum of the principal vertical deflection (σ_1) and the vertical pointing correction (σ_2).

a. Principal vertical deflection (σ_1).—σ_1 is the vertical lead necessary to compensate for the travel of the target during time of flight of the projectile. This variable is dependent upon the direction of the course of the target, speed of the target, time of flight of the projectile, ϵ_o and ϵ_p, and value of the principal lateral deflection angle (δ_1).

b. Vertical pointing correction (σ_2).—σ_2 is the vertical lead necessary to compensate for effects other than travel of the target. It is the algebraic sum of four variable quantities, vertical arbitrary adjustment correction (σ_{2a}), vertical pointing correction due to range wind (σ_{2w}), vertical pointing correction due to variation in muzzle velocity (σ_{2v}), and vertical pointing correction due to variation of atmopsheric density (σ_{2d}).

■ 30. ANGLE OF APPROACH (α).—For each of the two positions of the target, T_o and T_p, there is a corresponding angle of approach called α_o and α_p, respectively. The angle of approach in each case is the acute angle between the horizontal projections of the course of the target and line of position.

■ 31. WIND-FIRE ANGLE (β).—β is the horizontal angle measured between the vertical planes containing the axis of the bore and the ballistic wind. It is obtained by subtracting A_f from A_w. A_w, the azimuth of the ballistic wind, is the direction from which the wind is blowing. Add 6,400 mils to A_w, if necessary, in order to avoid a negative value of β.

■ 32. ANGULAR VELOCITY (Σ).—This element of data is not shown in the figures. It is the angle swept over by the target per unit of time. In the operation of tracking, the data computor resolves the angular velocity (Σ) into two components

(Σ_e) which is the rate of change in angular height and (Σ_a) which is the rate of change in azimuth.

■ 33. ALTITUDE (H).—Unlike the linear speed method, the angular travel method formulas developed to date are based on the assumption of constant altitude of the target. As a result H_p always equals H_o.

■ 34. ELEMENTS SIMILAR TO LINEAR SPEED METHOD.—The following elements of data are identical with those discussed under the linear speed method (sec. III): Azimuth of target (A_o, A_p); position of the target (T_o, T_p); slant range to target (D_o, D_p); angular height (ϵ_o, ϵ_p); time of flight (t_p); ground speed of target (S_g); quadrant elevation (ϕ); superelevation (ϕ_{sa}); fuze range (F); and firing azimuth (A_f).

CHAPTER 2

POSITION FINDING, FIRE CONTROL, AND GUNNERY

SECTION I

POSITION FINDING

■ 35. GENERAL.—Position finding is the process of determining the position of a target in space with reference to the battery and the determination of a future position of the target. In paragraph 7, it was emphasized that position finding should be accomplished instantaneously and that the small vulnerable area presented by an airplane demands the greatest accuracy in observation and in the calculation of firing data.

■ 36. USE OF INSTRUMENTS.—*a*. In proceeding to study the aspects of position finding by instrumental observation, it is well to recall that all observation instruments used for precise measurements are essentially the same as the surveyor's transit, which measures horizontal and vertical angles. A primary requirement for accuracy with such instruments is that the angles they measure are truly vertical and truly horizontal. The observing instruments used in the Coast Artillery Corps are so constructed that this requirement for accuracy is satisfied by leveling. While the actual process of leveling may vary with different instruments, the principles are identical, and the procedure will usually be apparent from an examination of the instrument or by consulting the handbook accompanying the instrument.

b. The location of the target with reference to the gun or observer requires the measurement of angles from very definite reference axes or reference planes. Therefore, as a general rule, all instruments must be oriented or so pointed that the horizontal angles measured will be in terms of angular units (azimuth) from an arbitrarily chosen reference direction. For uniformity, the reference direction, or direction of zero azimuth, is customarily chosen as north. As in the case of leveling, the actual methods of orienting may vary, but the procedure will usually be apparent. In addition, it is essential that vertical angles be measured from a horizontal plane. Therefore instruments must be adjusted or the scale which indicates the vertical angle must read zero when the line of sight is truly horizontal. The procedure in adjusting an instrument varies with different instruments and will not, as a rule, be readily apparent; hence a handbook must be consulted or competent assistance must be obtained.

c. Instruments are generally quite rugged in construction, but they must be carefully handled and should not be subjected to unnecessary shocks, jars, or strains. Screws, handwheels, and other moving parts should never be forced if they do not operate freely. Instruments are provided with weatherproof covers, packing boxes, carrying straps or handles, and other impedimenta for protection against weather and to facilitate careful handling. To avoid scratching the surfaces of lenses, prisms, and other optical elements, they should be cleaned only with a soft linen cloth or with optical paper especially furnished for the purpose. Instruments should be disassembled under the supervision of a competent technician.

■ 37. TARGET LOCATION.—*a*. With the foregoing in mind, the position-finding problem and means and methods employed in its solution will now be considered. The accurate location of a point which is inaccessible to the observer presents the usual triangulation problem. Referring to figure 8, it is clear that a properly oriented instrument, continuously directed at the target, will continuously and instantaneously furnish an azimuth (A_o) and an angular height (ϵ_0).

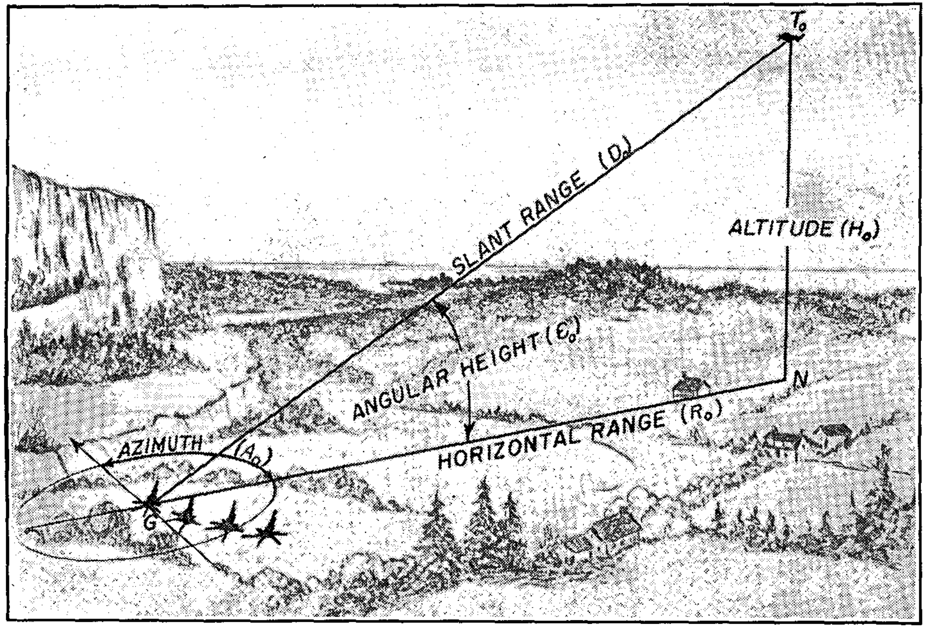


FIGURE 8.—Location of an airplane target; present position (T_0).

b. In order to solve the right triangle GT_oN (fig. 8), it is necessary that one angle and one side be known. ϵ_o is instantly and continuously available at the data computor. H or R must be determined in order to solve the triangle.

c. In selecting the side of the triangle to be measured, brief consideration of a specific example will be helpful. For an airplane flying toward the observer at 300 miles an hour at a constant altitude (H) of 10,000 feet, the horizontal range (R) will be changing uniformly at the rate of 150 yards per second and the slant range (D) will be changing nonuniformly from slightly less than 150 yards per second to 0 yards per second.

As the example assumes that the target was flying at constant altitude (H), there is no question as to the proper side of the triangle to measure. However, before making a final decision, the possibilities that a target will not fly at constant altitude (H) should be examined. The modern bombing airplane is capable of climbing, fully loaded, at a rate of about 8 yards per second. Compared to the rate of change in the horizontal (R) or slant (D) ranges, this rate of change in altitude (H) appears insignificant. Considering the possibility of a negative change in altitude (H), or "dive," dive bombers are suitable targets for automatic weapons, their suitability as gun targets being limited to that interval of time just preceding the "dive." The M4 director is capable of computing firing data for a target whose altitude is changing at a rate of not more than 50 yards per second.

d. Thus it is concluded, first, that the physical limitations of both the instruments and the operators make it desirable that the side of the triangle which changes at the slowest rate be selected for measurement; and second, that the capabilities of the normal targets for antiaircraft guns (military bombing and observation airplanes) are such that the altitude (H) "leg" of the triangle actually may change the least rapidly.

e. Having decided that H is the logical side of the triangle to measure, we can proceed with the determination of the present position of the target. We have three elements available, A_o, ϵ_o, and H. The present position of the target may be located by the coordinates A_o, R_o, and H; or A_o, ϵ_o, and D_o; or X_o, Y_o, and H_o.

f. When ϵ_o is less than +10°, the calculation of data is more accurate if D is the measured side of the triangle. In this case, the slant range to the target (D_o) is determined by the height finder and H_o is computed by the director. D_o is assumed to be equal to R_o and the present position of the target is located by the coordinates A_o, R_o, and H_o.

SECTION II

DETERMINATION OF ALTITUDE

■ 38. **GENERAL.**—*a.* There are two general systems of instrumental determination of altitude—the two-station system and the single-station system. In our service the altimeter, M1920, is used in the two-station system and a stereoscopic height finder is used in the single-station system.

b. Regardless of the method of altitude determination used, it is of primary importance that the data are accurate. The first determination should be obtained in a minimum of time after the assignment of a target, and successive determinations should be made as rapidly as possible.

■ 39. **SINGLE-STATION SYSTEM.**—The single-station system employs an instrument which is entirely self-contained. The unit consists of the following principal parts:

a. A self-contained stereoscopic range or height finder mounted on a cradle and tripod in order to enable it to be traversed and elevated as necessary.

b. Two auxiliary sighting systems for the trackers, who assist the observer by keeping the height finder directed at the target.

c. A data transmission system for instantaneously transmitting to the director the determined range or altitude.

d. A target designating system—that is, electrical transmission of A_o and ϵ_o from the director to the height finder—to insure that both instruments are on the same target.

■ 40. **PRINCIPLE OF STEREOSCOPIC HEIGHT FINDER.**—Stereoscopic height finding is based on the faculty of the eyes to determine when two objects (target and reticle) are in the same distance plane. This faculty is aided in the height finder by increasing the effective base line of the eyes to the length of the height finder and increasing the sharpness of vision by the magnifying power of the lenses of the instrument. In the height finder, the adjustment necessary to move the target image to the target reticle distance plane is a measure of the range to the target. The instrument can convert this range to altitude. (See TM 4–250.)

■ 41. REFERENCES TO STEREOSCOPIC HEIGHT FINDING.—Further detailed information on the height finder M1 will be found in section II, chapter 3, and in the handbook Height Finder M1, issued with the instrument. For information on stereoscopic training devices, see section VIII, chapter 3.

■ 42. TWO-STATION SYSTEM.—The two-station system of altitude determination employs one optical instrument at each end of a measured base line. The instrument contains charts and mechanical devices for the rapid and accurate solution of triangles. Communication by telephone must be maintained between the two instruments during the determination of altitudes. The accurate determination of altitude is dependent upon the accurate operation and orientation of the instruments.

■ 43. TWO-STATION PRINCIPLES.—*a*. Consider the triangle *AB′B″* (fig. 9) in the vertical plane. Designate the base line as *b*, the altitude as *H*, the angles at *B′* and *B″* as ϕ_1 and ϕ_2, respectively.

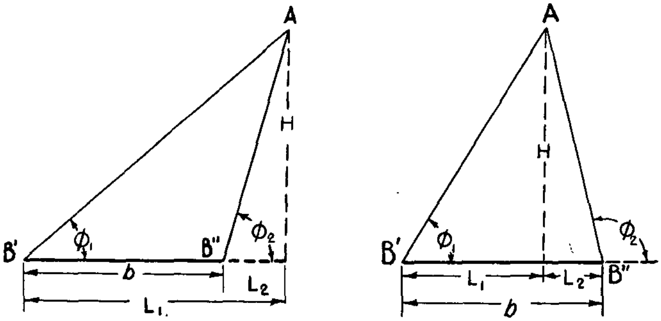


FIGURE 9.—Determination of altitude (two stations).

By simple trigonometry it follows that—

Example *a*	Example *b*
$L_1 = H \cot \phi_1$	$L_1 = H \cot \phi_1$
$L_2 = H \cot \phi_2$	$L_2 = H \cot (180° - \phi_2)$
	$= -H \cot \phi_2$
$b = L_1 - L_2$	$b = L_1 + L_2$
$= H (\cot \phi_1 - \cot \phi_2)$	$= H (\cot \phi_1 - \cot \phi_2)$
$H = \dfrac{b}{\cot \phi_1 - \cot \phi_2}$	$H = \dfrac{b}{\cot \phi_1 - \cot \phi_2}$

Expressed logarithmically,

$$\log H = \log b - \log (\cot \phi_1 - \cot \phi_2)$$

Therefore by placing an instrument at each end of a measured base line (b) and measuring the vertical angles, the altitude (H) to a point in the vertical plane which contains the base line is readily computed. The necessary data are, first, that the length of the base line (b) is known, and second, that the angles ϕ_1 and ϕ_2 are measured (as indicated in fig. 9, ϕ_1 interior and ϕ_2 exterior), in the vertical plane which includes the station at each end of the base line. It should be noted that the altimeter computes altitude (H) only for points in the same vertical plane as both stations. Manifestly, it will seldom occur that an airplane target will be found directly overhead. Hence the instruments must be so constructed as to permit accurate observation for any location.

b. In figure 10, let B' and B'' represent positions occupied by instruments at the ends of a horizontal base line of known length (b). $B'c$ and $B''d$ are both perpendicular to $B'B''$. They are horizontal axes for planes which may be rotated about them, $B'c$ serving as an axis for the plane $B'egc$, and $B''d$ serving as an axis for plane $B''egd$. The intersection of these two planes is a horizontal line; and, if both planes contain the same point in space, this line will contain that point and will be a certain distance above the horizontal plane containing the base line. For any given base line, this distance above the horizontal plane containing the base line depends on the angles formed by the rotated planes with the horizontal. The planes having been so rotated, lines of sight may be moved in these planes until they are on the same point in space. Being on the same point in space and lying in their respective planes, they must intersect on the line (ridge) where the planes intersect.

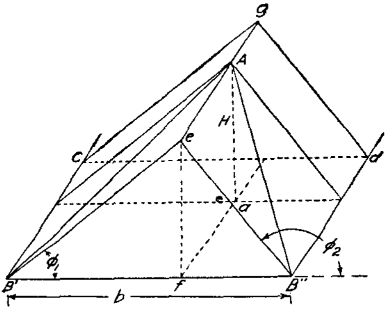


FIGURE 10.—Altimetric roof.

c. The two-station system makes use of the principle just described in determining the altitude of a target. It consists of two instruments (altimeters), one to be used at each end of a base line. Each instrument is capable of being oriented, thus establishing the axes *B'c* and *B''d*, as shown in figure 10. The line of sight has one motion about a horizontal axis perpendicular to the base line and a second motion about an axis at all times perpendicular to the rotated planes *B'egc* or *B''egd*. Thus, in following the target, each instrument is establishing the angle between its rotated plane and the horizontal plane of the base line. These rotated planes intersect in a horizontal line through the target. All points on this line are at the same altitude above the horizontal plane *B'cdB''*. If, then, the altitude of any point of this line through the target above the horizontal plane is determined, the altitude of the target is known. In *a* above we have solved the triangle in the vertical plane containing the base line. The formula developed,

$$\log H = \log b - \log (\cot \phi_1 - \cot \phi_2)$$

is true for all values of b, ϕ_1, *and* ϕ_2. It should be noted that ϕ_2 is the exterior angle at *B''* and ϕ_1 is the interior angle at *B'*. The actual construction of the instruments and the operation thereof are covered in section II, chapter 3.

d. In the preceding discussion the base-end stations are at the same elevation. The expression for altitude as given above will not hold when this condition does not exist. Consider the situation as shown in figure 11. Assume a target flying at 2,000 yards altitude (*H*) directly toward the battery in the vertical plane of the altimetric base line. The base line (*b*) is 2,000 yards, with *B'* at the battery and *B''* 200 yards above the battery.

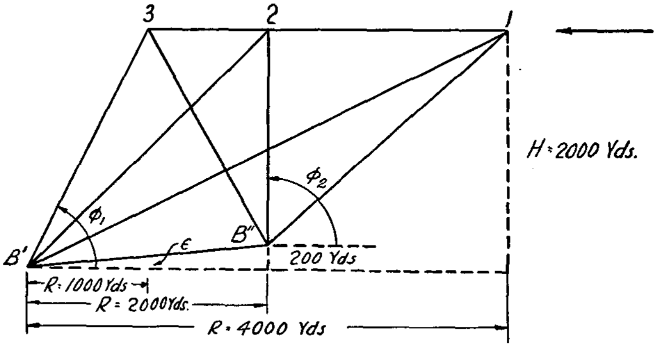


FIGURE 11.—Problem in determination of altitude.

When the target is at point 1, 4,000 yards from the battery

$$\cot \phi_1 = \frac{4{,}000}{2{,}000} = 2.00$$

$$\cot \phi_2 = \frac{2{,}000}{1{,}800} = 1.1111$$

Substituting these values in the formula

$$H = \frac{b}{\cot \phi_1 - \cot \phi_2}$$

$$H = \frac{2{,}000}{2.00 - 1.1111} = 2{,}250 \text{ yards. Error} + 250 \text{ yards}$$

In the same manner it can be shown that the altitudes computed by the altimeter will be

Point 2, 2,000 yards. Error 0
Point 3, 1,895 yards. Error —105 yards

Thus it will be seen that the error is neither constant in amount nor in direction and varies with the position of the target.

e. There is no provision on the altimeter, M1920, for making a mathematically accurate correction for the error introduced when the *B′* and *B″* stations are not at the same level; hence the application of an approximate correction must be resorted to. In the example given (fig. 11), it will be noted that the line joining the two stations makes an angle with the horizontal whose tangent is equal to $\frac{\text{difference in elevation}}{\text{length of base line}}$

$$\tan \epsilon = \frac{200}{2{,}000} = 0.100$$

$$\epsilon = 100 \text{ mils}$$

If the vertical angles read at each station are reduced by one-half this amount (50 mils) and again substituted in the fomula for *H*, the following values of altitude (*H*) will be computed

Point 1, 1,920 yards.
Point 2, 1,900 yards.
Point 3, 1,895 yards.

Realizing that 1,900 yards represents the altitude (*H*) of the target above the midpoint of the line joining *B′* and *B″*, it is clear that a correction of one-half the angular height (ϵ) from *B′* to *B″*, applied to each instrument, will provide a reasonably accurate computation of altitude (*H*) for all positions of the target, with a small constant error of one-half the difference in elevation between *B″* and *B′*, which can be removed by a flat scale correction. The method of applying corrections for the difference in elevation of *B′* and *B″* stations is discussed in paragraph 188.

■ 44. COMPARISON OF SINGLE-STATION AND TWO-STATION SYSTEMS.—*a*. *Availability of instruments*.—The present two-station altimeter, M1920, is an adaptation of a World War instrument. It is available in considerable quantities, and additional instruments can be procured quickly at a relatively low cost. The stereoscopic height finder, as an antiaircraft instrument, is a post-war development in this country, is difficult to manufacture, and is costly.

b. Accuracy.—Theoretically, the two-station system is the more accurate. Practically, the necessary "cramping" of scales to reduce the size of instruments and unavoidable personnel errors in operation offer little choice in accuracy between the two systems under normal conditions of operation.

c. Installation and control.—With respect to installation and control, the stereoscopic height finder is superior to the two-station system. It can be placed in operation much more quickly than the two-station system and operates under the direct control of the battery commander. The two-station system requires the establishment of a base line and the installation and maintenance of telephone communication. The lack of direct control over the distant station introduces an element of uncertainty as to whether both stations will "track" the same target in those situations where a number of potential targets are in the field of fire.

d. Transportation.—The 4-meter base stereoscopic height finder is a large bulky instrument weighing about 2,200 pounds when packed and requires wheeled transportation for movement over any considerable distance. The two-station system, including two altimeter instruments, telephones, and field wire, has about one-fourth the weight and may be "broken down" into loads convenient for handling.

e. Training of personnel.—The two-station system offers advantages over the stereoscopic height finder with respect to training of personnel. The required proficiency for altimeter operators is quickly reached, and no special qualifications for the operators are required. Proficiency, once attained, will seldom suffer appreciably through lack of continuous training. In contrast, stereoscopic observers must be carefully selected, carefully trained, and their proficiency maintained by continuous drill and practice.

SECTION III

PREDICTION; FUTURE POSITION

■ 45. DEFINITIONS.—*a.* Prediction is the process of determining the location of the target at some future instant based on the past performance of the target.

b. Future position of the target is that position in space at which it is expected the target will arrive at the end of the time of flight of the projectile.

■ 46. THE PREDICTION PROBLEM.—In paragraph 37, the methods of locating the present position of the target were explained. Briefly the present position may be located by certain combinations of the following elements: A_o, H, X_o, Y_o, ϵ_o, D_o, and R_o, all of which are either instantly available by the operation of tracking or are computed by some mechanism. The performance of the target is measured at the present position, and based on these data, performance of the target during time of flight of the projectile is predicted. The target occupies the present position only instantaneously. The relations between the various elements enumerated above exist only at that moment and are different from those existing the instant before and the instant after. As the data computor measures the performance at a certain instant, the prediction is based on what the plane is doing at that moment. If, for instance, the plane is flying on a rectilinear course, the prediction is made along the course extended in the same direction. If, however, the plane is flying a curvilinear course, the situation is different. Data computors cannot predict a curved course. All predictions are made along a straight line. Therefore, all predictions made on a curvilinear course will be along the tangent to the course at the present position of the target.

■ 47. METHODS OF PREDICTION.—There are two general methods of predicting the location of the future position of a target; the angular travel method and the linear speed method. As the names imply, the predictions of data computors which employ the angular travel method are based upon the observed angular speed of the target, while the predictions of data computors which employ the linear speed method are based on computed values of the target's ground speed and direction of flight. The standard antiaircraft director, M4, employs the linear speed method of prediction. However, some older types of directors employ the angular travel method of prediction. The design of future directors may be based on either method.

■ 48. **Angular Travel Method.**—The basis of the angular travel method is the measurement of the instantaneous angular speed or velocity of the target in azimuth and in elevation, and the multiplication of these instantaneous angular velocities by the time of flight. The quantities obtained by these multiplications will be the approximate lateral and vertical deflection angles. When suitable correction factors are introduced in the products, the principal lateral and vertical deflection angles will be obtained. The final form in which these predictions are utilized in pointing the gun depends upon the method of pointing used.

■ 49. **Angular Travel Error.**—The multiplication of instantaneous angular velocity by time of flight instead of average angular velocity by time of flight, or the solution of an equation which, in effect, accomplishes this, results in the determination of an approximate deflection angle (σ_x or δ_x) and the introduction of an error. This error is called the angular travel error. Referring to figure 12, consider as a specific example that an instantaneous vertical angular velocity has been measured at the point *a*, and that multiplication by the time of flight (*t*) has resulted in a line of direction through the point *b*, the arc *a–b* representing the angular travel of a target (vertically) during the time of flight. If this is correct, the target must be traveling on the arc of a

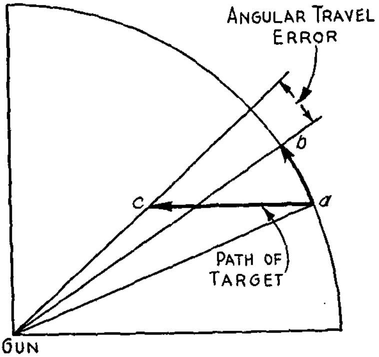


Figure 12.—Vertical angular travel error.

great circle at constant speed. However, the basic assumption made in antiaircraft gunnery is that the target moves in rectilinear flight. Therefore the path *a–c* represents the actual travel of the target during the time of flight (t), and the true line of direction should be through the point *c*. Hence, the prediction must be refined to correct for the angular travel error which is introduced by multiplying the angular velocity at the point *a*, which differs materially from that at the point *c*, by the time of flight. The correction may be accomplished in three general ways. If the instantaneous angular velocity (Σ) is multiplied by the true time of flight (t_p), first, a correcting multiplier may be used; or, second, a correction term of proper value (negative or positive) may be added to the result; and, third, the instantaneous angular velocity (Σ) may be multiplied by a fictitious time of flight (t') factor. Any one of these methods may be adapted to mechanical processes.

Certain courses exist where either one or both of the angular velocities are constant, for instance, a plane diving directly at the battery. But, it will be found that in nearly all conditions of flight, both the lateral angular velocity and the vertical angular velocity vary continuously, thereby introducing angular travel errors.

■ 50. **PRINCIPAL LATERAL DEFLECTION ANGLE (δ_1).**—The principal lateral deflection angle (δ_1) is the horizontal angle, measured at the gun position, through which the target will move in the time intervening between the firing of the gun and the arrival of the target and projectile at the future position. The magnitude of this angle is subject to exact mathematical determination under the basic assumptions of target flight. The general expression for this value is as follows:

$$\sin \delta_1 = \Sigma_a t_p \frac{\sin \epsilon_p \cos \epsilon_o}{\sin \epsilon_o \cos \epsilon_p}$$

where Σ_a (the instantaneous lateral angular velocity of the target in its present position) is expressed in radians per second. It is to be noted that the value of δ_1 depends upon the size of the principal vertical deflection angle as will be seen from the appearance of ϵ_o and ϵ_p above. Similarly, it will be found that the value of the principal vertical deflection angle is dependent upon lateral deflection. Thus, the equations for δ_1 and for σ_1 are simultaneous equations, neither of which may be solved without the other. The derivation of the above formula is found in paragraph 258.

■ 51. **PRINCIPAL VERTICAL DEFLECTION ANGLE (σ_1).**—The principal vertical deflection angle (σ_1) is the vertical angle, measured at the gun position, through which the target will move during the time intervening between the firing of the gun and the arrival of the target and the projectile at the future position. The magnitude of this vertical angle, like that of the principal lateral deflection angle, is subject to exact mathematical determination. The general expression for this value is as follows:

$$\sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} - \sin \delta_1 \tan \frac{\delta_1}{2} \sin \epsilon_o \cos \epsilon_p$$

where Σ_e (the instantaneous vertical angular velocity of the target at the present position) is expressed in radians per second. It should be noted that the expression for the value of the sine of σ_1 is made up of two parts. The first,

$$\Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o},$$

represents the product of future time of flight and the instantaneous vertical angular velocity corrected for the major part of the angular travel error (since it is multiplied by the ratio of

$$\left.\frac{\sin \epsilon_p}{\sin \epsilon_o}\right).$$

The second part of the expression for $\sin \sigma_1$ is called the complementary term, since it varies with the value of lateral deflection. The sign of this term is negative when the sign of σ_1 is positive and vice versa, but the effect of the complementary term is always to decrease the angular height to the future position regardless of the sign of σ_1. The derivation of the above formula is found in paragraph 258.

■ 52. **USE OF δ_1 AND σ_1.**—The values of δ_1 and σ_1 determined by the formulas in paragraphs 50 and 51 above are used in two different ways depending upon the method of pointing. In case 1½ pointing (par. 78) δ_1 and σ_1 are the principal deflections which are set on the sights of the guns. With δ_1 and σ_1 only set on the sight and the sight of the gun tracking the target, the axis of the bore is pointed at the future position of the target (T_p).

In case III pointing (par. 78), δ_1 and σ_1 are added algebraically to A_o and ϵ_o in order to get A_p and ϵ_p. T_p is located then in terms of A_p, ϵ_p, and H.

■ 53. LINEAR SPEED METHOD.—*a.* As used in our service, the linear speed method is based upon the continuous measurement of the ground speed (S_g) of the target and its direction of flight. As in the angular travel method, the present position of the target (T_o) is determined by the continuous tracking of the target thereby measuring A_o and ϵ_o, and the measuring of the altitude (H). R_o is computed mechanically from the data ϵ_o and H. T_o is then located to scale using the polar coordinates A_o and R_o. These polar coordinates are converted to rectangular coordinates X_o and Y_o. (See figs. 2 and 3.)

b. A device measures the instantaneous rates of change of X_o and Y_o. These rates are the E–W and N–S rates. The E–W and N–S rates are multiplied by the time of flight (t_p) to the future position (T_p) giving the E–W travel (ΔX) and the N–S travel (ΔY) during the time of flight. ΔX and ΔY are added algebraically to the coordinates of the present position X_o and Y_o giving X_p and Y_p. (See figs. 2 and 3.) X_p and Y_p are converted to polar coordinates A_p and R_p. Thus T_p is located in terms of A_p, R_p, and H_p.

SECTION IV

MECHANICAL SOLUTIONS

■ 54. GENERAL.—Mechanical computing devices are not uncommon; slide rules, adding machines, and cash registers are in everyday use. It is possible to obtain either a graphical or mechanical solution, or both, for almost any law of mathematics. Mechanical computing devices obtain answers very rapidly and in some cases instantaneously. This section considers the mechanical computing devices employed in the M4 director.

■ 55. **Variable Speed Drive.**—*a*. The variable speed drive is also known as the ball and disk integrator. It is used in the standard director—

(1) To perform multiplication or division.
(2) To change linear distance to rotary motion.
(3) As a variable speed drive.

b. The variable speed drive consists primarily of a flat disk (*M*), a cylinder (*R*), and two steel balls (*N*) mounted in a carriage one over the other and in contact with the disk and cylinder. The disk is rotated at a given angular velocity (ω). Rotation of the disk is transmitted through the steel balls to the cylinder. (See fig. 13.)

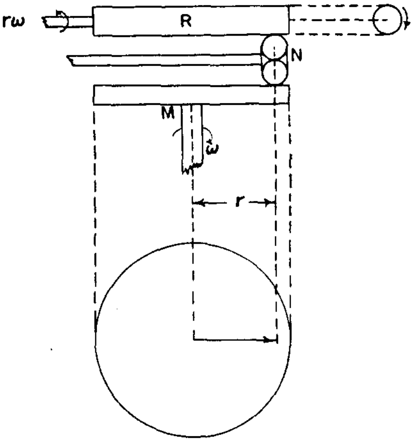


Figure 13.—Variable speed drive.

c. The operating principle of the variable speed drive is: the angular velocity of the cylinder is proportional to the angular velocity of the disk (ω) and to the displacement of the steel balls (r) from the center of the disk; that is,

$$\text{Angular velocity of cylinder} = \frac{\text{Angular velocity of disk} \times \text{displacement of balls from center of disk}}{\text{radius of cylinder}}$$

$$= \frac{\omega \text{ times } r}{\text{constant}}$$

Referring to figure 13, if the rotation of the disk (M) is in the direction shown, the rotation of the cylinder (R) will be shown. If the displacement of the balls (r) is zero, that is the balls are at the center of the disk (M) then

$$\text{Angular velocity of cylinder} = \frac{\omega \text{ times } 0}{\text{constant}} = 0$$

If the balls are moved to the left side of the disk (M), the rotation of the cylinder (R) will be in the direction opposite to that shown.

d. In the M4 director, the automatic prediction mechanism uses a variable speed drive to perform division. The disk is made to revolve at an angular velocity proportional to the reciprocal of the time of flight $\left(\frac{1}{t_p}\right)$. The displacement of the balls (r) is made proportional to prediction (ΔX, ΔY, or ΔH). Then the

$$\text{Angular velocity of cylinder} = \frac{1}{t_p} \times \text{prediction} \times \frac{1}{\text{constant}}$$

$$\text{But rate} = \frac{\text{distance}}{\text{time}}$$

Therefore the angular velocity of cylinder is proportional to the rate (either E–W, N–S, or altitude).

e. The automatic prediction mechanism also uses a variable speed drive to convert linear distance to rotary motion. (ω) must be constant. If the disk is driven by a constant speed motor, (ω) is constant. r is made proportional to the quantity which is to be converted from a linear distance to a rotary motion, the reciprocal of the time of flight $\left(\frac{1}{t_p}\right)$. Then the

$$\text{Angular velocity of cylinder} = \frac{\text{constant} \times \left(\frac{1}{t_p}\right)}{\text{constant}}$$

That is, the angular velocity of the cylinder is proportional to the reciprocal of the time of flight (t_p).

Likewise in the ballistic wind mechanism of the M4 director, r is made proportional to the E–W or N–S component of the ballistic wind. Then the angular velocity of the cylinder is proportional to the E–W or N–S component of the ballistic wind.

f. The range rate and altitude rate drives are used to supplement the manual operation of matching pointers in the M4 director. The disk is driven by a constant speed motor. The angular velocity of the cylinder is therefore proportional to the displacement of the balls. By adjusting the displacement, the operators can make either R_0 or H_0 change at a certain specified rate, or at a rate so as to keep the dials continuously matched. Such an operation can be done manually, but a power drive has the advantage of resulting in a smoother rate of change.

■ 56. DIFFERENTIAL GEARS.—*a*. The differential provides a method of combining two motions into one resulting motion which is the algebraic sum of the other two motions.

b. Essentially, a differential consists of three shafts interconnected by a train of gears. Figure 14 shows schematically what happens in a differential. Motion is imparted to shafts *A* and *B*. These motions are combined and result in the motion of the housing, which in turn is taken off by the shaft *C*. Any two of the shafts may be used for the input of data and the output will come out on the third shaft.

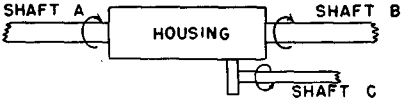


FIGURE 14.—Differential action.

c. The principle of the differential is best known in its application to the automobile. The same action takes place in the differentials of a director as in the differential of a car. All differential actions can be classified in three groups as follows:

	Input		Output
	Direction * and velocity of shaft A	Direction * and velocity of shaft B	Direction * and velocity of shaft C.
1 Adding	Counterclockwise ω revolution.	Clockwise ω revolution.	Counterclockwise $\frac{\omega+\omega}{2}$ revolution.
2 Canceling	Clockwise ω revolution.	Clockwise ω revolution.	Stationary.
3 Equating	Clockwise 2ω revolution.	Clockwise ω revolution.	Clockwise $\frac{2\omega-\omega}{2}$ revolution.

*The direction of rotation is as viewed looking down each shaft toward the differential in figure 14.

d. The adding differential, as the name implies, combines two motions so that the resulting motion is the algebraic sum. For example, when the director is in action, the azimuth transmitter is constantly positioned according to A_f. Any *dA* correction must be applied in such a way that it will not disrupt this flow of data. A differential is inserted in the system. The input of the differential is A_f and *dA*. The output is

$$Af \pm dA.$$

e. The canceling differential functions so as to keep the output zero. In figure 14, if shaft *A* is turned four revolutions clockwise, shaft *C* will turn. Now, if shaft *B* is turned four revolutions clockwise, shaft *C* will return to its original position. In other words, the output of the differential is zero.

f. The equating differential takes two motions (rates), compares them, and passes the difference to the output shaft. When the two motions are equal, the difference is zero, and therefore the output shaft will be stationary.

g. The same differential may perform any one of the three operations enumerated above. Figure 15 shows the differential used in the M4 director. The input and output of the differential are shaft (*A–B*) and gears *D* and *F*.

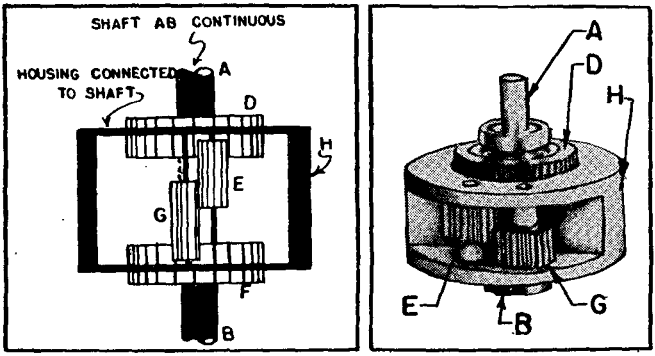


FIGURE 15.—Differential.

■ 57. **Three Dimensional Cams.**—*a.* A cam is defined as a plate, cylinder, or solid having a curved outline or groove, which rotates or translates about an axis and by its motion gives motion to another member or follower in contact with it.

b. Cams are used in the standard director for two different purposes:

(1) The ϵ_o cam solves for the horizontal range to the present position (R_o) using H_o and ϵ_o to position it.

(2) The ballistic cams solve for $\frac{1}{t_p}$, θ, and F using H_p and R_p to position them.

c. Any particular point on the surface of the ϵ_o cam represents a point in space whose coordinates are R_o and H_o. The lift of the cam follower or cam pin—that is, the distance of the point of the follower from the reference surface—is made proportional to the angular height (ϵ_o) of the point whose coordinates are R_o and H_o. The cam is rotated according to H_o and translated according to R_o. The follower is constrained by slides so as to have only one motion along its axis. In operation, the cam is first rotated until positioned in H_o. The cam is translated until ϵ_o measured from the cam is equal to ϵ_o measured by the elevation tracking telescope. The distance that the cam has been translated is proportional to R_o. (See fig. 16.)

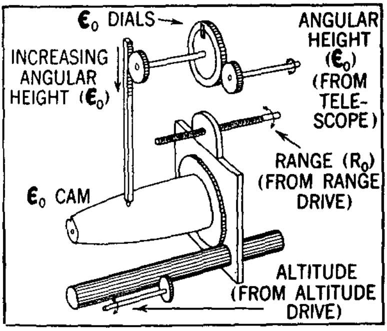


FIGURE 16.—ϵ_0 cam.

d. The ballistic cams are mechanical firing tables. A separate cam is necessary for each element $\frac{1}{t_p}$, ϕ, and F, but for ease of construction and operation, the three are mounted as an integral unit. Any particular point on the surface of a ballistic cam represents a point in space whose coordinates are H_p and R_p. By reference to firing tables, we can find the values of $\frac{1}{t_p}$, ϕ, and F for any point in space whose coordinates are H_p and R_p. The lift of each cam follower, that is, the distance from the point of the follower to the reference surface, is proportional to the values of $\frac{1}{t_p}$, ϕ, and F for the particular values of H_p and R_p. The followers are constrained by slides so as to have only one motion along their axes. The cams are rotated in R_p and translated in H_p. (See fig. 17.)

■ 58. COORDINATE CONVERSION MECHANISM.—*a.* Figure 18 illustrates the principle of the coordinate conversion mechanism. The present position of the target is located by polar coordinates A_o and R_o. The rectangular coordinates X_o and Y_o are measured by the displacement of the E–W and N–S slides from the N–S and E–W axes.

b. The actual mechanism (figs. 19 and 20) used for the conversion of coordinates employs the same principle illustrated in *a* above.

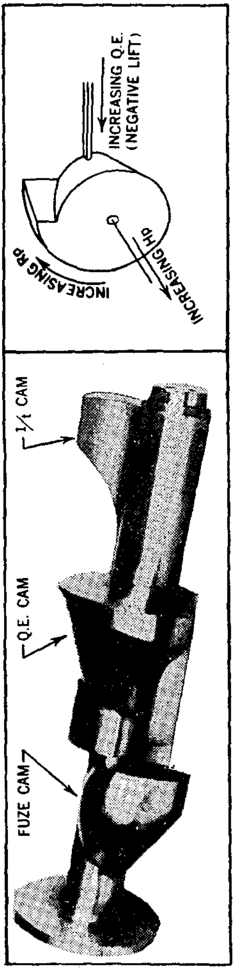


FIGURE 17.—Ballistic cams.

(1) To reproduce horizontal range to scale, a disk having a spiral groove is used. The center of the disk represents the gun position while the pin in the groove represents the target position. (See fig. 19.) The radial distance from the center of the disk to the pin represents the horizontal range to the target. To reproduce the target azimuth, an azimuth disk having a radial slot is placed next to the range disk so that the disk centers are common and the radial slot in the azimuth disk carries the target position pin and slide. By holding the azimuth disk stationary and turning the range disk, the target position pin is moved radially in or out along the slot in the azimuth disk. If only the azimuth disk moves, the pin swings about the disk center and at the same time slides

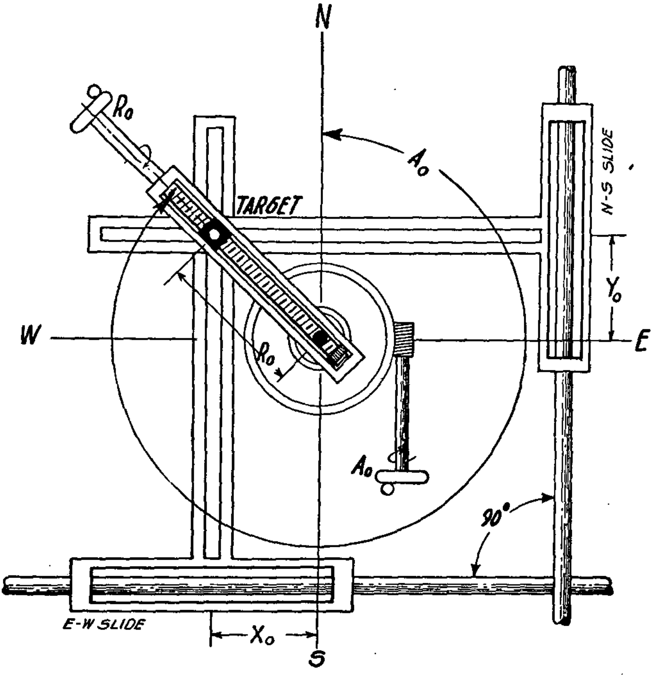


FIGURE 18.—Principle of coordinate conversion.

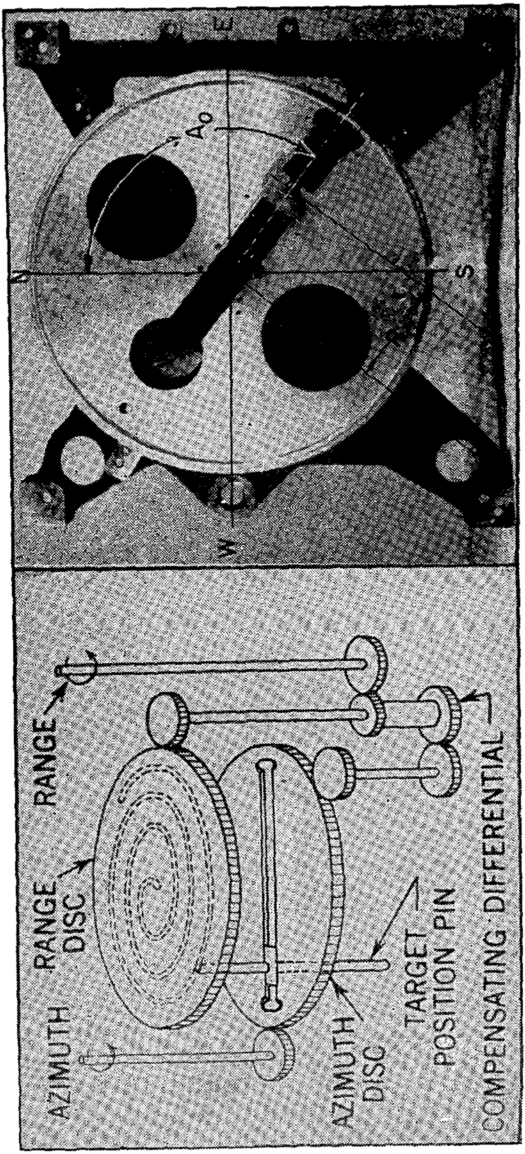


FIGURE 19.—Disk mechanism.

along the radial groove. A differential is inserted in the drive between the two disks so that a change in azimuth rotates both disks the same amount. Because of this, a change in azimuth does not change the horizontal range. Thus it is seen that by rotating the range disk and azimuth disk the target position pin is located by polar coordinates A_o and R_o in the case of the present position disks, and A_p and R_p in the case of the future position disks.

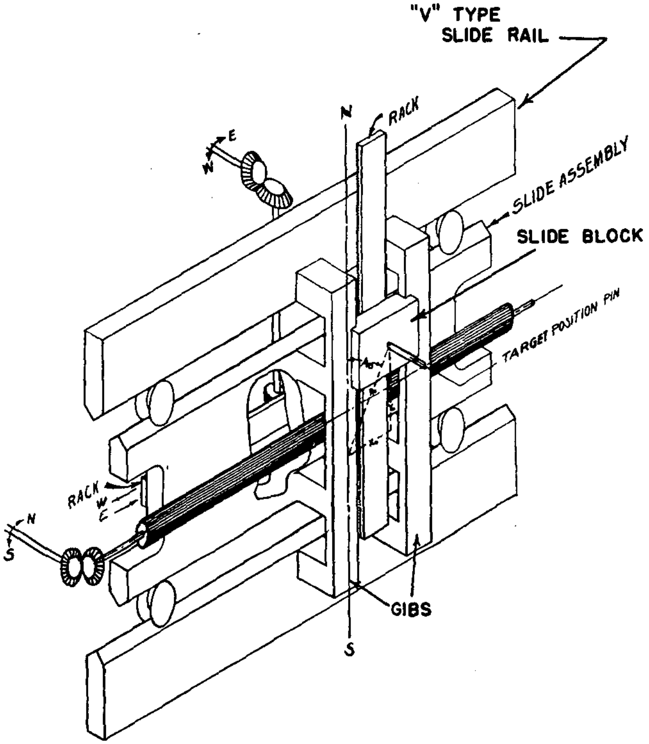


FIGURE 20.—Slide mechanism for coordinate conversion.

(2) The target position pin engages a slide block (fig. 20). The slide block is capable of two motions, one vertically on

the gibs (N–S or Y_o) and the other horizontally. For the horizontal motion (E–W or X_o) the entire slide assembly including the slide block and gibs rolls on the two V-type slide rails. Fastened to the slide block is a rack which engages with the long pinion. Fastened to the slide assembly is another rack which engages with a pinion. The motions of these two pinions are measured. The rate at which the pinions are turning is the E–W or N–S rate. The amount that the pinions have turned is X_o or Y_o on the present position disks and X_p and Y_p on the future position disks.

■ 59. AUTOMATIC PREDICTION MECHANISM.—*a*. Ordinarily the equation for prediction is:

$$\Delta X = \text{E–W. rate} \times t_p$$
$$\Delta Y = \text{N–S rate} \times t_p$$
$$\Delta H = \text{Altitude rate} \times t_p$$

In the solution of the prediction problem by the M4 director, it is more convenient to express the above equations in a different form which is:

$$E\text{–}W \text{ rate} = \Delta X \times \frac{1}{t_p}$$

$$N\text{–}S \text{ rate} = \Delta Y \times \frac{1}{t_p}$$

$$\text{Altitude rate} = \Delta H \times \frac{1}{t_p}$$

b. In paragraph 58 it is stated that the rate of turning of the pinions on the present position slides is the E–W or N–S rate. This rate is known as the "observed rate." In the altitude prediction mechanism the observed rate is set up by operation of the altitude rate drive. (See par. 55*f*.)

c. Figure 21 is a schematic diagram of an automatic prediction mechanism. Start at the $\frac{1}{t_p}$ cam in the lower left corner. The lift of the follower positions the ball carriage of the variable speed drive. According to paragraph 55*e*, the angular velocity of the cylinder is proportional to $\frac{1}{t_p}$. This cylinder, revolving at a rate proportional to $\frac{1}{t_p}$, is driving the disk of another variable speed drive in the upper left corner. Assume that the ball carriage has been displaced from the center a distance which we will call a prediction. Then by paragraph 55*d*—

Angular velocity of the cylinder=prediction $\times \frac{1}{t_p}$

But by *a* above:

Prediction $\times \frac{1}{t_p}$=rate (either E–W, N–S, or altitude).

Under the above circumstances, the variable speed drive is creating a rate which is called the "generated rate."

d. If we can make the generated rate equal to the observed rate, the displacement of the ball carriage is then proportional to the true prediction. The observed rate and the generated rate are the inputs of an equating differential. By paragraph 56*f*, the equating differential compares the two rates and passes the difference out through the third or output shaft. This output shaft of the equating differential is geared to the ball carriage of the variable speed drive. If the two rates (observed and generated) are not equal, the difference coming out through the output shaft moves the ball carriage and either increases or decreases the generated rate. When the two rates become equal, the difference is zero, and the output shaft is therefore stationary. The prediction is zero when the ball carriage is over the center of the disk. The amount that the output shaft of the equating differential has turned in positioning the ball carriage in order to equalize the rates is therefore proportional to the displacement of the ball carriage and hence proportional to the prediction.

■ 60. BALLISTIC WIND MECHANISM.—*a*. The ballistic wind causes the projectile to deviate from the normal trajectory. (See par. 86*d*.) In the M4 director, the wind is considered to have moved the future (predicted) position by amounts equal to the E–W and N–S components of the ballistic wind multiplied by the time of flight. This correction for ballistic wind is effected by correcting the generated rate in the automatic prediction mechanism.

b. Figure 21 shows schematically the ballistic wind mechanism. The components of the ballistic wind are obtained by operation of the wind component solver (fig. 55). Setting

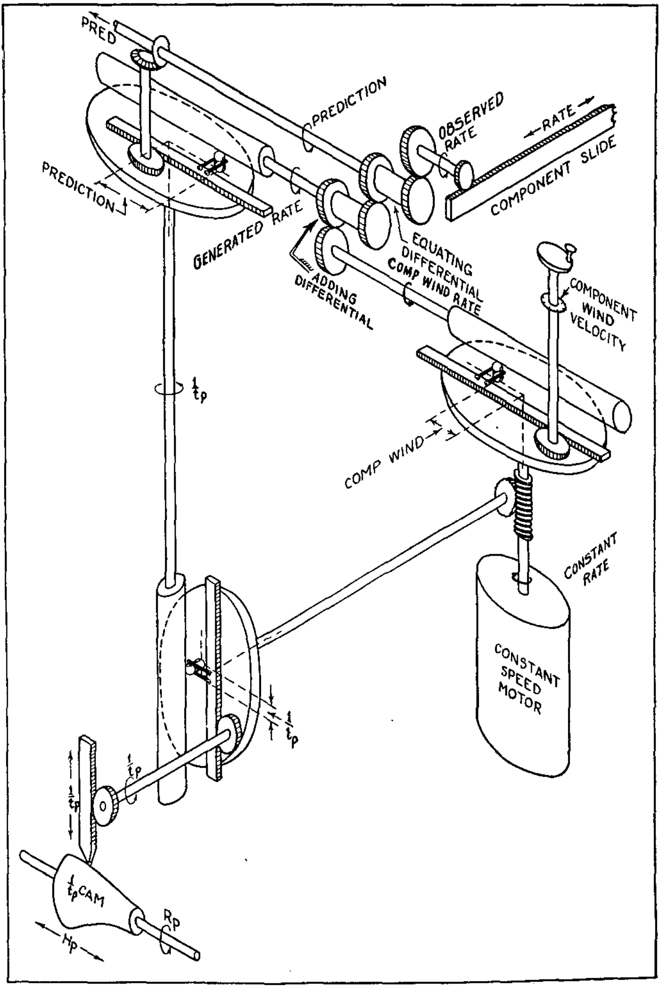


FIGURE 21.—Automatic prediction mechanism—ballistic wind mechanism.

the value of the wind component on the wind dial causes the ball carriage of the variable speed drive (on the right side of fig. 21) to be displaced from the center an amount proportional to that wind component. By paragraph 55*e*, the angular velocity of the cylinder is proportional to the wind component. This wind rate is added algebraically to the generated rate by a differential before the generated rate enters the equating differential (par. 56*d*). The output of the adding differential is therefore the generated rate ± the wind component rate. Hence the wind correction is included in the prediction.

c. The ballistic wind mechanism has another use in that it supplies rates for static check problems. When the director is stationary, the observed rate is zero and therefore the prediction is zero. The ballistic wind mechanism can be used to set up a rate in the automatic prediction mechanism which will take the place of the observed rate. In figure 21 the component rate passes through the adding differential to the equating differential where it causes the prediction shaft to turn, making a prediction and displacing the ball carriage of the variable speed drive (upper left). A rate which is fed into the adding differential is generated. When this generated rate is equal to the component rate, the rates will be equated by the differential and no further output will enter the equating differential to change the prediction. The generated rate is equal to the component rate. The wind dials are graduated from 0 to 50 miles per hour. Target velocities are greater than wind velocities, therefore problem velocity dials (graduated from 0 to 200 yards per second) are mounted adjacent to the wind dials. They are set by the same knob as the wind dials but are used only when setting in problems. In setting wind rates, the knob is restricted by a stop to approximately one revolution. In order to set target velocities, the knob is pulled out to pass the stop.

■ 61. MOVABLE INDEX DIAL.—*a*. The movable index dial is a means of adding one quantity to another algebraically. Figure 22 is a sketch of a spot dial on the M4 director. The complete dial consists of two concentric rings about a central disk. The outermost ring, with the words "TRIAL FIRE CORR." on it, is fixed. The second ring, called the movable index, is capable of rotation in either direction by using the movable index knob. The central disk is operated by the spotting handwheel and indicates the correction applied.

b. Suppose that the movable index is moved to down (minus) 10 as shown in the figure. If the indices are matched as shown, there is a spot of down (minus) 10 in the data computor although according to the spot dial and movable index the correction is 0. This is the procedure followed in making ballistic corrections before opening fire. (See par. 100.) If, as a result of firing, a correction of down (minus) 10 is ordered, the spot dial is turned by means of the spotting handwheel so that it reads down (minus) 10 with reference to the movable index. It will be noted that with reference to the fixed index on the outer ring, the correction is down (minus) 20. The device has added the two corrections algebraically. Its use eliminates mental addition by the operator

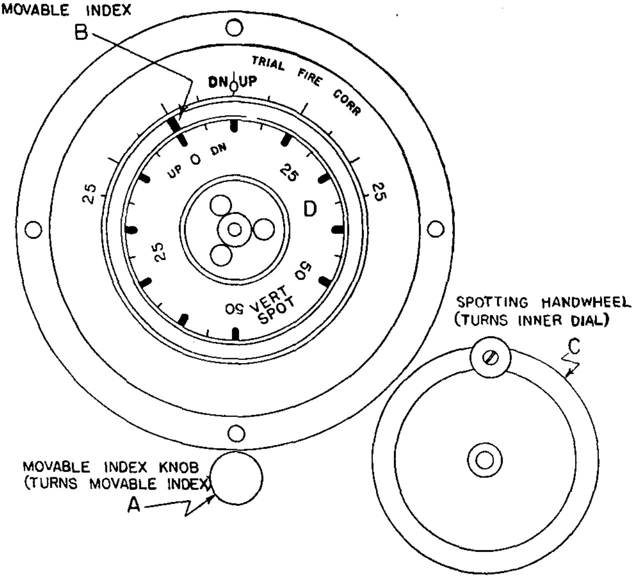


FIGURE 22.—Spot dial.

and thereby reduces the possibility of the occurrence of personnel errors.

SECTION V

FIRING DATA

■ 62. **GENERAL.**—*a.* Instruments used for the computation of antiaircraft artillery firing data are automatic in their action and the necessary firing data are obtained without reference to printed tables or charts. Firing table and trajectory chart data must be available for the designing of instruments and computations incident to calibration corrections and to trial fire. An understanding of the use of firing tables and trajectory charts is essential in connection with the conduct of antiaircraft fire, including the preparation and observation of fire.

b. Trajectories are calculated for a gun of given characteristics, developing a stated or assumed muzzle velocity, and firing a projectile with a given ballistic coefficient. In other words, each combination of gun and ammunition has its own characteristics. *Therefore, we must use the firing tables, trajectory chart, and ballistic cams pertaining to the particular combination of gun and ammunition being used.*

c. Firing tables and trajectory charts are available for use as follows:

Firing tables and trajectory chart No.	Normal MV	Date	Caliber of gun	Projectile and fuze
3 AA-I-2	2,400	December 1928	3″	Shell, HE, Mk. I; fuze Mk. III. Shrapnel, Mk. I; fuze Mk. III.
3 AA-J-2	2,600	October 1928	3″	Shell, HE. Mk. I; fuze Mk. III. Shrapnel, Mk. I; fuze Mk. III.
3 AA-K-2	2,800	February 1929	3″	Shell HE, Mk. IX; fuze Mk. III.
3 AA-L-1	2,600	October 1928	3″	Shell, HE, Mk. IX; fuze Mk. III.
3 AA-N-1	2,800	August 1929	3″	Shell, HE, Mk. IX; fuze M2.
3 AA-O-1	2,700	April 1939	3″	Shell, HE, M42; fuze M43.
105 AA-E-1	2,800	Not available for general circulation.	105-mm	Shell, HE, M38; fuze M2.
105 AA-C-2	2,800	do	105-mm	Shell, HE, M38; fuze Mk. IIIA1.
75 M-1		August 1930	75-mm	Shell, HE, Mk. III.

■ 63. **Firing Table Assumptions.**—Firing tables are prepared by the Ordnance Department for each type of gun and ammunition under a set of conditions arbitrarily assumed as standard. Their enumeration will serve to acquaint the reader with the more important factors which affect the trajectory.

Standard conditions.

Muzzle velocity (*MV*) (as listed in the table).
Wind (W), none.
Air density at the battery, 59° F. and 29.53″ of mercury.
Air saturation, 78 percent. (525.9 grains per cu. ft.)
Temperature of air at battery, 59° F.
Temperature of powder, 70° F.
Weight of projectile (as listed in table).

In addition, a standard atmosphere aloft is assumed; that is, atmospheric temperature and density vary with altitude (*H*) in a linear relationship. Drift (δ_{2d}) and lateral and vertical jump are determined experimentally.

■ 64. **Contents of Firing Tables.**—*a*. The present standard firing tables are published in book form. The first section gives general information pertaining to the gun and carriage and the projectile and fuze. It also contains a detailed explanation of the tables and of the meteorological message.

b. Part 1 of the tables contains charts and tables applicable to all combinations of projectile, fuze, and powder charge, and is the same in all antiaircraft artillery firing tables.

c. Part 2 consists of a number of sections, each of which gives data pertaining to a particular combination of projectile, fuze, and powder charge. This part of the firing tables includes the following:

(1) Trajectory data.
(2) Fuze setter data.
(3) Drift in yards and in mils.
(4) Probable error—
(*a*) In time of flight in seconds.
(*b*) Along the trajectory in yards.
(*c*) In plane of the trajectory in yards in direction normal to the trajectory.
(*d*) In deflection in yards.

(5) Differential effects on horizontal range, altitude, and angular height due to—

(*a*) Change in angle of elevation.

(*b*) Change in muzzle velocity.

(*c*) Rear wind.

(*d*) Change in air density.

(*e*) Weight of the projectile.

(*f*) A decrease of one division in corrector setting.

(6) Differential effects on deflection in yards and mils due to cross wind.

(7) Differential effect on time of flight in seconds due to a decrease of one division in corrector setting.

d. The effect of both vertical and lateral jump is included and combined with other elements in the tables and does not appear as a separate effect.

e. It should be noted throughout the differential variations listed in the firing tables that the algebraic signs, where given, are those for effects and not for corrections; further, that the signs for drift effects apply to panoramic sights in which the deflection scale readings increase as the line of sight is turned to the right. These sights are not used on antiaircraft artillery guns and care should be taken to apply the correction for drift effects in the proper direction.

f. Extracts from Firing Tables 3 AA–J–2a and 3 AA–O–1 are given in paragraph 257.

■ 65. TRAJECTORY CHARTS.—The trajectories plotted on the charts, together with the associated time of flight and fuze curves, the range and altitude components, and the quadrant elevation and angular height data, represent the results of the calculation of the trajectories in air for the guns and the ammunition named under the assumed standard conditions. The charts are constructed to show only that part of each of the trajectories which is included within the maximum time of burning or setting of the particular fuze used. Figures 23 and 24 show trajectory charts for Firing Tables 3 AA–J–2a and 3 AA–O–1.

■ 66. CORRECTIONS FOR NONSTANDARD BALLISTIC AND ATMOSPHERIC CONDITIONS.—Since ballistic cams in the data computor are constructed from data contained in the firing tables (par. 57*d*) it is obvious that the data from the instrument will be

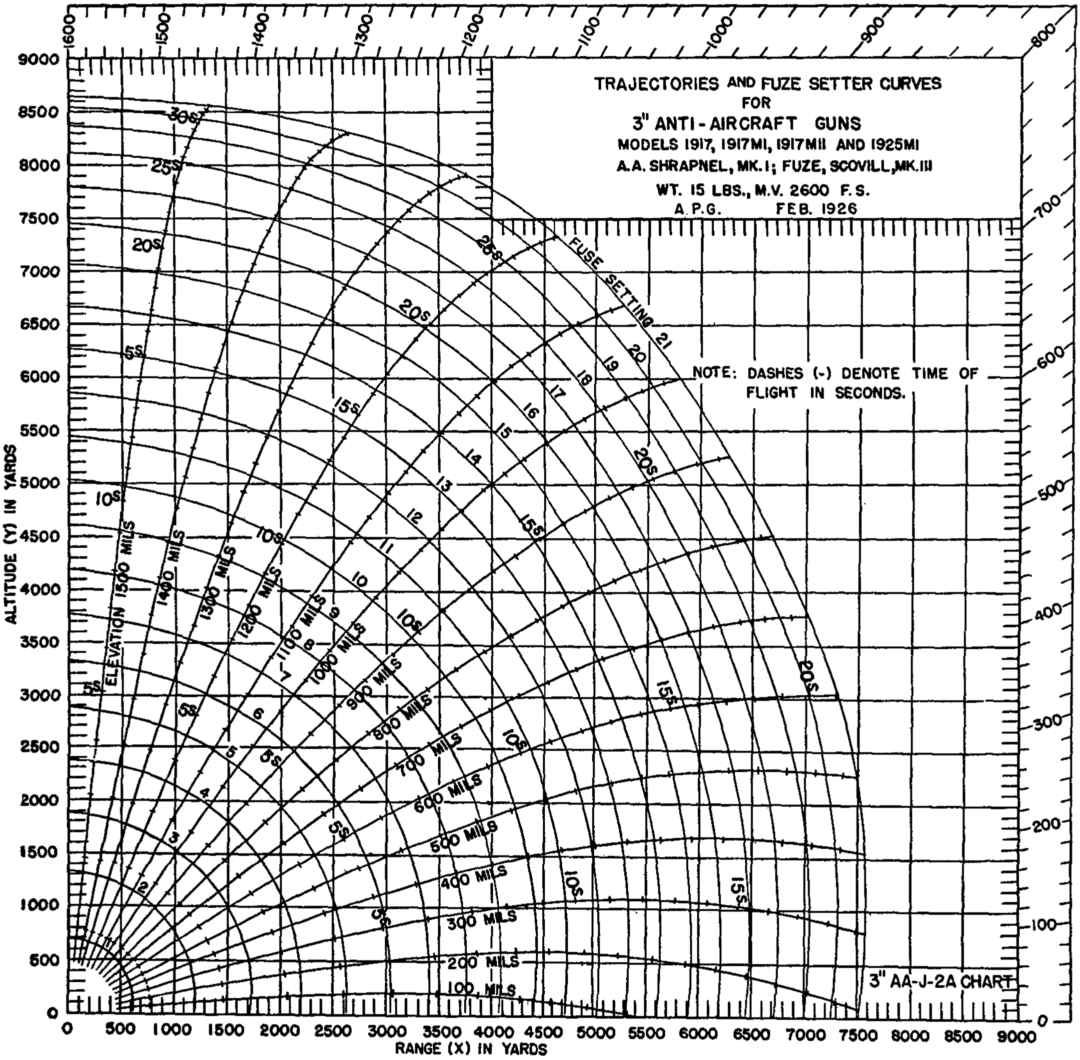


FIGURE 23.—Trajectory chart 3 AA–J–2a.

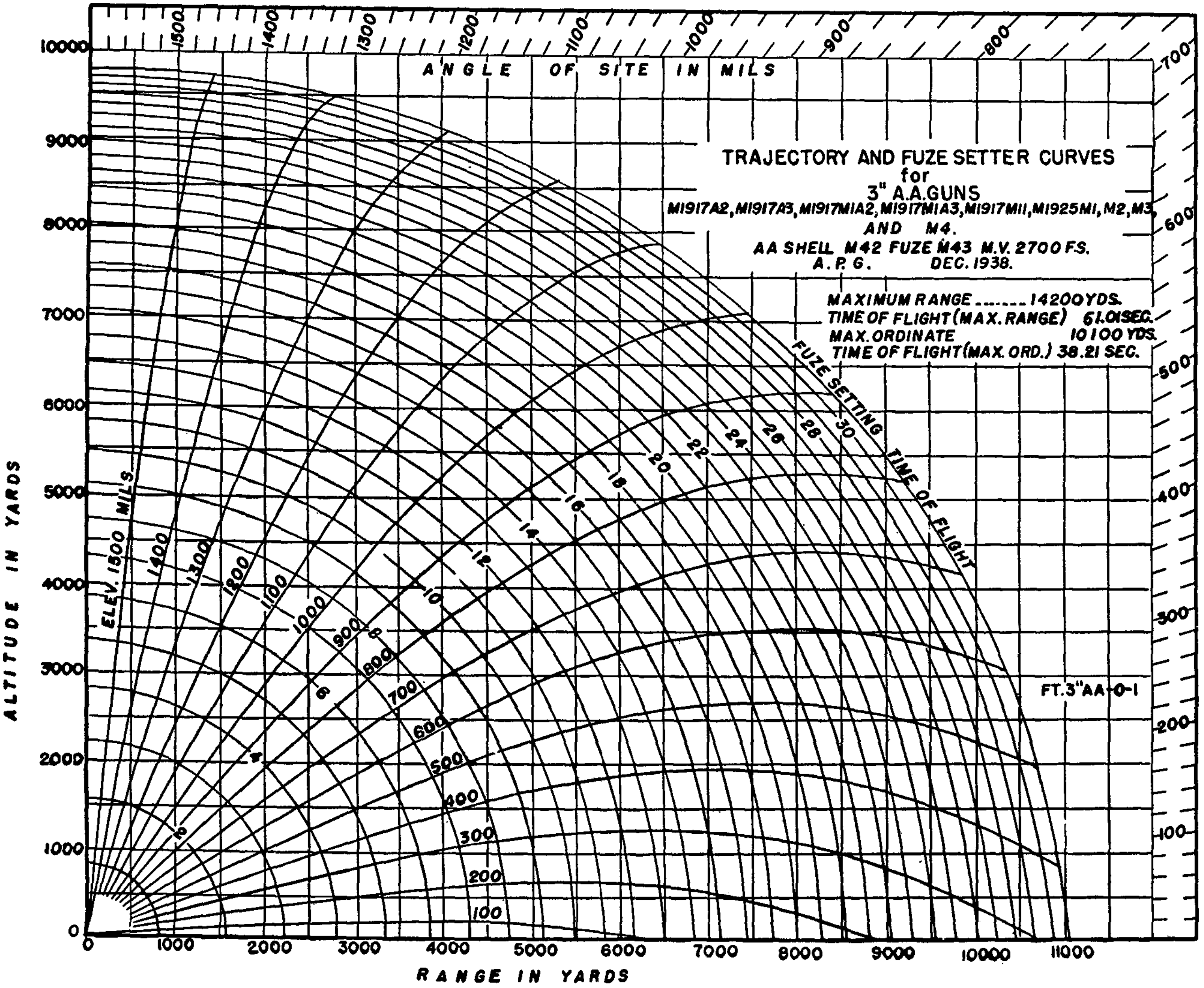


FIGURE 24.—Trajectory chart 3 AA-O-1.

the same as that which could be extracted from the firing tables. Therefore these data will be correct only when the conditions, as enumerated in paragraph 63, are standard. This will rarely, if ever, be the case. The variation of the different elements from standard conditions must be determined and corrections for their effect applied. The muzzle velocity (*MV*) to be expected may be determined approximately by studying the results of previous firings and by applying the effect of a difference in powder temperature from standard. The variation from standard in the weight of a projectile is determined at a glance from markings on the projectile. The actual conditions of the atmosphere remain to be determined.

■ 67. **Meteorological Message.**—*a.* The determination of the atmospheric conditions seldom devolves upon the battery commander. They are determined by other agencies and the information is furnished in the form of a coded meteorological message as indicated in the following example:

Coded message	Translation
MFS MFS 20570	Meteorological message from station FS 2—AA fire. 05—altitude of station 500 feet. 70—temperature at station 70° F.

	Zone		Direction of ballistic wind in mils from north	Speed of wind in m. p. h.	Density in percent of normal
	No.	Altitude in feet			
0241698	0	0	2,400	16	98
1231798	1	600	2,300	17	98
2221898	2	1,500	2,200	18	98
3211898	3	3,000	2,100	18	98
4211998	4	4,500	2,100	19	98
5202099	5	6,000	2,000	20	99
6202099	6	9,000	2,000	20	99
7192199	7	12,000	1,900	21	99
8182299	8	15,000	1,800	22	99
9182200	9	18,000	1,800	22	100

b. All measurements are made at the meteorological station, and if the location of the firing battery differs in altitude, suitable corrections must be made. Azimuth of the wind is always that from which the wind is blowing. The groups of figures for each zone contain data for ballistic wind and ballistic density. The term "ballistic" signifies a wind and density equivalent in effect to the sum of the winds and densities actually encountered up to the indicated altitude. Use the group of the meteorological message of which the altitude is nearest to, but not less than, the altitude of the target. Therefore, if a target at 13,000 feet altitude is being fired upon, only the group "8182299" need be decoded.

■ 68. **CORRECTED FIRING DATA.**—*a*. The effect of variations from standard conditions may be illustrated by a specific example.

Assume:

	Present position	*Future position*
Altitude (H) (yards)	4, 200	4, 200
Angular height (ϵ)	672	820
Horizontal range (R)	5, 400	4, 035
Quadrant elevation (ϕ)		900
Time of flight (t_p)		13. 1
Fuze range (F)		12. 7

Muzzle velocity (MV) 2,500 f/s (previous firings).

Temperature of powder, 70° F.

Azimuth (A_p) of target from battery, 1,800 mils.

From the preceding meteorological message for zone 8—

Wind azimuth (A_w)	1, 800 mils.
Speed	22 m. p. h.
Density	1% (decrease)

Referring to firing table extracts in paragraph 257, and trajectory chart, figure 23, the effects of these conditions on the path of the projectile are readily listed as follows:

Condition	Effect	
	Horizontal range	Altitude
Muzzle Velocity (MV) 50 f/s decrease (cams cut for 2,550 f/s)	−50 (ΔR_v)	−64 (ΔH_v)
Temperature of powder 70° F	0	0
Wind. Head wind 22 m. p. h.	−73 (ΔR_w)	−16 (ΔH_w)
NOTE.—From the azimuth of the target and the azimuth of the wind there is no cross-wind effect.		
Density 1 percent decrease	+13	+16
Total	−110 (ΔR)	−64 (ΔH)

To correct for these effects, the gun must be pointed in elevation so that the trajectory will pass through a point whose coordinates are

	Horizontal range	*Altitude*
Uncorrected coordinates, future position	4, 035 (R)	4, 200 (H)
Correction	110 (dR)	64 (dH)
Corrected coordinates	4, 145	4, 264

Which requires, from the trajectory chart, the following approximate firing data:

Quadrant elevation (ϕ)	898 mils
Fuze (F)	13.0

The only lateral effect on the trajectory from the conditions given is that of drift (δ_{2d}) 7 mils right. To correct for this, the gun must be pointed 7 mils to the left of the target, or at 1,793 mils azimuth.

b. With this convincing example of the necessity for correcting firing data, the question will naturally arise as to how the instantaneous and continuous calculation and application of these corrections may be incorporated with the mechanically computed uncorrected firing data. It will be found that methods exist in the calculation and application of corrections, ranging from the roughest approximations, applied manually and periodically, to the mechanically complex methods of instantaneous and continuous calculation and application. The method of applying corrections for nonstandard conditions is fully explained in paragraph 100.

SECTION VI

DATA TRANSMISSION SYSTEMS

■ 69. **GENERAL.**—There are three standard data transmission systems in use in the antiaircraft artillery at the present time; the telephone, the mechanical flexible cable, and the self-synchronous alternating current system.

■ 70. **TELEPHONE.**—The present standard field telephone is the EE–8. It is a highly efficient type of local battery telephone and is designed to be used with field telephone wire. It is used where necessary to transmit data over distances that are too great for the other two systems to operate satisfactorily; that is, distances in excess of 500 yards in the case of the A. C. system and 100 feet in the case of the flexible shaft system. It has the disadvantage that transmission of the desired data is not instantaneous and is subject to error.

■ 71. MECHANICAL FLEXIBLE SHAFT SYSTEM.—This system consists of a piece of stiff steel wire encased in a flexible metal housing. It is similar to the flexible shaft that connects the drive shaft of an automobile to the speedometer. The system transmits data instantaneously but has the disadvantage that it may be used for short distances only. It is relatively inexpensive and simple.

■ 72. A. C. SELF-SYNCHRONOUS DATA TRANSMISSION SYSTEM.—This system is used to transmit data from the director to the guns of a gun battery. It is completely self-synchronous and transmits data instantaneously. A power plant which furnishes 110-volt, 60-cycle, single-phase alternating current is required to operate the system. Multiconductor cables, connected by junction boxes, transmit the data and the power. Electrical data transmitters are included in the director; electrical data receivers are attached to the guns. The M3 and M4 systems, which are practically identical, are the present standard systems.

■ 73. THEORY OF OPERATION OF A. C. DATA TRANSMISSION SYSTEMS.—*a*. The transmission of data is accomplished in the following manner: In figure 25, let P_t and P_r be two similar coils of wire connected in parallel to a 110-volt, single-phase, A. C. line. These coils are fixed with respect to a frame. Let S_t and S_r be two similar coils mounted on shafts in such a manner as to allow them to rotate in the frame. The alternating current in P_t and P_r will induce alternating voltages in the coils S_t and S_r, but these coils are so connected that these voltages are opposite to each other. Since all parts are similar and similarly positioned, the voltages are also equal. The voltages therefore cancel each other and there is no current in the series circuit connecting coils S_t and S_r. Suppose, however, that the coil S_t is rotated in some manner, the angle of rotation being proportional to the data that it is desired to transmit. The similarity of position between the coils P_t and S_t and P_r and S_r is now destroyed, and the voltages induced in coils S_r and S_t will not be equal. A current will therefore flow in the series circuit connecting coils S_t and S_r. This current produces a torque which tends to rotate both S_t and S_r. S_t, however, is held by the mechanism which caused its initial rotation so that only S_r is free to rotate. S_r will rotate as long as there is a torque on it, and there will be a torque on it as long as there is current through it. When S_r assumes the same angular position with respect to P_r that S_t has with respect to P_t, the induced voltages will again be equal and opposite and therefore no current will flow. This angular position will be a position of stable equilibrium for the coil S_r, and the angle turned into S_t will be reproduced by S_r rotating through the same angle. In this system, the coil designated by the subscript "*t*" acted as the transmitter, since it was mechanically rotated proportionally to the data to be transmitted, while the coil designated by the subscript "*r*" acted as the repeater, since it "repeated" the angle set into the transmitter. Obviously, the two could have been interchanged.

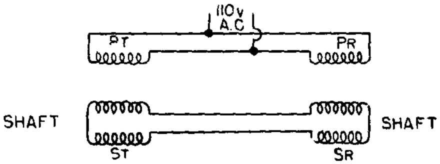


FIGURE 25.—Simple transmitter and receiver.

b. The above simple system has the serious disadvantage of having "dead points" at which the magnitude of the induced voltage is always zero. To eliminate these "dead points," the coils S_t and S_r are replaced by three coils each. The three coils are placed 120° from each other and connected in "Y" connection as shown in figure 26.

c. It is seen from the above (fig. 25) that the transmitter and repeater may be identical in every detail. In practice, however, slight differences exist between these units.

(1) The transmitter is made physically larger than the repeater so that several repeaters may be positioned by one transmitter.

(2) The repeater is provided with an oscillation damper to prevent oscillation about the equilibrium point.

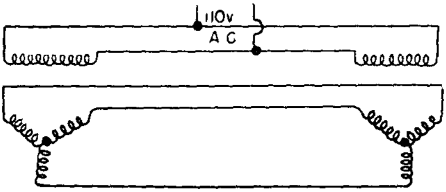


FIGURE 26.—Principle of the self-synchronous A. C. data transmission system.

■ 74. SINGLE OPERATION.—In a system consisting of a single transmitter and repeater, the units are connected as shown at the top of figure 27. The two primary windings are excited from a common source of 110-volt, single-phase, A. C. (or from the same phase, in the case of a multiphase supply) and the rotor windings are connected phase for phase. Figure 27 also shows the developed torque, excitation (primary) current, and induced (secondary) current from various angles of relative displacement. The torque is zero for both 0° and 180° displacement. For the 180° position, however, both the primary and secondary currents are a maximum, and this is a position of unstable equilibrium. The repeater will never operate of its own accord in this position, but will always synchronize when the primary windings are excited. Thus, on the resumption of power after an interruption, the units will automatically synchronize themselves.

■ 75. MULTIPLE OPERATION.—*a.* In a system consisting of a single transmitter and two or more repeater units, the operation is, in general, the same as the single operation. There are, in addition, several features to be noted. The torque angle characteristics for single operation given in figure 27 are dependent on the size of the transmitter and receivers. If a given size is taken as standard, then the torque developed by that size transmitter or repeater may be considered as the standard torque. If two repeaters are operated from one transmitter of the same size as the repeaters, the torque, developed in each repeater at any given angular displacement, will be only ⅔ of the standard torque. In general, the developed torque, T_r, will be

$$T_r = \frac{2T}{n+1}$$

where T=standard torque
n=number of repeaters

In order to bring this developed torque up to the standard torque, the transmitters are usually made larger than the repeaters.

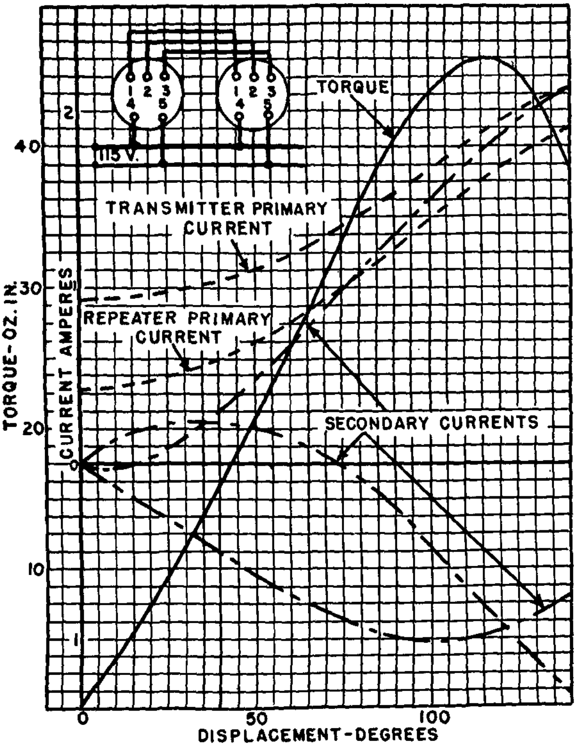


Figure 27.—Approximate characteristics of A. C. synchronous units.

b. If the load (friction, inertia) on the separate repeater units differs, the lightly loaded units will help the transmitter to keep the more heavily loaded units in proper synchronism, and much greater than standard torques may be developed in the more heavily loaded unit. This is accompanied, however, by an increase in the size of the displacement angle of the entire system. Therefore, if the rotation of a single repeater is opposed by inertia or friction, all other repeaters in the same circuit have a displacement error greater than normal.

■ 76. EFFECT OF EXTERNAL VOLTAGE AND IMPEDANCE.—The torque on the coils S_t and S_r, in figure 25, arises from the interaction of the magnetic fields due to the current induced in S_t and S_r and the current in P_t and P_r.

a. External voltage.—The effect of voltage changes is then obvious.

Since $I_p = \frac{E_p}{Z_p}$ where

E_p = voltage impressed on P_t (or P_r)
Z_p = external impedance of circuit + internal impedance of P_t or P_r = constant
I_p = current in P_t or P_r,

we see that the torque will decrease as E_p decreases. It is desirable, therefore, to maintain an equal voltage (110 volts) on both transmitter and repeater primaries. In order to accomplish this, an autotransformer or tapped resistor is included with the generating unit to step up or lower the voltage at the remote units, thus compensating for the differences in line drop and equalizing the voltages at the transmitter and repeater primaries.

b. External impedance.—The torque depends also on the current in the secondary windings. This current will be

$$I_s = \frac{E_{st} - E_{sr}}{Z_{st} + Z_{sr} + Z_e} \text{ per phase, where}$$

$(E_{st} - E_{sr})$ = net induced voltage per phase
$(Z_{st} + Z_{sr})$ = impedance of the windings
(Z_e) = external impedance due to the connecting wires

The term Z_e affects the phase of the currents in the secondaries, and the greater the value of Z_e the less the current, hence the less the torque. When Z_e becomes comparable with $(Z_{st}+Z_{sr})$ serious difficulties may arise. For this reason it is highly desirable to keep the resistance of the connecting lines as low as possible, and keep this resistance the same for all of the secondary windings.

■ 77. **Data Transmission for Antiaircraft Batteries.**—Three sets of data must be supplied to an antiaircraft gun; elevation, azimuth, and fuze range. The mechanisms by which these data are determined are not pertinent to this section. It is sufficient to state that in the standard data computors, the three sets of data are supplied automatically and continuously, and that the gun is kept laid in azimuth and elevation by the matching of the mechanical gun indices with the data pointers. Similarly, the fuze setter is kept set by matching its mechanical fuze-setting index with the transmitted data indicated by the fuze setter receiver's pointer. The electrical transmission of altitude from the stereoscopic height finder and the target designating system (par. 39*d*) are also included in the system.

Section VII

APPLICATION OF FIRING DATA TO GUNS

■ 78. **General.**—*a*. Firing data for antiaircraft firing includes data for pointing the gun and data for setting the time fuze so that the projectile will burst at the future position of the target.

b. Pointing the gun includes the application to the gun of the direction and elevation data required to cause the trajectory to pass through the target. The form in which these data must be furnished depends upon the method of pointing employed.

c. There are four general methods of pointing guns:

(1) *Case I*.—In which the direction and quadrant elevation are both given by means of the sight.

(2) *Case I½*.—In which the direction is given by the sight and the quadrant elevation is given by a combination of the sight and an elevation scale or graduated drum.

(3) *Case II.*—In which the direction is given by the sight and the quadrant elevation is given by means of an elevation scale or graduated drum.

(4) *Case III.*—In which the direction is given by means of an azimuth scale and the quadrant elevation is given by means of an elevation scale or graduated drum.

d. Case I½ pointing is no longer a standard method and no further discussion of it will be made. Case II has never been used with antiaircraft firings.

e. The two remaining methods, case III and case I, are described in paragraphs 79 and 80.

■ 79. CASE III POINTING.—*a.* The elements of firing data for case III pointing are firing azimuth (A_f), quadrant elevation (ϕ), and fuze range (F). Each of these elements of data is determined by the data computor and transmitted continuously and electrically to the guns. The gun is properly pointed when the operating personnel elevate and traverse the gun and operate the fuze setter so that the mechanical pointers of the receivers coincide with the electrical pointers.

b. Transmission of data by telephone or word of mouth for case III pointing is possible, but this process is so slow that its use is precluded except as an emergency method, and then its use should be confined to guns not equipped with sights. When sights are available and an electrical data transmission system is not installed or is not in serviceable condition, case I pointing is employed.

■ 80. CASE I POINTING.—*a.* In paragraph 156 it is stated that the director M4 is provided with a means of determining data for case I firing. It is necessary that the guns be equipped with sights to use this method. At present, sights are not standard equipment on the guns. In the future such equipment may become available. Case I pointing will then, in all probability, be used only as an emergency system of fire control.

b. The elements of firing data for case I pointing are lateral deflection, vertical deflection, and fuze range. Each of these elements is determined by the director and transmitted by telephone to the guns. At the guns, these data are set on the appropriate dials. The gun is then properly pointed when the gun pointer tracks the target with his telescope. It should be noted that there is no provision for incorporating dead time in the computation of data by the director M4. Consequently, when case I pointing is used the data are only approximate.

SECTION VIII

CLASSES, TYPES, AND METHODS OF FIRE

■ 81. GENERAL.—Antiaircraft artillery gunfire is divided and subdivided into classes, types, and methods as shown on p. 70.

■ 82. DEFINITIONS.—The following definitions apply to the classes, types, and methods of fire:

a. Preparatory fire.—Fire that is conducted for the purpose of determining or verifying corrections to firing data.

b. Calibration fire.—Preparatory fire having for its purpose the determination of the separate corrections to be applied to the individual guns of a battery in order to cause the bursts to occur in a definite pattern in the sky.

c. Trial fire.—Preparatory fire having for its purpose the determination of corrections for the battery as a whole to compensate for deviations not corrected for in the normal operations of data computation.

d. Verification fire.—Preparatory fire having for its purpose the test of the mechanical adjustment of all guns and fire-control equipment of the battery and of the accuracy of the corrections determined as a result of calibration fire and trial fire.

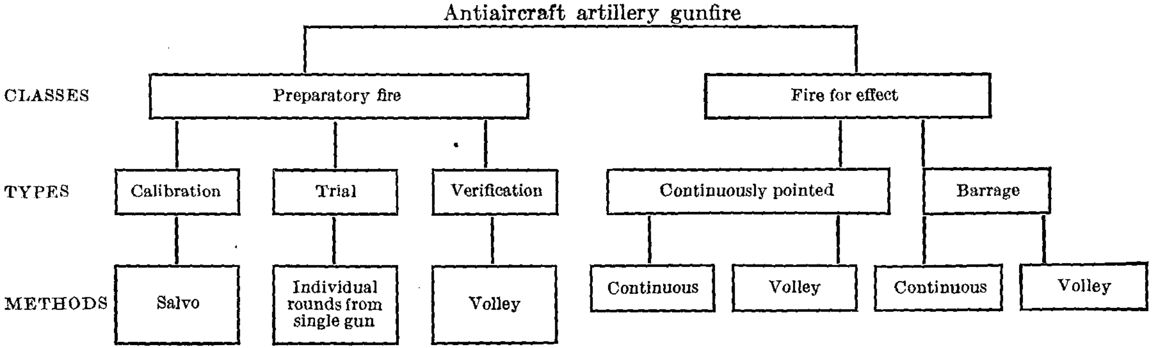
e. Salvo fire.—Fire in which the guns of the battery fire one after another in order, as Nos. 1, 2, 3, and 4.

f. Fire for effect.—Any fire conducted against a hostile target.

g. Continuously pointed fire.—Fire in which the fire-control devices are directed on the target and the data vary continuously with the position of the target.

h. Barrage fire.—Fire having for its purpose the placing of a curtain or barrier of fire, executed on predetermined firing data, across the probable course of enemy aircraft.

i. Continuous fire.—Fire conducted at the normal rate without interruption.


Antiaircraft artillery gunfire
CLASSES
Preparatory fire
Fire for effect
TYPES
Calibration
Trial
Verification
Continuously pointed
Barrage
METHODS
Salvo
Individual rounds from single gun
Volley
Continuous
Volley
Continuous
Volley

j. Volley fire.—Fire in which each gun of the battery fires a specified number of rounds at the maximum rate without regard to the other guns of the battery.

SECTION IX

EXTERIOR BALLISTICS

■ 83. GENERAL.—*a.* In the preceding sections, the fundamental operations of locating an airplane target and calculating firing data have been presented. Despite the care with which the firing data are calculated and the guns pointed, it should not be expected that all projectiles fired from a gun will strike the target. It becomes necessary to investigate more thoroughly the factors which affect the path of a projectile. The solution of the various problems may then be approached with greater understanding.

b. The solution of these problems involves the application of principles of gunnery, which is defined as "the art and science of firing guns." Application of the principles of gunnery has for its purpose the reduction or elimination of the effect of those factors which cause a projectile to deviate from its intended path. This section presents a consideration of these factors, together with the methods which have been evolved for solving the various antiaircraft gunnery problems.

■ 84. DEFINITIONS.—Ballistics is defined as "the science of the motion of projectiles." It is divided into two main parts—interior ballistics and exterior ballistics.

a. Interior ballistics is the study of the motion of the projectile while still in the bore of the gun, together with the chemical and physical phenomena which cause and attend this motion. It provides a determination of the relationship between the projectile, powder, and gun, and the velocity of the projectile and corresponding powder gas pressures at any point in the bore, with particular reference to the muzzle velocity and maximum pressure. Its chief application is found in problems of design and manufacture.

b. Exterior ballistics is the study of the motion of the projectile after it has left the gun. Its practical application is in the calculation of trajectories, construction of firing tables, and computation of other data essential to the solution of gunnery problems. It is the basis of the art of gunnery and therefore of prime importance to the artilleryman.

■ 85. **STANDARD TRAJECTORY.**—*a.* The antiaircraft artilleryman must be provided with accurate information for every point of a considerable arc of the trajectory with particular emphasis upon the time element. Only a portion of the trajectory, principally the ascending branch, is useful due to the time limitation of a fuze. The elements of primary importance to the antiaircraft artilleryman are illustrated in figure 28. Although the useful portion of a trajectory might be extended by increasing the time of burning of the fuze, it is well to point out that there is a practical limit which must be established.

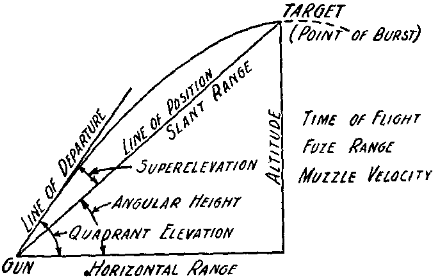


FIGURE 28.—Elements of a trajectory (antiaircraft guns).

b. The simplest problem of the trajectory is the hypothetical case of a projectile fired "in vacuo." Considering that the projectile leaves the gun with a known velocity (v) and in a known direction, there being no force, except gravity, acting upon it after it leaves the gun, the equation of its path reduces to that of a simple parabola. (See fig. 29.) The coordinates of the point *P* are:

$$x=OM\cos\phi=Vt\cos\phi$$
$$y=OM\sin\phi-MP=Vt\sin\phi-\tfrac{1}{2}gt^2$$

(g=acceleration due to gravity)
(t=time of flight)

The equation of the parabola is:

$$y=x\tan\phi-\frac{gx^2}{2V^2\cos^2\phi}$$

The equations for x and y above may be expressed as simultaneous differential equations as follows:

$$\frac{dx}{dt}=V\cos\phi \qquad \frac{d^2x}{dt^2}=0$$

$$\frac{dy}{dt}=V\sin\phi-gt \qquad \frac{d^2y}{dt^2}=-g$$

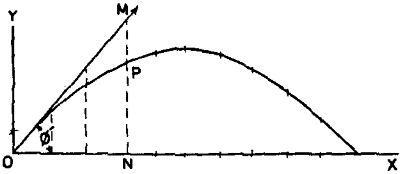


FIGURE 29.—Trajectory in vacuo.

c. Under normal conditions, when a projectile leaves a gun, it is acted upon by two forces, the force of gravity and the resistance of the air. This latter force is usually called the "retardation" and is very complex. It will be recalled that a rotating motion is imparted to the projectile while it is in the bore of the gun due to a twist in the rifling, for the principal reason of insuring stability in flight. This rotating motion has a decided effect upon the air resistance. When a projectile leaves a gun, it possesses a certain amount of kinetic energy which must be partially expended in overcoming air resistance as follows:

(1) Displacement of a volume of air from the path of the projectile.

(2) Skin friction between the surface of the projectile and the particles of air.

(3) Formation of eddy currents around the projectile.

(4) Formation of a partial vacuum in rear of the projectile.

(5) Wave motion set up in the air by the projectile.

(6) Gyroscopic wobbling.

d. Resistance of the air operates to change all the characteristics of the "trajectory in vacuo." Application of the natural laws of "applied mechanics" has been proved by experiment to be inadequate in calculating the trajectory in free air. The retardation force due to air resistance is considered as dependent upon—

(1) The relative velocity between projectile and air, which takes into consideration the motion of the air (wind).

(2) The condition of the air, which takes into consideration such factors as temperature, pressure, saturation, and, from these, density.

(3) (*a*) The size, weight, and shape of the projectile. These characteristics of the projectile are combined to facilitate calculations and expressed by a single number called the ballistic coefficient" (C), which is considered as a measure of the power of the projectile to overcome air resistance. The value C is

$$C=\frac{w}{id^2}$$

where w is the weight of the projectile in pounds; d, the diameter in inches; i, the coefficient of form.

(*b*) The value of i is determined empirically and referred to an arbitrarily chosen standard shape of projectile which is assigned a coefficient of 1.

e. The calculation of trajectories is performed by the Ordnance Department. The standard equations of "applied mechanics," having proved inadequate, are supplemented by empirical formulae which have been derived as a result of experimental firings. The equations of the trajectory in air which are used are as follows:

$$\frac{d^2x}{dt^2}=-vE\cos\phi$$

$$\frac{d^2y}{dt^2}=-vE\sin\phi-g$$

where v represents the velocity of the projectile; g, the acceleration due to gravity; E, a function of the retardation, R, $(E=R/v)$.

NOTE.—Compare the above formulae with the simultaneous differential equations in *b* above, which are the equations of the trajectory "in vacuo."

The retardation factor R is determined from the empirical formula

$$R=\frac{vG(v)H(y)}{C}$$

in which

$G(v)$, read the "G-function of v," represents the retardation of a standard projectile ($C=1$), and is obtained from ballistic tables;

$H(y)$, read the "H-function of y," is a function of the height of the projectile above the muzzle of the gun and introduces into the value of R the change in density of the air with altitude, $H(y)=e^{-hy}$, where $e=2.7182$, the base of Naperian logarithms, y=altitude, and h=constant; C is the ballistic coefficient.

Formerly, these were solved by the laborious processes of numerical integration. They are now solved by a computing machine known as a differential analyzer, which reduces the time required for the solution of complex differential equations, in some cases, from a matter of days to a matter of a few minutes.

f. Starting with an initial set of conditions—that is, ballistic coefficient, muzzle velocity, and angle of departure—the antiaircraft trajectory is computed, taking successive points, each of which corresponds to a certain time of flight. The trajectory thus calculated is known as a standard trajectory. The calculation of the standard trajectory is the primary problem in ballistics.

■ 86. DIFFERENTIAL EFFECTS.—*a. General.*—Trajectories are computed for standard conditions, but seldom, if ever, will the artilleryman find standard conditions existing at the time of firing. Therefore the secondary problem in ballistics is to determine the effect of variations from these standard conditions. The Ordnance Department calculates the effects of variations from standard conditions wherever they are of sufficient magnitude to be appreciable. These calculations are included in the firing tables in the form of "differential effects tables" (par. 257). The mathematical equations from which these effects are calculated are quite complex and generally only first-order effects are considered. First-order effects are linear in nature, that is, they may be represented by a straight line. If at a specific point on the trajectory an increase of 10 f/s in muzzle velocity increases the horizontal range attained by a projectile by 25 yards, a decrease of 10 f/s will decrease the range by the same amount, and a change of 100 f/s in either direction will be ten times that for a 10 f/s change. A detailed study of these effects is of the utmost importance since most of the gunnery problems which confront the antiaircraft artilleryman arise from the deviation of a projectile from its standard trajectory.

b. Muzzle velocity.—(1) A point on the trajectory chart, 3 AA–J–2a (fig. 23), at a horizontal range of 4,740 yards

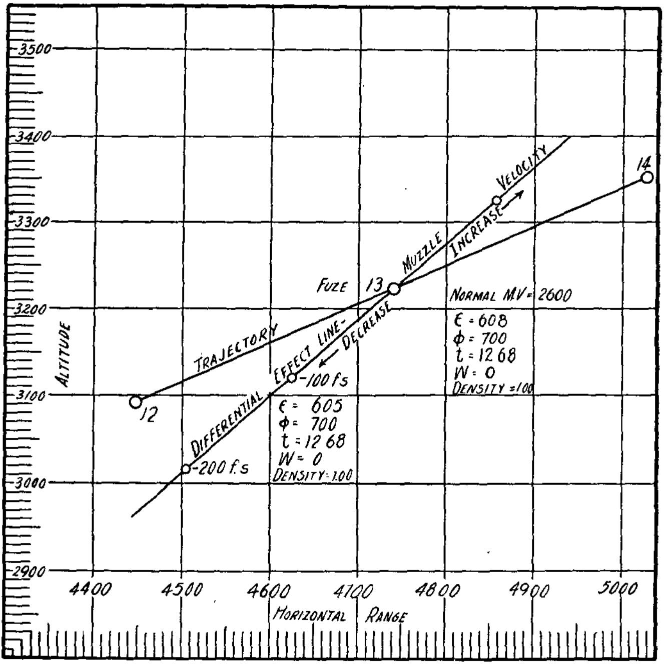


FIGURE 30.—Differential effect line—muzzle velocity.

and an altitude of 3,223 yards, is arbitrarily selected. The trajectory through this point may be plotted from data contained in table XIX of the extracts of Firing Tables 3 AA–J–2a, paragraph 257. From table XXII, paragraph 257, data may be obtained for plotting a straight line through this point which represents the differential effects due to a change in muzzle velocity. The situation is illustrated in figure 30. This is a graphic representation of information contained in the firing table. If a projectile were fired under standard conditions, it should be expected to burst at the point $R=4{,}740$, $H=3{,}223$. If the muzzle velocity changed and all other conditions remained unchanged, it would burst somewhere along the differential effect line. It should be carefully noted that a variation from standard muzzle velocity changes the altitude, horizontal range, and angular height of the expected point of burst, but does not change the time of flight or the quadrant elevation.

(2) The causes of variations from standard muzzle velocity are numerous, but those of principal interest to the artilleryman are erosion of the gun and varying temperatures of the powder charge. Antiaircraft guns are classified as high-velocity guns, and their accuracy life may be considered as much shorter than that of guns ordinarily used for firing at land or water targets. For example, a certain combination of gun, projectile, and powder charge might be designed to develop a muzzle velocity of 2,600 f/s and would normally be expected to develop this velocity. However, the wear or erosion in a gun is directly proportional to the number of rounds fired from it; hence a decrease in developed muzzle velocity may be expected to accompany continued firing, even though identical projectiles and powder charges are used. Antiaircraft guns use fixed ammunition, and in calculating standard trajectories a powder temperature of 70° F. is assumed. Variations from this temperature result in appreciable changes in developed muzzle velocity.

c. *Ballistic density*.—(1) Continuing consideration of differential effects in the vicinity of the point $H=3{,}223$, $R=4{,}740$, the effects of a variation in ballistic density from standard will be found in table XXII, paragraph 257, and may be represented graphically as shown in figure 31. A projectile fired under standard conditions should be expected to burst at the point $R=4{,}740$, $H=3{,}223$. With a variation in ballistic density, all other conditions remaining standard, it should burst somewhere along the differential effect line, which results in a change in the altitude, horizontal range, and angular height of the expected burst.

(2) The standard ballistic density is based upon a temperature of 59° F., a barometric pressure of 29.53 inches of

mercury, and a saturation of 78 percent. It is also assumed to vary in a standard manner with altitude above the ground. Wide variations in ballistic density are to be expected over an extended period of time. Normally, the changes over brief periods of time will be small.

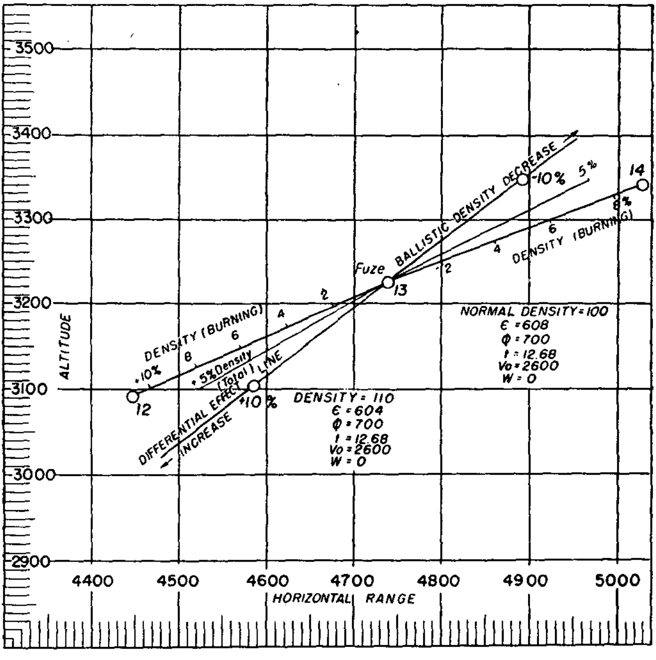


FIGURE 31.—Differential effect line—ballistic density.

(3) In addition to the effect of density on the trajectory as shown in (1) above, density materially affects the time of burning of powder-train fuzes. Part 1GB, page 7, of Firing Tables 3 AA–J–2a shows graphically the effect of density on the time of burning. These effects are measured along the trajectory, a greater than normal density causing the time of burning to decrease. Figure 31 shows both effects of density. The vectorial sum of the effects of a 10-percent

variation in density (ballistic and burning) is also shown in figure 31. In practice, the effect of variations in muzzle velocity and density are averaged. (See par. 97*h*.)

d. Ballistic wind.—(1) Standard trajectories are computed under the assumption that there is no wind, a condition which will seldom, if ever, confront the artilleryman. The effect of wind upon a projectile depends upon the direction of the wind (A_w), the velocity of the wind (W), the direction of the plane of fire (A_f), and the time of flight (t). For convenience, the wind is resolved into two components as illustrated in figure 32. Considering for the moment only the effect of a range wind, a differential effect line may be plotted (fig. 33) from information contained in Table XXII, paragraph 257, in the same manner as those for variations from standard muzzle velocity and density.

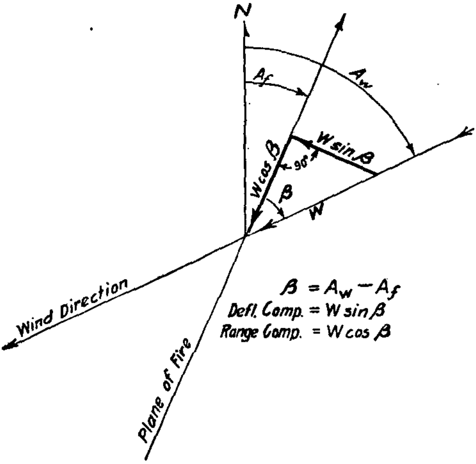


FIGURE 32.—Vector diagram of ballistic wind.

(2) A projectile fired under the standard conditions of no wind should be expected to burst at the point R=4,740, H=3,223. The effect of a range wind is to cause the burst to occur somewhere along the differential effect line for wind, thus changing the altitude, horizontal range, and angular

height of the expected burst. As a general rule, the direction and velocity of the ballistic wind are not subject to rapid changes, but the effect of the wind depends upon the direction of the target from the gun, and hence is subject to very rapid changes in the case of an airplane target.

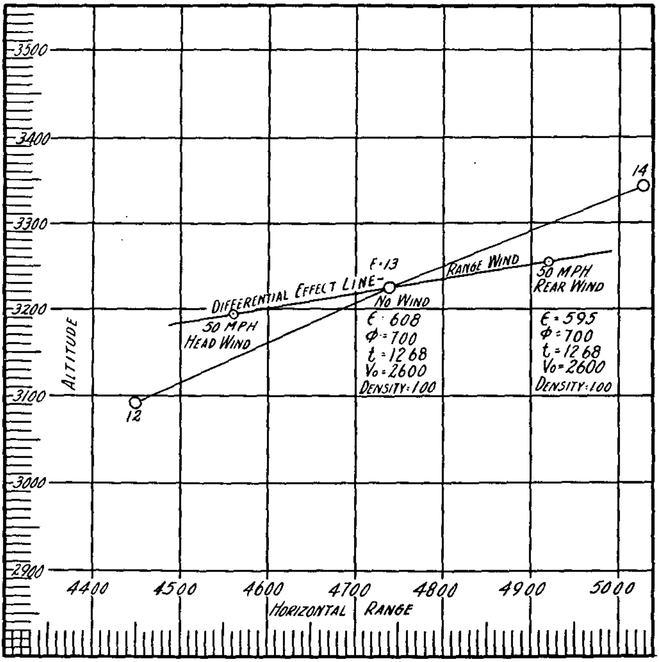


FIGURE 33.—Differential effect line—ballistic wind.

e. Quadrant elevation and fuze setting.—(1) The effects of two other variations are of importance; a change or an error in setting quadrant elevation on the gun, or the fuze range on the projectile. These effects are illustrated in figure 34. It will be noted that a change in fuze setting moves the burst along the trajectory and a change in quadrant elevation moves the burst along the ϕ line. In either case the altitude, horizontal range, and angular height of the expected burst are changed. Note that differential effect lines for these elements, taken from data contained in Table XXII, paragraph 257, provide very close approximations of the trajectory and ϕ line in the vicinity of the point under consideration.

(2) Errors in quadrant elevation usually arise from some maladjustment or malfunctioning of matériel. However, the time of burning of a powder train fuze is affected by a number of factors, among which are—

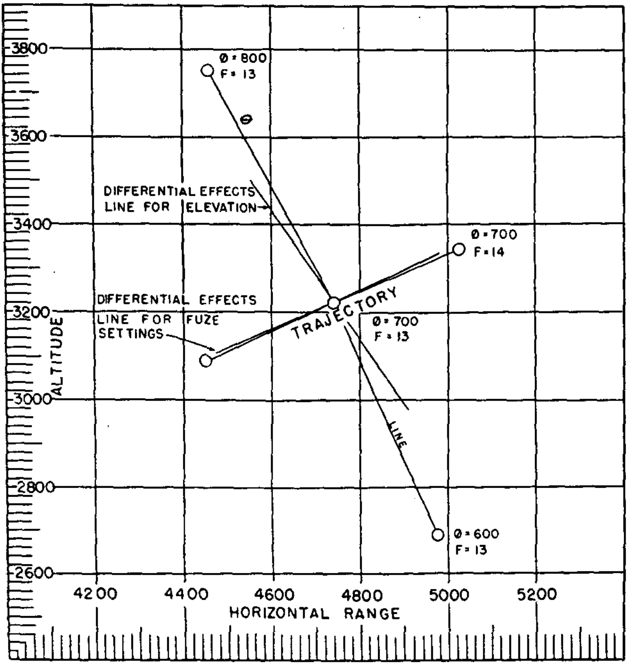


FIGURE 34.—Differential effect lines—quadrant elevation and fuze setting.

(*a*) Atmospheric pressure under which it burns.

(*b*) Temperature of the fuze.

(*c*) Speed at which it is rotating while burning.

(3) Not infrequently a difference in time of burning will be noticed between fuzes of different manufacture or different lots made by the same manufacturer. Conditions of storage sometimes affect the rate of burning of the powder train. The mechanical fuze is unaffected by these factors.

f. Altitude.—Although this element, strictly speaking, pertains solely to the position-finding problem, the effect of change of altitude upon the position of the burst is of interest. The change in the position of the burst is effected through a change in the calculated firing data, which is based upon the elements of the target's position. As illustrated in figure 35, a change in altitude (ΔH) with no change in angular height will move the expected point of burst along the line of position.

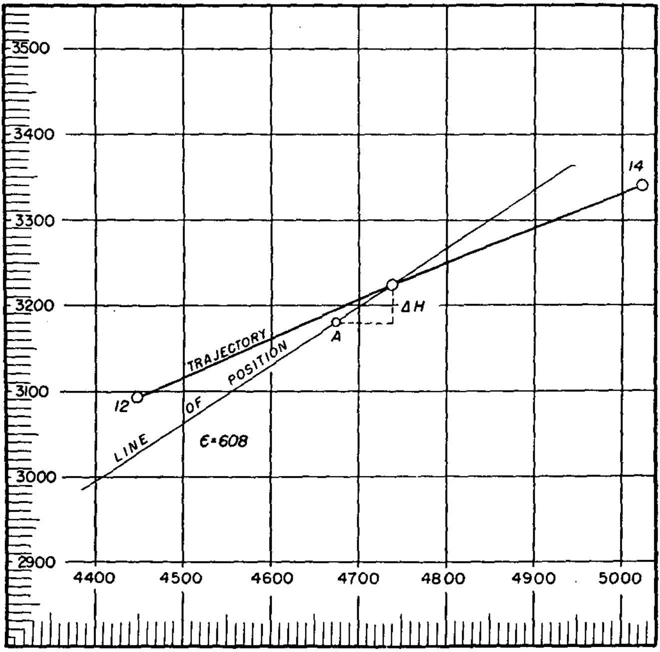


FIGURE 35.—Differential effect line—altitude.

g. The differential effects due to the earth's rotation and variations in weight of projectile, which are of considerable magnitude in firing long-range seacoast guns, are not of particular importance in antiaircraft gunnery problems. Variations in air temperature affect density and power temperature corrections.

■ 87. CROSS WIND AND DRIFT EFFECTS.—*a*. The resolution of the effect of ballistic wind into two components, a range component and a deflection component, is discussed in paragraph 86*d*. The deflection component of the wind manifestly causes a deviation of the projectile from its standard trajectory in direction (azimuth). In figure 32 it is clear that the deflection component of the wind will tend to carry the projectile to the left. The angular deviation will be proportional to the velocity of the deflection component, time of flight of the projectile, and quadrant elevation at which the projectile leaves the gun. Differential effect tables for cross wind will be found in the firing tables as in the case of the range wind component. The magnitude of the cross wind component depends upon the azimuth of the target and will vary quite rapidly in the case of an airplane target.

b. Drift is the horizontal angular deviation of the projectile from its plane of departure from the gun, caused by the rotation of the projectile and the resistance of the air. It varies with time of flight and quadrant elevation. Tables containing values of drift are contained in firing tables. (See table XX, par. 257.)

■ 88. DANGER SPACE OF SHELL BURSTS.—*a*. The danger space resulting from the burst of a 3″ antiaircraft high-explosive shell has been found to have a shape approximating the shape generated by the revolution of the area, shown in figure 36, about its long axis. It resembles a mushroom. This danger space has been determined by experiment and represents the volume which is filled with shell fragments of sufficient size and velocity to secure penetration of an arbitrarily chosen standard material.

b. The dimensions of this danger space are of importance in solving gunnery problems related to securing "hits" on a moving airplane target. It is to be noted that projectiles bursting beyond the target are ineffective. For effectiveness projectiles must burst at the target or just short of it.

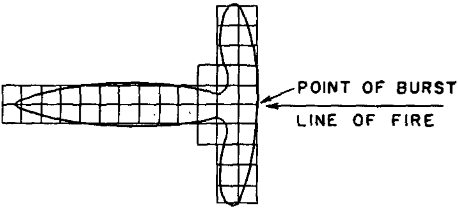


FIGURE 36.—Danger space of 3'' antiaircraft shell burst.

SECTION X

ERRORS AND PROBABILITIES

■ 89. **DISPERSION AND ERRORS.**—*a*. In section IX, the more important reasons for the deviation of a projectile from its standard trajectory are briefly analyzed. During the discussion, the behavior of only a single projectile was considered. Let it now be assumed that a very large number of shots, each with the same fuze setting, is fired from a gun which is carefully pointed at the same azimuth and elevation for each shot fired and that, as far as can be determined, standard conditions prevail for each shot fired. Experience has shown that these shots will be scattered in range and in direction, laterally and vertically. This scattering is called "dispersion". The shots may be expected to arrange themselves about a definite point, called the "center of dispersion", in a manner which may be approximately predicted mathematically. The center of dispersion will not necessarily coincide with the point at which fire is directed, and its location can never be determined precisely as it is the mean point of burst of an infinite number of shots. The mean point of burst of a finite number of shots is called the "center of burst".

b. The factors which prevent all projectiles from bursting at the same point and which cause that point to deviate from the intended target are known as "errors". A complete explanation of the causes of errors or the mathematical theory underlying them is not within the scope of this manual. However, it may be said that the laws of probability and the theory of errors as applied to seacoast artillery firing (FM 4–10), apply with equal force to fire against aircraft. The essential difference lies in the fact that in seacoast artillery, dispersion in a horizontal plane only is considered while in antiaircraft artillery it is necessary to consider a dispersion in volume. Errors are divided into two general classes:

(1) Accidental errors are those errors which cause a dispersion of shots about the center of burst. Accidental errors, such as those arising from inaccurate or careless operation of fire-control instruments, inaccurate pointing of guns, or backlash in the mechanism may be largely eliminated through careful training of the operating personnel and careful adjustment of matériel. Indeterminate accidental errors are caused by round-to-round variations in the characteristics of the matériel, such as variations in the shape and surface of projectiles and relative location of their centers of gravity and variations in the action of the gun and carriage. It is because these indeterminate errors are sometimes compensating and at other times additive, that dispersion occurs. The dispersion of a particular gun is referred to as its armament error.

(2) Systematic errors are those errors which cause the center of burst to deviate from the point being fired on. Systematic errors arising from sources which are known and understood, such as known variations from standard muzzle velocities, densities, or ballistic winds, are calculable and may be almost completely eliminated by the application of methods described below. Indeterminate systematic errors such as those which arise from an empirical determination of atmospheric conditions and the disregard of second and higher order differential effects, added to those determinate errors which cannot be eliminated, are responsible for the deviation of the center of burst from the point being fired on. The elimination of this latter class of errors is probably one of the most difficult problems confronting the antiaircraft artilleryman. No complete solution has been found as yet, approximate methods being resorted to as will be shown later.

c. If a very large number of shots are fired from an antiaircraft gun at a fixed point, they will be dispersed about the center of burst in range along the trajectory, and in deflection both laterally and vertically. The dispersion can be represented graphically by a geometrical figure which may be called a dispersion volume. If each of the three dimensions is divided into eight equal parts, it will be found that the points of burst will be arranged about the center of burst as indicated by the approximate percentage figures given in figure 37. The dispersion volume may be divided into zones, laterally, vertically, and in range, within which 50 percent of the shots fired will burst. (The 50 percent zones are shown in figure 37.) It should be noted that each of the faces shown in the geometrical figure corresponds to the dispersion ladder as applied to seacoast artillery.

■ 90. PROBABILITY.—*a.* The discussion of dispersion has been based upon the assumption that a very large number of shots

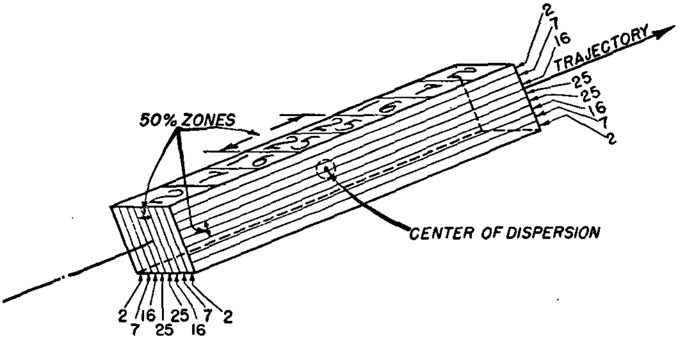


FIGURE 37.—Dispersion volume.

is fired. The artilleryman must constantly deal, however, with a relatively small number of shots. It is necessary to consider the shots actually fired as samples from a larger group and to resort to a branch of mathematics called "Probability," which deals with the likelihood that a situation concerning which information is not complete will occur. For example, since the dispersion volume (fig. 37) provides an indication of where 50 percent of the shots fired may burst, a reasonable conclusion is that any single shot fired has an even chance of bursting within a 50 percent zone. Also, considering the smaller number of shots as a sample of a larger group, a reasonable assumption is that half the shots fired will burst within a 50 percent zone.

b. The physical dimensions of the dispersion volume are subject to variations which depend upon the time of flight to, and quadrant elevation of, the point at which the gun is being fired. These dimensions are determined at the proving grounds, as a result of a limited number of shots fired at various points, and tabulated in firing tables in the form of probable errors in yards along the trajectory, in deflection laterally, and in deflection vertically. A probable error is defined as "the error which is as likely as not to be exceeded, a value which, in the long run, will be exceeded one-half the time, and not exceeded one-half the time." By referring to the diagram of the dispersion volume (fig. 37), it will be seen that a probable error is one-half of the width of the 50 percent zone.

c. (1) There are several features of the theory of errors and laws of probability as applied to antiaircraft firing that are of particular importance. When the deviations of shots from the target can be measured, the most probable center of burst is determined by taking the algebraic mean of such deviations. It will frequently happen, particularly when firing at a rapidly moving target, that it will be impracticable to measure deviations. In such a situation sensings may be obtained and advantage may be taken of a rule of probability which states: "The most probable position of the center of impact (or burst) is that which, in a large number of trials, would produce in the same ratio those outcomes which have been observed." For example, consider that of four shots fired from an antiaircraft gun, three were seen to burst "short" of the target and one "over." Under the law given, the relative frequency of shorts and overs observed is assumed to be the same as if a very large number of shots had been fired; that is, 75 percent short and 25 percent over. The center of burst must be short of the target, since, if it were at the target, 50 percent of the shots would have burst on each side. In the problem given 75 percent burst short of the target, and since it is assumed that 50 percent burst short of the center of burst, 25 percent must be assumed to have burst between the center of burst and the target. Therefore the most probable position of the center of burst is one probable error short of the target. It must be kept in mind, however, that in making use of this law the behavior of a limited number of shots will not always agree with that of a very large number.

(2) To locate the center of dispersion and to know it as such would require the firing of an infinite number of shots, a task impossible of accomplishment. However, it should be clear that the center of burst determined from even a small number of shots is a more reliable indication of the center of dispersion than that determined by any individual shot, but for any number a probable error exists in locating the center of dispersion. This error may be determined in a simple manner from the equation

$$E_{pc}=\frac{E_p}{\sqrt{n}}$$

where

E_{pc} is the probable error in location of the center of dispersion,

E_p is the probable error of a single shot, and

n is the number of shots.

Consider, for example, that the firing table probable error along the trajectory for a given point is 50 yards. The following table shows the probable error in location of the center of dispersion (along the trajectory) for various numbers of shots fired:

No. of shots (n)	1	2	3	4	5	6	8	12	16
E_{pc}	50	35	29	25	22	20	18	14	12

Thus it will be seen that the error, E_{pc}, is halved by firing four shots instead of one, but that it is necessary to fire twelve more in order to again halve the error. 50 percent of the error introduced by assuming the center of burst as the center of dispersion is eliminated by basing the determination of the center of burst on four rounds.

(3) By applying the rules of probability, it is possible to calculate the chances of securing a burst at a target. For example, assume that the dispersion volume illustrated in figure 37 is based upon firing table data for $\phi=700$ and $F=13$. Consider a target whose center coincides with the center of burst and whose dimensions are 20 yards along the trajectory, 15 yards laterally, and 18 yards vertically. It can be shown that the probability of securing a burst in this small volume is approximately 0.03, which means that of 100 shots fired at

this target, three might be reasonably expected to burst in this small volume.

(4) The dispersion volume illustrated in figure 37 includes 100 percent of all shots fired. This is a close approximation of the mathematical laws. However, about 1 percent of a very large number of shots may be expected to burst more than four probable errors from the target. In firing a smaller number of shots, there is no assurance that this small percentage will not occur early in the series. If such shots did occur and were taken into consideration in determining the center of burst of a small group of shots, they would exert an undue influence on the calculations. Hence it is considered sound practice to disregard wild shots, which are defined as those which burst more than four probable errors from the center of burst.

(5) One of the hypotheses of a rule of accidental errors is that "Plus errors and minus errors occur with the same frequency in a large number of trials and hence have equal probabilities." An example of the application of this rule will be found in the operation of laying a gun in elevation with a quadrant. It is unlikely that a gun can be set precisely at the same elevation on two successive trials. However, a justifiable assumption may be made that the average setting of a large number of trials will be the true elevation, as plus and minus errors occurring with the same frequency tend to compensate each other.

■ 91. APPLICATION.—*a*. The ultimate object of all artillery fire is to hit the target. The foregoing discussion has indicated that gunnery is not an exact science. However, armed with the knowledge that errors do exist in firing and that they tend to follow certain rules, the artilleryman may act to reduce or eliminate them as far as possible. The principal problems in gunnery are concerned with the elimination of errors in firing. The solution of such problems involves the eliminating of determinate errors, reducing dispersion, and placing the center of impact on the target and keeping it there.

b. The procedure may be divided into two phases. In the first phase, by careful preparation, which includes the test and adjustment of all matériel, thorough training of personnel, and preparatory firings, determinate errors may be largely eliminated and disperson reduced. In the second phase, fire is directed at the target and the compensation for indeterminate errors which cause a deviation of the center of impact from the target is undertaken. This latter problem is the more difficult of solution.

c. (1) Preparatory fire is usually directed at fixed points in space under conditions which permit the maximum degree of accuracy in determining errors. The elimination of errors is undertaken by applying corrections to firing data.

(2) Fire for effect is directed at airplane targets which move at high speed. This situation does not permit a determination of errors and the application of corrections with a degree of accuracy comparable to that for preparatory fire, since the conditions under which shots are fired are continually and rapidly changing. However, since the accuracy of the rules of probability increases with the number of shots fired, the solution of the problem is aided by the fact that generally the fire of more than one gun is directed at the target. The solution is further aided by maintaining the highest rate of fire, consistent with accuracy, from all guns, since by so doing an approximation results of the condition that all shots should be fired under conditions as nearly identical as possible.

SECTION XI

PREPARATORY FIRE

■ 92. **PREPARATION OF FIRE.**—Careful preparation of fire is essential for all types of artillery. Preparation for fire against aerial targets is more difficult and complex than for other types of targets since the antiaircraft problem is one of three dimensions. It is important that this preparation is made carefully and accurately because of the short time the target can be engaged and the difficulty of fire adjustment. Furthermore, the pilot of an enemy airplane can be expected to maneuver as soon as he sees the first burst. As the adjustment of fire on a maneuvering target is even more difficult, every possible effort will be made to place the first bursts on the target. Preparation of fire includes—

a. Training of personnel.

b. Test, adjustment, and check of matériel.

c. Test and adjustment of pointing system.

d. Preparatory fire.

■ 93. **TRIAL FIRE.**—*a.* All fire-control instruments are designed on the basis of firing table data which assume the existence of standard conditions. The purpose of trial fire is to determine the magnitude of the errors, due to unknown causes, and apply corrections to firing data in such a manner that the center of burst will be moved onto a point called the trial shot point (*TSP*).

b. The corrections for errors determined as a result of trial fire should be—

(1) Equally effective in all parts of the field of fire.

(2) In such a form that they can be applied to any fire-control system in use.

(3) Applied to correct the basic cause of the error. The correction should not cause the data computor to make an error in the calculation of basic data.

c. Extended investigation of all the known methods of determining and applying trial fire corrections has been conducted in the past. None of the methods proved entirely satisfactory. The method described in paragraph 107 is theoretically sound and gives good results.

d. The frequency with which trial fire is conducted will depend upon the tactical situation, availability of suitable meteorological data, and knowledge possessed by the battery as to performance of the matériel.

■ 94. **TRIAL SHOT POINT.**—*a.* The trial shot point (*TSP*) is a definite fixed point in space at which trial shots are fired. The location of this point is determined by its angular height, horizontal range or altitude, and azimuth.

b. While any point within effective range of the matériel might be selected as a trial shot point, trial fire usually is conducted at one of the following points:

TSP No.	Firing table	ϕ	*F*	ϵ	*H*	*R*
1	3 AA-J-2a	700	13	608	3, 223	4, 740
2	3 AA-J-2a	700	7	661	2, 213	2, 914
3	3 AA-J-2a	500	13	403	2, 154	5, 153
4	3 AA-O-1	900	15	814	5, 095	4, 957

■ 95. MATÉRIEL PREPARATIONS—TRIAL FIRE.—Emplacement of the guns is discussed in FM 4–125. Necessary steps for the preparation of matériel for firing are listed in FM 4–120. See Technical Manuals or Ordnance Department pamphlets pertaining to the matériel in question for the methods by which the tests and adjustments to the guns and mounts are made. The methods of making the tests and adjustments to the instruments are explained in sections I, II, and III, chapter 3. Orientation and synchronization are discussed in chapter 4.

■ 96. SELECTION OF TRIAL SHOT POINT (*TSP*).—*a.* Choice of the trial shot point to be used is governed by the gun and ammunition being used, visibility, ceiling, and expected altitude and course of enemy targets. *TSP* Nos. 1, 2, and 3 are for use with 3″ AA shrapnel, Mk. I (FT 3 AA–J–2a), *MV,* 2,600 f/s. *TSP* No. 1 is at medium altitude and range and is the *TSP* most commonly used. *TSP* No. 2 is at a shorter range and lower altitude and is used when the visibility does not permit observation at either of the other points. *TSP* No. 3 is at a longer range and lower altitude than *TSP* No. 1 and should be used in preference to *TSP* No. 2 when the ceiling is not high enough to observe *TSP* No. 1. *TSP* No. 4 is for use with 3″ AA shell HE, M42 (FT 3 AA–O–1), *MV,* 2,700 f/s; other suitable points may be selected.

b. (1) The choice of a suitable azimuth is governed by the following considerations:

(*a*) Safety of the field of fire.

(*b*) Visibility from the distant (O_2) station.

(*c*) Accuracy of observation from O_2.

(*d*) Probable direction of approach of enemy targets.

(2) The second consideration must be borne in mind particularly when there are a number of clouds below the *TSP.* While there may be perfect visibility from the battery position (O_1), a cloud may obscure the *TSP* from O_2. In order to comply with the third consideration, the azimuth of the *TSP* should be selected so that the horizontal projections of the lines of sight from O_1 and O_2 to the *TSP* will intersect at an angle of approximately 90°.

c. Trial fire is not restricted to the four points selected in paragraph 94. *TSP* Nos. 1, 2, and 3 were selected as the

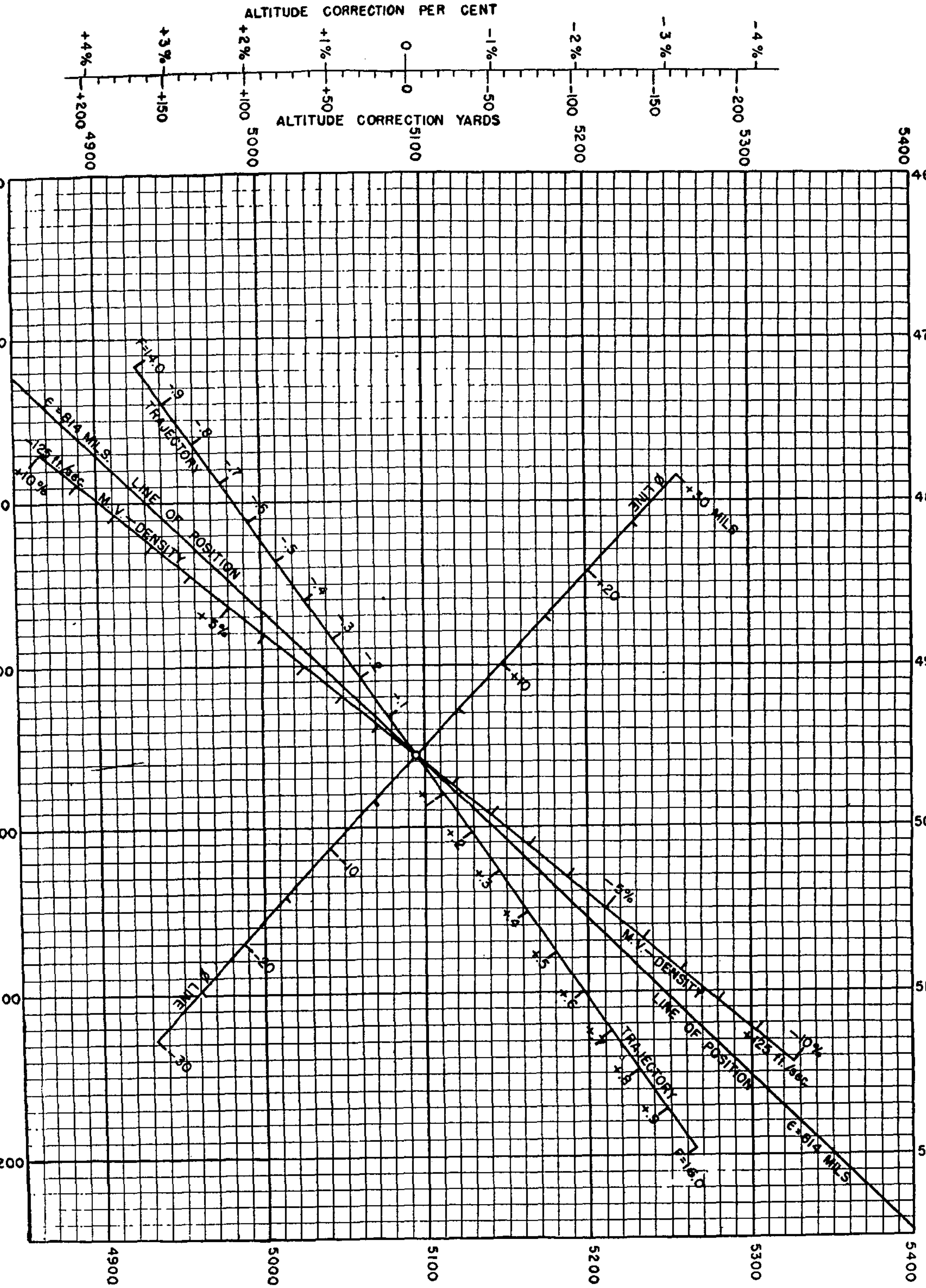


FIGURE 38.—Trial shot chart for *TSP* No. 4.

3-inch AA gun M1917 or M3 (MV 2,700 f/s). Data from Firing Tables 3AA–O–1: $\phi=900$, R=4957, $\epsilon=814$, F=15, H=5095, t=15; drift=4 mils.

result of numerous test firings, and consequently should be used except when unusual conditions justify the selection of a different point. Trial shot charts must be constructed from firing-table data for the *TSP* selected.

■ 97. **CONSTRUCTION OF TRIAL SHOT CHART.**—The following problem illustrates the method of constructing a trial shot chart:

a. Assume *TSP* No. 4.

ϕ=900 m	R=4,957 yards
F=15	H=5,095 yards
FT=3 AA–O–1	ϵ=814 mils
MV=2,700 f/s	

b. Plot the point for F=15 (the *TSP*) on cross-section paper at R=4,957 yards and H=5,095 yards as shown in figure 38.

c. Extracting from tables K–2 and K–3, Firing Tables 3 AA–O–1: At F=15 and ϕ=900, a minus 0.1 of a unit fuze range change has the following effects:

$$\Delta R = -24 \text{ yards}$$
$$\Delta H = -17 \text{ yards}$$

Multiplying these effects by 10, we get the effect of —1 unit of fuze range change or ΔR= —240 yards and ΔH= —170 yards. Plot a point on the chart (fig. 38) 240 yards to the left and 170 yards below the point F=15. Join this point with the *TSP* and extend the line an equal amount on the other side of the *TSP*. Subdivide the above line into 10 equal segments on each side of the *TSP* and label as shown in the figure. This line is the trajectory.

d. Extracting from tables E–1 and E–2, Firing Tables 3 AA–O–1: At F=15 and ϕ=900, a +10 mils change in ϕ, has the following effects:

$$\Delta R = -57 \text{ yards}$$
$$\Delta H = +54 \text{ yards}$$

Multiplying the above figures by 3, we get the effects of +30 mils change in ϕ or ΔR= —171 yards and ΔH= +162 yards. Plot a point on the chart 171 yards to the left and 162 yards above the *TSP*. Join this point with the *TSP*. Extend the line below the trajectory. Subdivide into equal segments and number as shown. This is the ϕ line.

e. Extracting from table B, Firing Tables 3 AA–O–1: At $F=15$ and $\phi=900$, $\epsilon=814$ mils.
Through the *TSP* draw a straight line, making an angle of 814 mils with the horizontal. This is the line of position.

f. On the left edge of the chart draw the altitude correction scale in yards. The scale is the same as the vertical scale of the chart.

g. Determine the altitude correction percent scale as follows: Altitude $\%\times$altitude=altitude of *TSP*. In the case of

TSP No. 4—Altitude$=\frac{5095}{\%H}$.

For example: when $\%H=96\%$ (-4%)

$$\text{altitude}=\frac{5095}{.96}=5307 \text{ yards.}$$

Calculating for different $\%H$ and tabulating:

		Altitude (*yds.*)
96%	—4%	5307
97%	—3%	5253
98%	—2%	5199
99%	—1%	5146
100%	0%	5095
101%	1%	5045
102%	2%	4995
103%	3%	4947
104%	4%	4899

Plot the above altitudes on the left of the chart and label each according to the percent as shown in figure 38. The units of this scale are not equally divided.

h. Extracting from tables F–1 and F–2, Firing Tables 3 AA–O–1: At $F=15$ and $\phi=900$, a —100 f/s change in *MV*, has the following effect:

$$\Delta R=-145 \text{ yards}$$
$$\Delta H=-185 \text{ yards}$$

Multiply each of the above effects by 1.25. Then $\Delta R=-181$ yards and $\Delta H=-231$ yards. These are the effects for —125 f/s change in *MV*. Extracting from tables I–1 and I–2, FT 3 AA–O–1: At $F=15$ and $\phi=900$, a $+10\%$ change in density has the following effects:

$$\Delta R=-193 \text{ yards}$$
$$\Delta H=-228 \text{ yards}$$

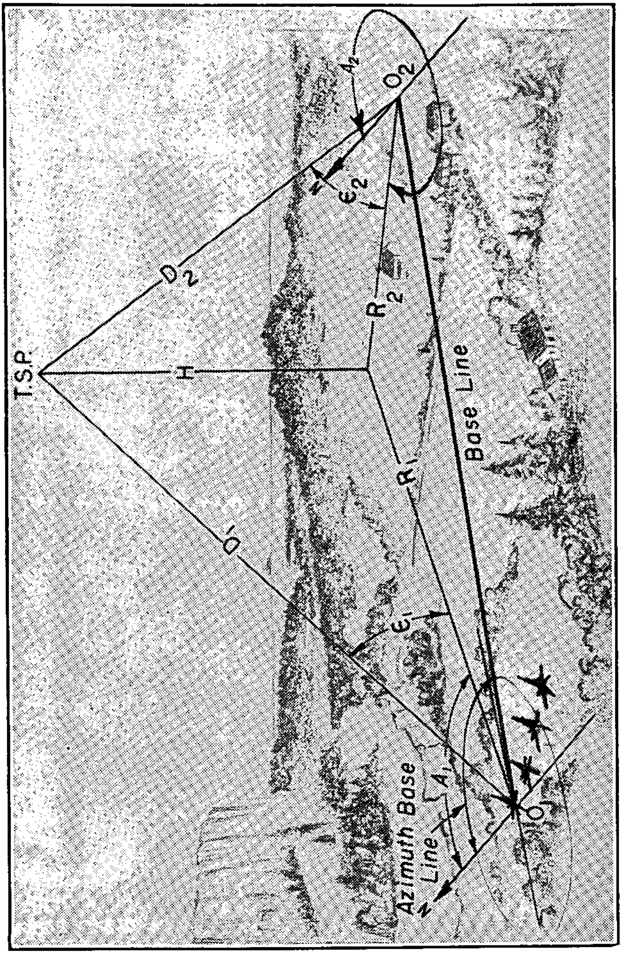


FIGURE 39.—O_1 and O_2 data.

Averaging the effects for —125 f/s and +10 percent change in density,

$$\Delta R = -187 \text{ yards}$$
$$\Delta H = -230 \text{ yards}$$

Plot a point on the chart 187 yards to the left and 230 yards below the *TSP*. Join this point with the *TSP* and extend the line an equal amount on the other side of the *TSP*. Divide the line into 10 equal segments on each side of the *TSP* and label as shown. This line is the *MV—density line* on which —125 f/s *MV* is equivalent to +10 percent change in density.

■ 98. DATA FOR THE O_1 and O_2 STATIONS.—*a*. In order to measure the deviations of the bursts from the *TSP*, it is necessary that the instruments be laid on the *TSP* selected. The various angles and distances concerned in computing the O_1 and O_2 data are shown in figure 39. The problem is to determine the azimuth and angular height of the *TSP* from each observing instrument. Figure 40 shows the two triangles which must be solved.

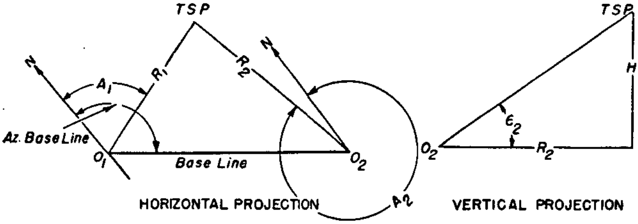


FIGURE 40.—Triangles solved in determining O_1 and O_2 data.

They can be solved by trigonometric formulas. Two rapid methods have been developed to solve the problem:

(1) The Lewis chart.

(2) The Crichlow slide rule.

b. The successive steps to be followed when using the Lewis chart method are tabulated and an illustrative problem is given in paragraph 248.

c. The successive steps to be followed when using the Crichlow slide rule method are tabulated and an illustrated problem is given in paragraph 249.

■ 99. **POINTING OBSERVATION INSTRUMENTS—TRIAL FIRE.**—*a. Bilateral observation.*—The observation instruments determine the deviations of a burst from the *TSP* at which they are directed. The necessity for accurate pointing of the instruments is obvious, since errors in pointing will result in erroneous deviations. Both the O_1 and O_2 instruments must be accurately leveled and oriented. After a *TSP* is selected, the data for the O_2 instrument (A_2 and ϵ_2) are telephoned to the O_2 station, where they are used to point the instrument at the *TSP*. As the O_1 instrument is generally at the battery position, it is customary to transmit the O_1 data (A_1 and ϵ_1) orally to the operator, who then points the instrument at the *TSP*.

b. Unilateral observation.—One observation instrument located at the O_1 (battery position) station is used. It is set up, oriented, and pointed at the *TSP* in the same manner as the O_1 instrument described in *a* above. In addition, the height finder is pointed at the *TSP* with data furnished to the O_1 station corrected for parallax, if necessary.

■ 100. **COMPUTING BALLISTIC CORRECTIONS—TRIAL FIRE.**—*a.* (1) The actual *MV* of the guns will frequently differ from the standard (powder tag *MV*) for the following reasons:

(*a*) Erosion of the bore and deterioration of powder.

(*b*) Ballistic density is nonstandard.

(*c*) Temperature of the powder is nonstandard.

(2) In addition, nonstandard ballistic density affects the time of burning of powder train time fuzes.

b. The effects of the above factors, as given in firing tables, are difficult to apply to the director. Tables which convert the firing table data to a form readily applicable to the director have been prepared. These tables are given in paragraph 256. *Always apply ballistic corrections before firing.*

c. All of the factors enumerated above, except time of fuze burning, are reduced to an effect on *MV* and then added algebraically to give the total *MV* variation.

d. Ballistic cams are cut for *MV* below standard because such a value is closer to the average *MV* developed throughout the life of the gun. In the M4 director, the cams are cut for 2,550 f/s for shrapnel and 2,700 f/s for shell.

e. Variation in developed *MV* from that for which the ballistic cams are cut is determined either by the method described in paragraph 135, or a value is assumed, based on such factors as the powder tag *MV* and the previous number of rounds fired from the guns. (Muzzle velocity decreases 3 f/s for every 100 rounds fired.) This is the variation from the *MV* for which the cams are cut.

(1) Effect on *MV* due to ballistic density is obtained from table VIII, paragraph 256.

(2) Effect on *MV* due to temperature of powder is obtained from table IX, paragraph 256.

f. The total *MV* variation is corrected for by a vertical correction (applied to the vertical spot dial) and an altitude correction (applied to the altitude spot dial). The amount of the correction ($d\phi$ or dH_o) is obtained from the ballistic tables, paragraph 256. These corrections ($d\phi$ and dH) are tabulated for *MV* variations of 25, 50, 75, and 100 f/s. Select the table closest to the total *MV* variation determined in *e* above. Extract the correction from the table using the *H* and *F* of the target as arguments. (In the case of trial fire, use the *H* and *F* of the *TSP*.)

g. The ballistic correction for time of burning of powder train fuzes due to ballistic density is extracted from either table I or II, depending upon whether the ballistic density is above or below normal. The tables give the correction to fuze (applied to the fuze spot dial) in corrector divisions for a ±10 percent change in density. Smaller percent changes are proportional. Enter the proper table using *H* and *F* as arguments and take the proportional amount of the correction tabulated. (In case of trial fire, use *H* and *F* of the *TSP*.) This correction is *not* applied when using mechanical fuzes.

h. The ballistic corrections obtained in *f* and *g* above are independent of any other corrections which may be applied. In other words, such corrections as trial fire corrections, correction for constant fuze error, and adjustment corrections (sec. XIII) are made in addition to the ballistic corrections. The ballistic corrections, as examination of the tables will disclose, change as the *H* and *F* of the target vary.

i. Ballistic corrections are applied before firing trial shots. They are also applied before fire for effect. The proper altitude and fuze range (*H* and *F*) determine the proper corrections. (See illustrative problem, par. 250.)

■ **101. Setting Trial Shot Data in Director.**—*a.* The successive steps to be followed in determining the corrected firing data depend upon the type of data computor being used. In general, as the data computors turn out data based on standard conditions (par. 66), it is necessary to correct for nonstandard conditions. Corrections are made on the data computor for as many of the nonstandard conditions as are known and which are capable of correction. The successive steps to be followed in the M4 director are as follows:

(1) Be sure that the data computor is leveled and oriented, and that the synchronization has been checked. (See ch. 4.) Check to see that the proper ballistic cams are in place.

(2) Set in the necessary parallax. If no parallax is necessary, check to see that there is no parallax set in the data computor. (See par. 159.)

(3) Traverse the data computor until the present azimuth dials indicate the azimuth of the *TSP*.

(4) Elevate the telescopes of the data computor until the ϵ_0 dials indicate the angular height of the *TSP*.

(5) Set the altitude of the *TSP* on the H dial.

(6) Using the wind component solver mounted on the left side of the data computor, determine the N–S and E–W components of the ballistic wind obtained from the meteorological message.

(7) Set the components of the ballistic wind obtained in (6) above on the wind rate dials. A ballistic wind from the NE has a north and an east component. Set the north component on the scale marked "north" and the east component on the scale marked "east." Likewise a ballistic wind from the SW has a south and a west component which are set on the scales marked "south" and "west."

(8) Determine the ballistic corrections for the *TSP*. (See par. 100 and illustrative problem, par. 250.)

(9) Apply the ballistic corrections determined in (8) above to the spot dials. The corrections are $d\phi$ and dH. A dF correction is necessary if a powder train time fuze is being used. If no correction to a particular element is needed, be sure that particular spot dial is set at zero.

(10) Obtain the drift for the *TSP* from the firing tables. Add this value, with sign as shown, to +10 ₥ when firing shrapnel, and to +7 ₥ when firing shell. The result, with

sign as determined, is the net drift correction which is applied to the *dA* spot dial. (The director makes a flat drift correction of —10 mils when firing shrapnel and —7 mils when firing shell.)

(11) Turn on the power.

(12) Match the ϵ_0 dials by the R_0 handwheel. Check to be sure that the range rate dial is set at zero. Observe the present horizontal range counter. If it moves, there is a range rate set in. Adjust the range rate knob until the counter does not creep.

(13) Set the altitude rate dial at zero and operate the altitude follow-up motor for a short time so as to remove any altitude prediction which may have been left in the data computor. The altitude prediction motor should be turned off during the firing of trial shots.

(14) Corrected firing data are now available at the guns which can be laid for firing at the *TSP* by matching the pointers at the guns.

b. Methods of determining the corrected firing data for other types of directors are found in handbooks pertaining to the particular instrument.

■ 102. FIRING TRIAL SHOTS.—*a.* The gun selected to fire the trial shots must be prepared as outlined in paragraph 95 before firing the trial shot problem.

b. The matching of the elevation and azimuth pointers should be checked after the gun is loaded for each round. The setting of the fuze on each projectile should be checked against the fuze range as determined by the data computor. It must be remembered that a calibration correction to the fuze (par. 239) on the gun firing the trial shots will cause the fuze setting on the projectile to vary by the amount of the calibration correction. The rounds should be fired without loss of any more time between rounds than is necessary to observe the bursts accurately, record the deviations, and perform the duties incidental to firing.

c. Normally, not less than five trial shots are fired, all from one gun of the battery. The shots upon which corrections are based must be normal rounds. Rounds that result in abnormal deviations because of defective fuzes or other reasons should be disregarded. Therefore, prior to firing the trial shots from mobile guns in a new position, one or more rounds should be fired from each gun in order to settle the mounts.

■ **103. OBSERVING BURSTS AND DETERMINING *CB*—TRIAL FIRE.**—It is of primary importance that the deviation of the center of burst (*CB*) of the trial shots be determined with the greatest accuracy practicable. There are two methods of observing the trial shot bursts and determining the coordinates of the *CB;* unilateral observation and bilateral observation. The first is the simpler but is less accurate; the second, while more accurate, requires the use of an observation base line. Bilateral observation should be used when practicable.

a. Unilateral observation.—(1) Unilateral observation is frequently necessary when sufficient time for the establishment of a base line does not exist. Because of the expected frequency of such situations in time of war, this method, while less accurate, is of no less importance than the bilateral method.

(2) The O_1 instrument and the height finder are pointed, using the angular height and azimuth of the *TSP*.

(3) The following data must be recorded for each shot:

Data:	*Source*
Altitude of burst	Height finder.
Angular height of burst	B. C. telescope, M1.
Lateral deviation of burst	

(4) When the data pertaining to all the trial shots have been obtained, they are averaged to determine the location of the *CB*. The angular height and altitude of the *CB* are sufficient data to locate the *CB* on the trial shot chart.

b. Bilateral observation.—(1) Bilateral observation should be used whenever time and other conditions permit. The location of the O_2 station must be known. It can be determined either from a survey or from an accurate large-scale map.

(2) For operation of the bilateral system, two battery commander's telescopes M1 (or instruments of equal accuracy and utility), must be available; one at the O_1 station (battery position) and the other at the O_2 station (flank position). The spotting telescope on the M4 director can be used at the O_1 station in lieu of a separate instrument. In general, the

distant station O_2 should be located so that the horizontal projection of the angle O_2TO_1 is approximately 90°, T being the trial shot point and O_1 the battery station.

(3) The O_1 and O_2 instruments are pointed on the *TSP* using data determined by one of the two methods outlined in paragraph 98.

(4) The following data must be recorded for each shot:

Data:	*Source*
Vertical deviation of burst	O_1 instrument
Lateral deviation of burst	O_1 instrument
Range deviation of burst (in mils)	O_2 instrument

(5) When the deviations of all the trial shots have been obtained, they are averaged to determine the lateral and vertical deviations of the *CB* as determined at the O_1 position and the range deviation of the *CB* as determined at the O_2 station. With these data, the location of the *CB* may be determined from the Crichlow slide rule or the Lewis chart.

■ 104. CONVERSION OF DEVIATIONS TO HORIZONTAL PLANE—TRIAL FIRE.—The observation instruments at O_1 and O_2 measure the lateral and range deviations, respectively, of the burst from the *TSP* in the inclined plane. Before we can use the deviations of the *CB*, we must measure these angles in the horizontal plane because the Lewis chart and the Crichlow slide rule solve the horizontal triangle. (See par. 98.) These deviations must be multiplied by the ratio

$$\frac{\text{slant range}}{\text{horizontal range}} = \frac{1}{\cos \epsilon}$$

This conversion can be done by means of the Crichlow slide rule by following the instructions printed on the face of the slide rule. Another method is to use the graph shown in figure 41. A larger chart is furnished with each set of Lewis charts. It is used as follows: Select the curve on this chart whose value equals the lateral deviation in the slant plane. Mark the point where this curve crosses the horizontal line whose ordinate equals the angular height of the *TSP* from the observing station. The abscissa of the point just determined is the lateral deviation in the horizontal plane. Vertical deviations are never converted to the horizontal plane.

■ 105. PLOTTING *CB* ON TRIAL SHOT CHART—BILATERAL OBSERVATION.—It is necessary to determine the horizontal range to the *CB* from O_1 before the *CB* can be plotted on the trial

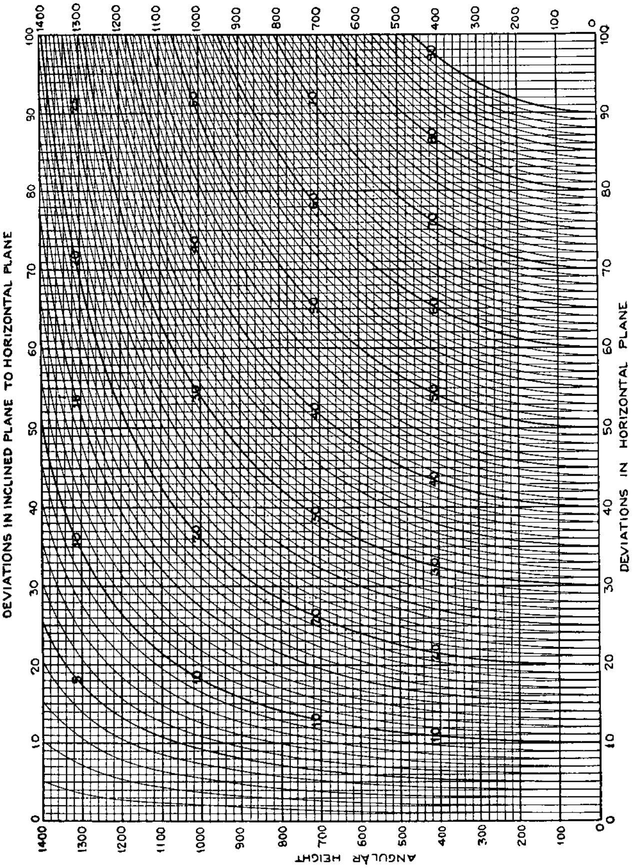


FIGURE 41.—Chart for conversion of mil deviations from inclined to horizontal plane.

shot chart. This range can be determined by means of either the Crichlow slide rule or the Lewis chart.

a. Crichlow slide rule method.—Examination of figure 42 will show that the angles used in solving the horizontal triangle O_1—CB—O_2 are the interior angle on the right and the exterior angle on the left end of the base line. Using the rules given in paragraph 207, right deviations are added to and left deviations are subtracted from the O_1 and O_2 angles to the *TSP* to get the new O_1 and O_2 angles to the *CB*. Deviations are first converted to the horizontal plane. The new *T* angle is the difference between the new O_1 and O_2 angles. The horizontal triangle O_1—CB—O_2 is to be solved for the horizontal range O_1 to *CB*. Set the arm "S" of the Crichlow slide rule to the value of the new O_2 angle to *CB* on scale *D*.

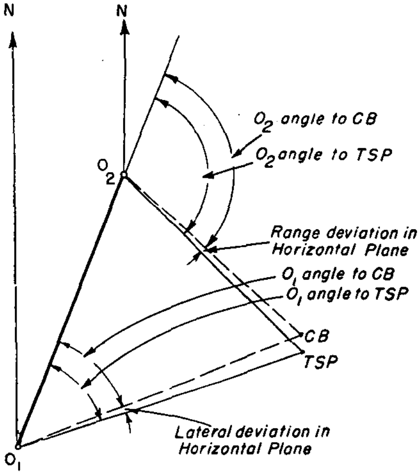


FIGURE 42.—Determining the O_1 and O_2 angles to *CB*.

Without moving the arm "S," set the arm "L" to the value of the new target angle (*T*) (interior angle at *CB*) on scale *D*. Without changing the angular displacement between the arms "S" and "L," set the arm "S" to the length of the base line on scale *E*. Under the arm "L" on scale *E* read the horizontal range O_1 to *CB*.

b. Lewis chart method.—Examination of figure 42 shows that the angles used in solving the horizontal triangle O_1—CB—O_2 with the Lewis chart are one interior and one exterior angle. Using the rules given in paragraph 203, right

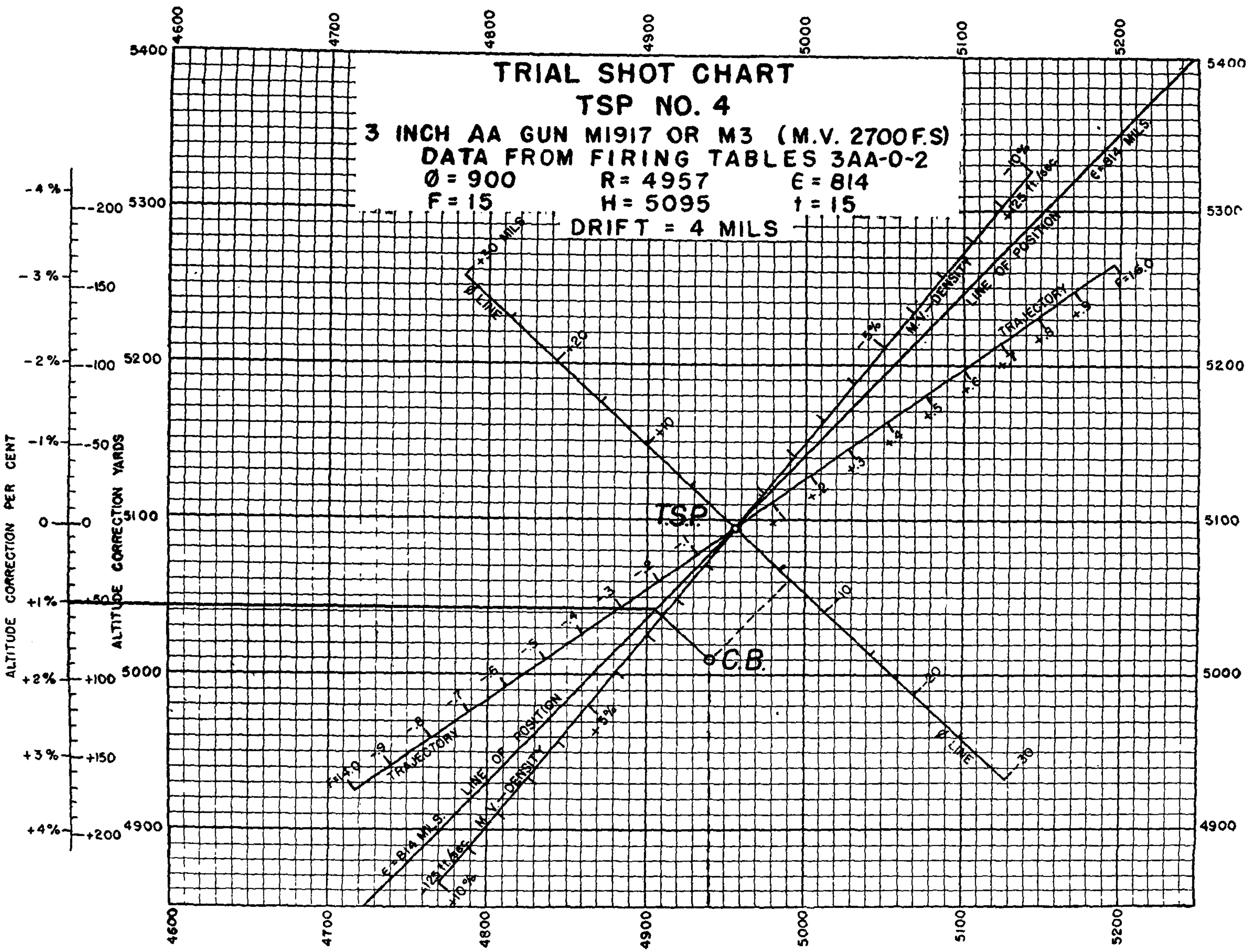


FIGURE 43.—Use of trial shot chart—trial fire.

deviations are added to and left deviations subtracted from the O_1 and O_2 angles to the *TSP* to get the new O_1 and O_2 angles to the *CB*. Deviations are first converted to the horizontal plane. The *CB* is plotted with the new O_1 angle to *CB* as abscissa and the new O_2 angle to *CB* as ordinate on the Lewis chart. Mark the point *CB*. Place the log range scale on the vertical line passing through *CB* with the base line length in line with the zero ordinate line of the chart. Opposite *CB* read the value of the horizontal range O_1 to *CB* on the log range scale. (See also fig. 92.)

c. Plot the *CB* on the trial shot chart as follows: Draw a vertical line on the chart through the abscissa equal to the horizontal range O_1 to *CB*. Draw a line parallel to the line of position through the point on the ϕ line corresponding to the observed vertical deviation of the *CB*. The intersection of these two lines is the *CB*. Mark it so on the trial shot chart. (See fig. 43.)

NOTE.—In drawing the trial shot chart for a trial shot problem only the ϕ line and the line of position need be shown.

■ 106. PLOTTING *CB* ON TRIAL SHOT CHART—UNILATERAL OBSERVATION.—Draw a horizontal line on the trial shot chart through the ordinate equal to the altitude to the *CB*. Draw a line parallel to the line of position through the point on the ϕ line which corresponds to the observed vertical deviation of the *CB*. The intersection of these two lines is the *CB*. Mark it so on the trial shot chart.

■ 107. DETERMINING TRIAL SHOT CORRECTIONS.—*a*. Paragraphs 105 and 106 describe the methods of plotting the *CB* on the trial shot chart.

b. The trial shot corrections are determined as follows: The observed vertical deviation of the *CB* with the sign reversed is the $d\phi$ correction. Draw a line through the CB parallel to the ϕ line until it intersects the line of position. From this intersection draw a horizontal line to the left until it intersects the $\%H$ scale. This intersection with the $\%H$ scale is the $\%H$ correction. (See fig. 43 and illustrative problem, par. 251.)

■ 108. DETERMINATION OF LATERAL CORRECTION FROM TRIAL FIRE.—The observed lateral deviation of the *CB* from O_1, converted to the horizontal plane, with the sign reversed is the lateral (*dA*) correction.

■ 109. REMOVAL OF BALLISTIC CORRECTIONS.—*a.* Prior to the firing of trial shots ballistic corrections were placed on the spot dials of the director (par. 101*a*(9)). These corrections were based on *F* and *H* for the *TSP* and therefore are not applicable to a target appearing at a different *F* and *H*. The ballistic corrections (exclusive of ballistic wind corrections) are removed after trial fire is completed because it is easier and less conducive to errors to apply an entirely new correction than to correct a correction already applied to the director. (See illustrative problem, par. 252.)

b. In paragraph 101*a*(10), it is stated that prior to the firing of trial shots a *dA* spot was placed on the spot dial of the director in order to refine the flat correction for drift. This correction is made only so that the *CB* will be as close to the *TSP* as possible. The lateral correction (par. 108) determined from trial fire corrects for all variations except drift. It would be unwise to attempt to refine the drift correction at other points than the *TSP*, especially since the drift correction incorporated in the director is an average value selected for the portion of the field of fire where targets are most likely to be encountered. Consequently the *dA* spot (applied before trial fire for the refinement of the drift correction) is removed after firing the trial shots and only the *dA* as a result of trial shots is used to open fire for effect.

■ 110. APPLICATION OF TRIAL SHOT CORRECTIONS.—*a.* Regardless of the method used, the trial fire corrections determined are $d\phi$, *dA*, and *%H*. The corrections, $d\phi$ and *dA*, can be applied to the spot dials as soon as determined. *%H* cannot be applied to the spot dial because it is a percentage correction. When the altitude of the target is determined, *dH* is computed ($dH = \%H \times H$) and applied to the spot dial.

b. Figure 22 shows the vertical spot dial ($d\phi$). The other spot dials are similar. The trial fire correction is set on the spot dial by turning the spotting handwheel until the proper value is opposite the movable index.

■ 111. RECORDS.—*a.* Each time a trial shot problem is fired the following records should be kept:

(1) Meteorological message.

(2) Ballistic corrections applied.

(3) Deviations of the *CB*.

(4) Location of *TSP*.

b. These data are necessary for the determination of the fuze error and the developed muzzle velocity. (See par. 133.)

■ 112. SUMMARY OF TRIAL SHOT FIRING.—The process of firing trial shots and determining corrections therefrom may be briefly summarized as follows:

a. Complete all matériel preparations as outlined in paragraph 95.

b. Select a trial shot point and decide upon a suitable azimuth for the *TSP*.

c. Compute the data to point the O_1 and O_2 instruments at the *TSP*, using either the Lewis chart or the Crichlow slide rule, and the proper firing tables.

d. Orient the observing instruments at the O_1 and O_2 stations and point each instrument at the azimuth and elevation of the *TSP*.

e. Compute the ballistic corrections for the *TSP*. (See par. 100.)

f. Compute the corrected firing data by the procedure tabulated in paragraph 101.

g. Fire five shots (or more if necessary to obtain five normal rounds) with the gun set on these data, checking the laying of the gun and setting of the fuze before each round is fired.

h. Observe the firing of each shot, using the most accurate method available. The vertical (above or below) and lateral (right or left) deviations of each burst are measured at the O_1 station. The range deviation (over or short) of each burst is measured at the O_2 station. Compute the average vertical and lateral deviations from O_1 and the average range deviation from O_2 in order to determine the deviation of the *CB* from the *TSP*.

i. Convert only the lateral deviation of the *CB* from O_1 and the range deviation of the *CB* from O_2 (both observed in the slant plane) to deviations in the horizontal plane, using the conversion chart (fig. 41) or the Crichlow slide rule.

j. Determine the horizontal range to the *CB* from O_1, using either the Crichlow slide rule or the Lewis chart.

k. Plot the *CB* on the trial shot chart, using the observed vertical deviation of the *CB* and the horizontal range to *CB* from O_1. (See par. 105.)

l. The $d\phi$ correction is the observed vertical deviation with sign reversed. Scale the *%H* correction from the trial shot chart.

m. The lateral (*dA*) correction is the observed lateral deviation of the *CB* (corrected to the horizontal plane) with the sign reversed.

n. Remove the ballistic corrections and the *dA* spot (refinement to the drift correction) applied prior to the firing of the trial shots. The ballistic corrections will be reapplied as soon as *F* and *H* for the target can be determined.

o. Apply the trial shot corrections $d\phi$ and *dA* determined in *l* and *m* above to the spot dials of the director. The *%H* correction is applied to the *dH* spot dial as a flat correction as soon as the altitude of the target is determined.

p. Keep a record of the meteorological message, ballistic corrections, and deviations of the *CB* for future reference.

q. If unilateral observation was used, vary the above procedure as follows:

(1) In *h*, the altitude of the burst is measured by the height finder instead of measuring the range deviation from O_2.

(2) In *k*, plot the *CB* on the trial shot chart, using the observed vertical deviation of the *CB* and the altitude of the CB. (See par. 106.)

■ 113. CALIBRATION FIRE.—The purpose of calibration fire is to determine from the relative location of the centers of burst of the several guns of a battery the corrections which must be applied to each gun in order to obtain either a center of burst common to all guns of the battery or an arbitrary pattern of bursts. Calibration fire is undertaken upon receipt of new guns and when analysis of the results of fire indicates that the former calibration corrections are no longer effective. Calibration corrections, when determined, are recorded and applied to the individual guns and are not changed until superseded by corrections determined at a later calibration firing. Since the corrections are applied to the individual guns, the corrections must be in terms of A, ϕ, and F.

■ 114. **Matériel Preparations—Calibration Fire.**—The same matériel preparations as are outlined in paragraph 95 for trial fire must be completed prior to calibration fire.

■ 115. **Removal of Previous Corrections on Guns.**—It is never a good policy to correct a correction if it can be avoided. Consequently all corrections are removed from the guns before conducting calibration fire. The calibration corrections compensate for factors which are causing the guns to shoot an undesirable pattern in the sky.

■ 116. **Selection of the Calibration Point.**—The choice of the calibration point is governed by the same considerations as the choice of the *TSP* (par. 96). *TSP* No. 1 or No. 4 is recommended as the calibration point unless circumstances prevent their use.

■ 117. **Computation of O_1 and O_2 Data.**—The computation of the data for the O_1 and O_2 stations is exactly the same as described in trial fire. (See par. 98.)

■ 118. **Pointing Observation Instruments—Calibration Fire.**—See paragraph 99 for information concerning the pointing of observation instruments.

■ 119. **Computing Ballistic Corrections—Calibration Fire.**—The same procedure as outlined in trial fire, paragraph 100, is followed.

■ 120. **Computing Corrected Firing Data.**—The same procedure as outlined in trial fire, paragraph 101, is followed.

■ 121. **Firing a Settling Shot.**—A settling shot should be fired by each gun prior to the calibration firing so as to settle the gun.

■ 122. **Firing Calibration Fire.**—Five rounds should be fired from each gun. The matching of the elevation and azimuth pointers is verified after each gun is loaded for each shot. The fuze setting of each projectile is checked against the fuze range as determined by the director. The guns are fired alternately so that changing conditions affect all guns in a similar manner. Only sufficient time to insure the accurate pointing and leveling of the guns and the accurate observation and recording of the bursts from O_1 and O_2 is allowed to elapse between rounds. If for any reason any of the bursts have abnormal deviations, that particular round is disregarded and additional rounds are fired so as to have recorded data for five normal shots from each gun.

■ 123. **OBSERVING BURSTS AND DETERMINING CB—CALIBRATION FIRE.**—Bilateral observation should always be used for calibration fire. If time and other considerations prohibit bilateral observation, the firing of calibration fire should be dedeferred until bilateral observation can be obtained. (See par. 103*b* for data to be recorded at each station.) The deviations of all the shots for each gun are averaged to get the deviations of the *CB* for each gun.

■ 124. **CONVERSION OF DEVIATIONS TO THE HORIZONTAL PLANE—CALIBRATION FIRE.**—The deviations of the *CB* measured in paragraph 123 are in the inclined plane. Use the conversion chart (fig. 41) or the Crichlow slide rule to convert the lateral deviation from O_1 and the range deviation from O_2 to the horizontal plant. (See par. 104.)

■ 125. **PLOTTING CB OF EACH GUN ON TRIAL SHOT CHART.**—Using the same methods outlined in paragraph 105, plot the center of burst for each gun on the trial shot chart. Identify each *CB* with the gun which fired it by the notation *CB*1, *CB*2, *CB*3, and *CB*4. (See fig. 97.)

NOTE.—In preparing a calibration chart only three lines need be shown, the ϕ line, the line of position, and the trajectory.

■ 126. **PARALLAX CORRECTIONS.**—*a.* Calibration corrections which cause the fire of the battery to converge in one part of the field of fire will cause it to diverge an equal amount when firing in the opposite direction. Hence, it is common practice to apply calibration corrections so that the guns shoot parallel. In this way, the danger volume of the battery is increased since the guns are, under service conditions, emplaced some distance apart; the flat calibration corrections will hold equally well in all parts of the field of fire.

b. The *CB*'s should make a pattern in the sky which will have the shape and dimensions of the lay-out of the guns on the ground. The calibration corrections to each gun must be based on the deviation of each *CB* from points displaced laterally and in range from the common point *T'*. (*T'* is the point in space at which the director and the observation instruments at O_1 and O_2 are pointed.) These displacements from *T'* are equal respectively to the lateral and range displacement of each gun from the center of the square which the guns form on the ground. The computation of calibration corrections is greatly simplified if the plane of fire is taken along one of the diagonals of the square. The director is placed at the center of the square for calibration fire.

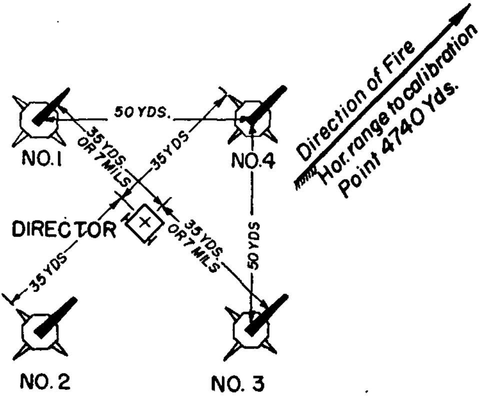


FIGURE 44.—Battery emplacement.

■ 127. **PLOTTING CALIBRATION POINT FOR EACH GUN ON TRIAL SHOT CHART.**—*a.* Figure 44 shows a typical battery emplacement. Assume *TSP* No. 1 is used as the calibration point and that the plane of fire is along the diagonal of the square through gun No. 4. The trial shot chart being a vertical plane through the calibration point, the vertical and range deviations but not the lateral deviations can be plotted. The calibration point for each gun (*C*1, *C*2, *C*3, and *C*4) will have the same relative locations around the point *T'* as the guns have around the center of the square. *C*1 and *C*3 will therefore be coincident with *T'*. As guns Nos. 2 and 4 are displaced minus and plus 35 yards in range from the center of the square, *C*2 and *C*4 will be displaced minus and plus 35 yards along the horizontal line through *T'*. (See fig. 45.)

b. The lateral deviations of each calibration point from *T'* (they cannot be shown on the trial shot chart) are computed as follows: 35 yards at 4,740 yards range subtends an angle of $\frac{35}{4.74}$ mils, equals 7 mils approximately. Therefore the lateral displacements of the individual calibration points will be *C*1 left 7 mils, *C*2 line, *C*3 right 7 mils, *C*4 line.

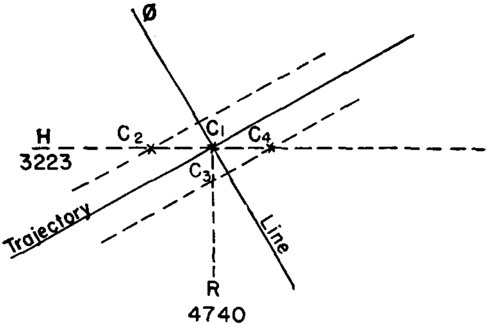
■ 128. TARGET PRACTICE CONDITIONS.—Under target practice conditions the guns may be emplaced so close together that we can ignore the parallax corrections in computing the calibration corrections. In this case the points *C*1, *C*2, *C*3, and *C*4 coincide with *T'*.

■ 129. CALIBRATION CORRECTIONS USING TRIAL SHOT CHART.—*a*. Figure 45 shows a trial shot chart on which *CB*4 and *C*4 only have been plotted. Through *CB*4 draw a line parallel to the ϕ line. Through *C*4 draw a line parallel to the trajectory. The distances, which are the $d\phi$ and dF corrections, are shown in figure 45. These distances are measured by the scales superimposed on the ϕ line and the trajectory of the trial shot chart. As *CB*4 is below the line parallel to the trajectory through *C*4, the $d\phi$ correction is plus. As *CB*4 is short of *C*4, the dF correction is plus.

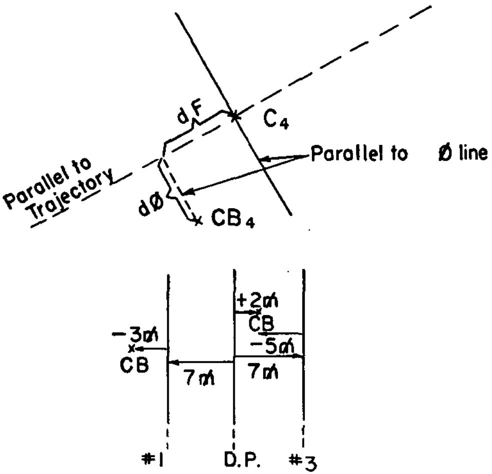
b. To compute the dA correction, subtract the lateral deviation of *CB*4 as observed from O_1 (converted to the horizontal plane), from the lateral parallax correction of *C*4 (which in paragraph 127*b* was shown to be line for the battery emplaced as shown in figure 44). In this particular case, the observed lateral deviation of *CB*4 with sign reversed is the dA correction. If the deviation of No. 1 gun were left (—) 10 mils as spotted from the O_1 station, the dA correction would be $-7-(-10)=+3$ mils. Similarly, if the deviation of No. 3 gun were right (+) 2 mils as spotted from the O_1 station, the dA correction would be $+7-(+2)=+5$ mils. (See fig. 45.) These computations should always be checked by drawing a figure.

c. Repeat the above computation for each gun.

d. If we applied the calibration corrections as computed above to the individual guns, we would then have the guns



VERTICAL CALIBRATION CORRECTIONS.



LATERAL CALIBRATION CORRECTIONS

#1 = -7-(-10) = + 3m̸
#3 = +7-(+2) = + 5m̸

FIGURE 45.—Plotting individual calibration points and center of burst for each gun on the trial shot chart.

shooting the correct pattern in the sky and in addition the center of the pattern would be at the *TSP*. It will be found that such corrections would be relatively large on each gun because they would include corrections normally made by trial fire corrections.

e. In paragraph 93*b*(3), it is stated that the corrections should not cause the director to make an error in basic data. Changing the fuze range violates this consideration because it changes the time of flight of the projectile. In making calibration corrections, we knowingly violate this consideration because there is no alternative. We can keep the resulting error to the minimum, however, by selecting the base piece with a view to insuring small fuze corrections. For example, suppose the fuze corrections determined were No. 1, +2; No. 2, +4; No. 3, +4; and No. 4, +6. It is obvious that with either No. 2 or No. 3 gun as a base piece only two guns will require corrections and these will be small and of opposite sign. If either No. 1 or No. 4 is taken as the base piece, there will be three corrections all of the same sign and one correction much larger than the others.

f. A base piece is selected whose fuze corrections, when subtracted from the fuze correction of the other guns of the battery, will cause the least amount of fuze change. The calibration corrections for the guns are determined by subtracting all of the calibration corrections for the base piece from the respective calibration corrections for the other guns. Note that by following this procedure the calibration corrections applied to the base piece are zero. It will be seen that when done in the above manner the calibration corrections move three of the guns with respect to the fourth or base piece. The desired pattern is obtained and no large *dF* corrections will be necessary. A simple rule to follow is: Change the sign of the base piece corrections and add algebraically to the respective corrections of the other guns to obtain the final calibration corrections. (See illustrative problem, par. 253.)

■ **130. Application of Calibration Corrections.**—Calibration corrections must be applied to the individual guns. The *dF* corrections are applied to the fuze setters. When case III pointing with electrical data-transmission is employed, the mechanical pointers of the data receivers are displaced from their normal positions. Complete instructions for applying calibration corrections to the individual guns are found in section IV, chapter 4.

■ 131. SUMMARY OF CALIBRATION FIRING.—The following steps outline the procedure of calibration fire:

a. Remove all corrections which have been applied to the individual guns.

b. Complete all matériel preparations as outlined in paragraph 95.

c. Select a trial shot point to be used as a calibration point.

d. Compute the O_1 and O_2 data for the TSP selected as described in paragraph 98.

e. Point the observation instruments at O_1 and O_2 on the *TSP*.

f. Following the the method prescribed for trial fire (par. 100), compute the ballistic corrections for the calibration point.

g. Following the methods prescribed for trial fire (par. 101), compute corrected firing data for this point and lay all instruments on this point.

h. Fire a settling shot from each gun.

i. Fire five rounds from each gun, verifying the laying of the gun and the setting of the fuze for each round as in trial fire.

j. Observe the deviations of each burst, using bilateral observation. Average the deviations of the bursts fired from each gun and determine the deviations of the individual centers of burst.

k. By means of the conversion chart (fig. 41) or the Crichlow slide rule, convert the lateral deviations from O_1 and the range deviations from O_2 (observed in the slant plane) to deviations in the horizontal plane.

l. Plot the several *CB*'s on the trial shot chart using the same methods employed in trial fire. (See par. 105.) Identify each *CB* with the gun from which fired by the notation *CB*1, *CB*2, *CB*3, and *CB*4.

m. Compute the displacement of the calibration point for each gun and plot these points on the trial shot chart. Identify each point with the corresponding gun by the notation *C*1, *C*2, *C*3, and *C*4.

n. Determine the *dφ* and *dF* correction for each gun from the trial shot chart. (See par. 129*a*.) Determine the *dA* correction as outlined in paragraph 129*b*.

o. Select a base piece and compute the calibration corrections to be applied to each gun as outlined in paragraph 129*d*.

p. Apply the individual calibration corrections to the data receivers on the guns. (See sec. IV, ch. 4.)

■ 132. VERIFICATION FIRE; THE BURST PROBLEM.—*a.* Verification of the corrections which have been determined and applied as a result of calibration and trial fire is accomplished through the execution of verification fire commonly called a burst problem. A burst problem is one in which the four guns of the battery are fired at a burst placed in the air from one of the guns. A shot is fired and the burst is assigned as a target. Its altitude is read and set in the data computor, data are sent to the guns, and all guns open fire. Two to four rounds per gun are usually fired.

b. In this type of preparatory fire, the whole position finding service functions and it therefore provides a valuable check on the efficiency and accuracy of the entire system. Verification fire discloses errors in orientation, leveling, and synchronization. It also serves to verify the results of calibration and trial fire. However, verification fire cannot be considered as a substitute for calibration and trial fire.

c. Care should be taken not to remove the calibration or trial fire corrections unless the errors are definitely determined. The positions of the bursts having been determined with considerable accuracy, the trial shot corrections should ordinarily not be changed as a result of range deviations determined in verification fire. The most probable cause of range deviations is in determination of altitude of the target burst. The only value of range deviations in verification fire is that they show whether or not the battery has been effectively calibrated.

■ 133. DETERMINATION OF DEVELOPED MUZZLE VELOCITY AND FUZE ERROR.—*a. General.*—This discussion deals with the determination of the value of the fuze error. It also deals with the determination of the actual developed muzzle velocity. It is important that the developed muzzle velocity and fuze error is known. This information may be determined without additional firing if proper records of previous trial fire problems have been kept. With this information and with an accurate meteorological message, proper settings may be made and fire for effect opened with a reasonable expectancy of hits even when there has been no opportunity to conduct trial fire immediately preceding the action.

b. Theory.—The results of any one trial shot problem may include errors due to improper leveling of the gun or data computor, due to incorrect determination or application of the data contained in the meteorological message and due to other unknown systematic errors. In a series of trial shot problems, these errors will all be present in varying quantities. However, if the results are averaged, the errors which follow the laws of probability will tend to compensate each other. Therefore, it may be assumed with considerable confidence that the averaged results of a series of carefully conducted trial shot problems will contain only the effects of fuze error and variation from the expected or assumed muzzle velocity. If the density and powder temperature in any of these problems were different from standard and were not corrected at the time of firing the trial shots, it will be necessary to correct the coordinates of the center of burst.

c. The average *CB* for all recorded firings is moved to the muzzle-velocity line by a correction in fuze setting and thence to the *TSP* by a change in the muzzle-velocity setting. The amount that the *CB* must be moved parallel to the trajectory to the *MV* line is the fuze error. The amount that the *CB* must be moved along the *MV* line to the *TSP* is the muzzle-velocity error.

■ 134. **PLOTTING THE AVERAGE *CB* OF A GROUP OF TRIAL SHOT PROBLEMS.**—*a.* In plotting the average *CB* of a group of trial shot problems when determining the developed *MV* and fuze error, the following conditions may arise which affect the problem:

(1) The same base line was not used in all the trial shot problems.

(2) The same base line was used, but the azimuth of the *TSP* was not the same for all the problems.

(3) Ballistic density or powder temperature, or both, were not corrected for in all the problems.

b. Before the *CB* can be averaged, the data must be reduced to a common basis. In the case of *a*(1) and (2) above this can be done by solving each problem individually for the horizontal range to the *CB* from O_1. In the case of *a*(3) above the coordinates of each *CB* (ϵ and *R*) are corrected for the effects of ballistic density and temperature of the powder, using the differential effect tables in the firing tables.

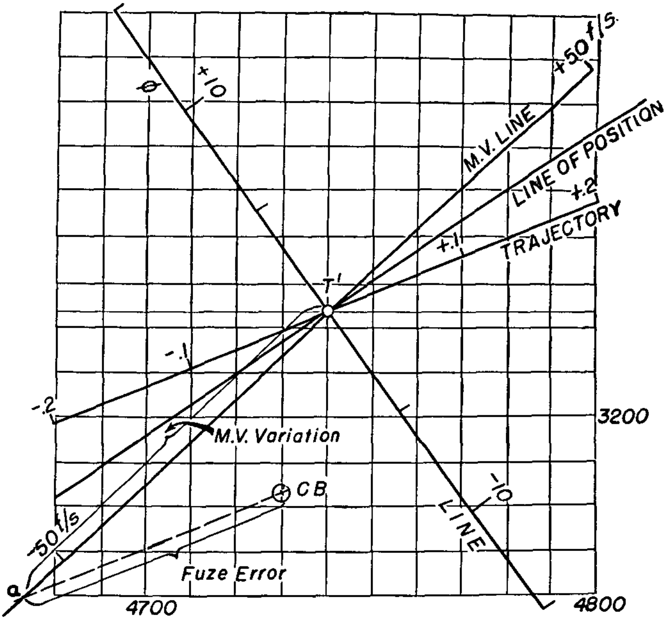


FIGURE 46.—Developed *MV* and fuze error from the trial shot chart.

c. Having reduced all *CB*'s to a common basis, we can now plot the average *CB* on the trial shot chart, using ϵ and *R*. (See illustrative problem, par. 251.)

■ 135. DEVELOPED *MV* AND FUZE ERROR FROM TRIAL SHOT CHART.—*a.* Figure 46 shows the average *CB* of a group of trial shot problems plotted on the trial shot chart. Draw a line through *CB* parallel to the trajectory until it intersects the *MV* line at *a.* The length of the line *CB–a* is the fuze error. Laying off this distance on the trajectory, it measures approximately 0.2. As the *CB* was below the *MV* line, the correction is minus. The fuze correction is therefore —0.2 or —2 corrector divisions.

b. The intersection of the line with the *MV* line, that is, the point *a,* is the variation of the *MV.* In figure 46, the *MV* variation reads —58 f/s. For points below the *TSP* the muzzle velocity is below normal; for points above the *TSP* the muzzle velocity is above normal. As the density and powder temperature effects have already been removed, the *MV* variation is from the original computed or assumed *MV* under standard conditions. (See illustrative problem, par. 254.)

■ 136. ILLUSTRATIVE PROBLEMS.—Problems illustrating the rules and methods described in paragraphs 98 to 135, inclusive, are found in paragraphs 248 to 254.

SECTION XII

FIRE FOR EFFECT

■ 137. GENERAL.—*a.* Fire for effect is any fire directed at hostile targets. The type of fire normally used by antiaircraft guns against hostile aircraft is designated as continuously pointed fire. In this type of fire all fire-control instruments are continuously pointed at the target and proper firing data continuously computed, transmitted, and applied on the guns. Continuous fire is opened at the limiting range, and the normal rate of fire is maintained by all guns until the target is destroyed, passes out of range, or a target offering a greater threat appears. Volley fire is used only in special situations where it is applicable, as against a maneuvering target or to conserve ammunition.

b. In section XI the various types of preparatory fire are discussed in detail. Although the artilleryman will normally be concerned with the problems of trial fire more frequently than any other type of preparatory fire, it is essential that he understand all types. It is also essential that he realize that complete preparation of fire is not limited to the actual mechanics of firing trial shots but includes the preparation of his men by thorough training in their duties, preparation of matériel by frequent, careful adjustments and tests, and careful planning and establishment of a system of observation and adjustment of fire.

c. A battery commander must be prepared to deal with situations during fire for effect where the judicious application of corrections to firing data will increase the effectiveness of his fire.

d. Adjustment of fire is the process of placing the center of burst on the target or adjusting point and keeping it there. If adjustment is to increase the effectiveness of fire, it is essential that the artilleryman thoroughly understand the effect of applying corrections to firing data during fire for effect, and the methods to be employed must be completely and carefully planned.

■ 138. CONDUCT OF FIRE.—The procedure followed in firing an antiaircraft artillery gun battery employing the normal type of continuously pointed fire may be summarized as follows:

a. The battery receives information of the approach of enemy aircraft.

b. The battery commander assigns the target.

c. The battery commander or range officer causes the director and height finder to track the target. At the same time the target is picked up and tracked by all other fire-control and spotting instruments in use. The range officer designates the observer who is to report range deviations.

d. The range officer, or a qualified enlisted assistant, computes the corrections for fire for effect (par. 100) and applies the necessary corrections to the director. The range officer signals the battery commander as soon as the data are being computed smoothly and satisfactorily. Fire is opened at the command COMMENCE FIRING, normally given by the battery commander, and maintained at the normal rate until the command CEASE FIRING or SUSPEND FIRING is given. Officers or qualified enlisted assistants stationed at the director observe the lateral and vertical deviations and make the necessary adjustments to bring the center of burst on the line of position. The range officer or qualified enlisted assistant at the director receives the range deviations and makes the necessary adjustments in altitude.

e. For details of the methods of spotting and adjusting fire, see section XIII.

■ 139. BARRAGE FIRE.—*a.* The antiaircraft artillery barrage is a type of fire which has for its primary purpose the denial of a point or route to enemy aircraft. It is fired when continuously pointed fire cannot be used. It is an extravagant and in most cases ineffective method of fire. There are conditions, however, under which a barrage is the only type of fire which gives promise of success. The following examples show the conditions under which barrages may be used:

(1) Where the enemy airplanes have been located approximately but due to clouds cannot be seen.

(2) At night, when illumination is not available, a barrage must be fired. Under such circumstances, one method is to determine the approximate location of the enemy aircraft by means of sound locators. A barrage is then fired by all available guns to cover the probable path of the enemy airplanes. The barrage is placed along this route of approach and held stationary for a certain prescribed time. At the end of this time all guns cease firing and another approximate location of the enemy attacking forces is made. This procedure is continued until the enemy aircraft has been destroyed or has left the field of fire of the guns.

(3) Another condition under which barrage fire will be employed exists when the director has been rendered unserviceable. If only the height finder or one or both altimeters have been rendered unserviceable, however, barrage fire need not be resorted to, as continuously pointed fire can be maintained by estimating the altitude and then adjusting fire.

b. (1) To employ barrage fire successfully the prospective path of the target and the location of the probable objective must be known. The altitude, angular height, and azimuth of a point in space in the prospective path of the target are then determined, so that a volume of fire placed about that point will accomplish the mission desired in the time available.

Where barrages are to be fired by numerous batteries for the purpose of intercepting bombardment or other types of attack, however, such as during a night attack when no illumination is available, the points at which the various batteries will fire must as a rule be determined in advance by higher commanders. In general, a series of barrage points will be chosen as soon as the units are in position. The points having been selected and identified, higher authority can then call upon various batteries or battalions to fire barrages on the point or points as desired.

(2) A suitable barrage will be secured if a quadrant elevation, azimuth, and fuze range are selected for each gun so that the points of burst will fall at the approximate corners of a vertical square, 200 yards to a side, with the center of the square at the point selected as indicated above. When the guns are pointed in this manner, the normal dispersion will account for a reasonable distribution of shell fragments about the point selected.

SECTION XIII

SPOTTING AND ADJUSTMENT OF FIRE

■ 140. SPOTTING.—*a*. In the preceding sections the means and methods have been described by which the position of a target is determined and firing data calculated and applied at the gun, to the end that a projectile fired from a properly pointed gun will burst upon reaching the target. Despite the thoroughness and care with which these operations are accomplished, all projectiles fired from a gun will not burst at the calculated points. The reasons for this phenomenon are numerous and some are quite complex in theory, but the fact remains that deviations of bursts from their expected position (the target) will frequently occur. Experience in artillery firing has shown that a knowledge of the magnitude and direction of these deviations is of considerable importance, in that it may lead to the judicious application of proper corrections to firing data and increase the probability of hitting the target. This gives rise to the necessity for spotting which is defined as the process of determining deviations. Deviation is defined as the angular or linear (or both) displacement of a burst, or a series of bursts, from the target or the point at which fire is directed.

b. Spotting methods must not only be adapted to the means available but also to the methods of firing being employed. Obviously, the slow, deliberate firing of a single gun at a fixed point and the rapid continuous firing of four guns at a rapidly moving target present two entirely different problems which affect the choice of methods in spotting. As contrasted with seacoast artillery spotting, in which deviations in range and azimuth are measured, antiaircraft artillery spotting must include measurements in three dimensions; in range, in direction laterally, and in direction vertically.

c. Spotting methods are influenced by the manner in which corrections to firing data may be applied; for example, if corrections are applied in linear units (yards), deviations should be determined and expressed in the same units.

d. Spotting must be accomplished at the instant the burst occurs. Unless this is done, the magnitude of the deviation will be increasingly in error due to the movement of the target and the effect of wind on the burst itself.

■ 141. METHODS OF SPOTTING.—There are two methods of spotting; the unilateral method, in which all deviations are determined at one station usually located at the battery position, and the bilateral method, in which lateral and vertical deviations are determined at the battery and range deviations at a distant station. The location of an antiaircraft artillery gun battery will generally determine the arrangements for spotting. A battery should take advantage of all possible means for observation of fire. It may often be necessary, however, for a battery located in a forward combat area and operating under conditions requiring frequent movement and denying the use of extensive communication to use only such means as are available at the battery position. In all cases, spotting for antiaircraft artillery batteries must be continuous and the facilities for spotting must be as complete as conditions permit. In view of the time factor, the method of spotting used during fire for effect must permit instantaneous adjustment of fire.

■ 142. UNILATERAL SPOTTING.—Lateral and vertical deviations are determined at the battery position. The present types of directors are equipped with separate spotting telescopes. Due to the time factor during fire for effect, the same officers or assistants who determine lateral and vertical deviations must also make the necessary adjustment corrections and adjustment must immediately follow the determination of deviations in each case. This precludes the use of separate angle measuring instruments requiring transmission of the deviation data. Range deviations are determined by using a stereoscopic height finder at the battery position as a spotting instrument. Ordinarily only sensings are obtained, but the magnitude, where possible, is given in such general terms as "Way over," "Over," "Hit," "Doubtful," "Short," and "Way short." The spotter is connected by telephone with the range adjusting officer at the data computor and calls out the sensings continuously over his telephone. Stereoscopic spotting is difficult and is inaccurate if the bursts are not on or close to the line of position and should not be used when other methods are available.

■ 143. **BILATERAL SPOTTING.**—Lateral and vertical deviations are obtained as in the unilateral method. Range deviations are obtained with suitable instruments located at distant stations and are read in angular units (mils) in the slant plane containing the target and the spotting base line. Range deviations may also be determined in terms of a fuze range pattern as read at the distant station. (See par. 150.)

■ 144. **CONDUCT OF SPOTTING.**—*a*. Optical instruments used for spotting have reticles graduated in mils along the vertical and horizontal axes as shown in figure 47. The relation between the burst and the axes determines the deviation read. In figure 47 the burst is shown at right 10, below 5 mils.

b. When spotting from the flank station, the deviations are read left or right the same as in the instrument at the battery position. It is not necessary to read the vertical deviations from the flank. Due to the restricted field of view in the telescope at a flank station, it may be necessary to supplement it with a range rake in order to obtain deviations of bursts which occur outside of the field of view of the telescope.

c. Experience has shown that a mentally alert and experienced observer can measure deviations in one direction only (right or left) (high or low), to the nearest mil, during slow deliberate firing at a fixed point such as is used in firing calibration or trial shots, and to the nearest 5 mils when firing a single gun (average maximum rate of 25 rounds per minute) at a rapidly moving target. When firing two guns at maximum rate, he may reasonably be expected to measure to the nearest 5 mils the deviation of about 60 percent of the bursts which occur. When firing three or four guns at maximum rate at a single target, it is beyond the capabilities of any human observer to measure the deviations of more than a very few of the individual bursts with any accuracy. However, the average observer possesses the ability to measure to the nearest 5 mils without any computation the average deviation of a group of bursts. This information is potentially of more value than measurement of individual deviations during firing at a rapidly moving target, as it obviates the necessity for calculating the average of individual deviations before applying a correction to firing data.

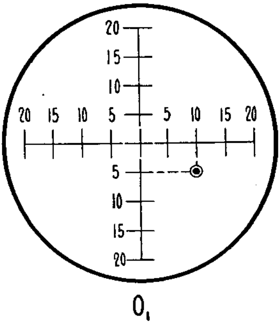


FIGURE 47.—Observed deviations.

■ 145. ADJUSTMENT OF FIRE.—Adjustment of fire is the process of determining and applying corrections to firing data in such a manner as to move the center of burst to the adjusting point and keep it there. Adjustment of fire and spotting are very closely allied. Without spotting there can be no adjustment. The method of spotting will largely determine the method of adjustment. The effectiveness of the adjustment will increase or decrease with the accuracy of the spotting. Adjustment does not obviate the necessity for trial fire.

■ 146. TIME FACTOR.—*a*. As in the case of calculating firing data for antiaircraft guns, the time factor affects profoundly the fire adjustment problem. Its influence is so marked that an understanding of the part it plays is essential to the intelligent application of adjustment corrections. Consider as a specific example (using trajectory chart 3 AA–J–2a, fig. 23), a bombing plane approaching a battery of four 3'' antiaircraft guns whose normal rate of fire is 100 rounds per minute. Let it be assumed that the airplane is flying directly toward the battery at a constant altitude of 3,000 yards with a constant speed of 300 miles per hour. From the trajectory chart, it will be noted that the airplane enters the field of fire at a horizontal range of 7,300 yards. The time of flight to this point is about 21 seconds. If fire is opened so that the first bursts occur when the airplane enters the field of fire, it is a matter of simple arithmetic to show that the battery will have fired about 35 rounds before the first bursts are seen, and as a corollary, before the need for an adjustment correction will be apparent. If a reasonable allowance of 5 seconds is made for the process of spotting the center of burst of the first four shots and applying an adjustment correction (if necessary), the effect of the correction will not be apparent until the 44th round is seen to burst. During this period, the plane will travel for 26 second (21+5) plus the time of flight of the 44th round (approximately 7 seconds). Traveling at 150 yards per second, the airplane will be at a horizontal range of approximately 2,350 yards when the first shot fired with adjusted data (the 44th round) is seen to burst.

b. From the example in *a* above of the marked influence of the time factor on the adjustment problem, several conclusions may be drawn.

(1) Opportunities for adjustment of fire will be extremely limited. As a general rule, it will be useless to attempt adjustment during fire for effect unless the target remains in the field of fire of the battery for a period longer than 30 seconds.

(2) Prompt action is necessary if adjustments are to be effective. Adjustment cannot be withheld until deviations are determined for a large number of shots. Adjustment

should begin with the first few shots observed, but should not be based on less than four shots.

(3) Readjustment should be made on subsequent shots where necessary. If in the example given in *a* above, an adjustment had been made on the basis of the first four shots, and the 12th and 14th shots were observed as hits in range, it would be logical to at once remove any range adjustment correction that had previously been made.

(4) Adjustment corrections must be made boldly. Each correction applied should be of such magnitude as to bring the center of burst onto the target or adjusting point. Time will not permit of piecemeal adjustment.

■ 147. **Application of Corrections to Firing Data.**—*a.* Before attempting to apply adjustment corrections to firing data during fire for effect, the artilleryman must be thoroughly familiar with the effect of such corrections on the position of bursts. Summarizing briefly, facilities may be provided for applying corrections during fire for effect, depending upon the type of fire-control instruments, as follows:

(1) Vertical adjustment correction is normally applied in terms of mils "Up" or "Down," and to the full value of the vertical deviation observed, "Below" or "Above". Irrespective of the manner in which it is applied, the net result is to change the quadrant elevation at which the gun is laid which moves the burst along the $d\phi$ line. (See fig. 48.)

(2) Lateral adjustment correction is normally applied in terms of mils, "Right" or "Left", and to the value of the lateral deviation observed, "Left" or "Right". The observed deviations must first be converted into the horizontal plane as prescribed in paragraph 148*c*. The net result is to change the lateral pointing (azimuth) of the gun and move the burst laterally by the amount indicated.

(3) Present altitude correction is normally applied in yards, "Up" or "Down," and to the full value of the range deviation observed, converted into terms of altitude by one of the methods described in paragraph 148*d*. The net result is to change one of the basic elements used in calculating firing data and thus move the burst along the line of position.

(4) Fuze range correction is normally applied only as a result of calibration fire or to correct for density effect on the

time of burning of powder train time fuzes. It results in moving the burst along the trajectory. The reason such a correction is not applied during fire for effect is obvious. The target's future position is predicted upon the basis of time of flight of the projectile. The application of a correction in fuze range will change the time of flight of the projectile without changing the calculations for the target's future position, thereby causing a deviation of the projectile from the line of position both laterally and vertically as well as along the trajectory.

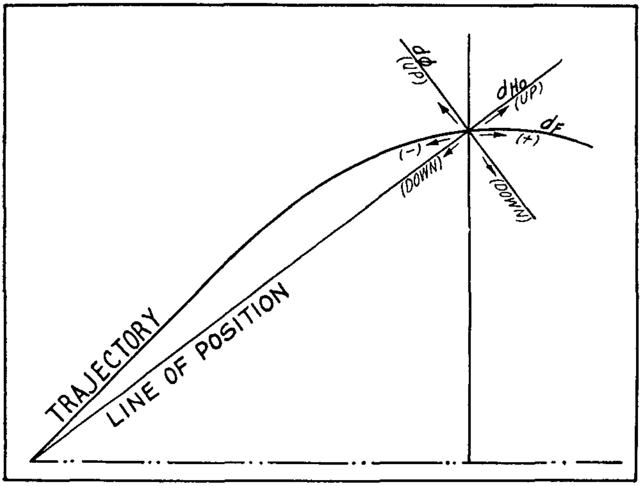


FIGURE 48.—Effect of corrections.

b. Effects on position of the burst, resulting from corrections to firing data, are illustrated in figure 48.

■ 148. METHODS OF ADJUSTMENT OF FIRE.—*a*. With an understanding of the effect upon the position of bursts of corrections to firing data, the ground work is laid for a discussion of methods of adjusting fire during fire for effect. The first step in adjusting fire, that is, determination of deviations of bursts from the target, has been presented in paragraph 144. Influence of the time factor requires that spotting and adjusting shall be combined as far as practicable into a single operation; that is, the observer of the deviations should also apply the adjustment corrections. All the directors are provided with facilities for spotting and correcting vertical and lateral deviations. Range deviations, being observed at the height finder or at a flank station, must be relayed to the range officer or qualified assistant usually by telephone.

b. In range spotting during fire for effect, it was assumed that the burst occurred on the line of position. If adjustment of fire could be accomplished slowly and deliberately, the first step would be to apply corrections laterally and vertically to bring bursts on to the line of position and then observe range deviations. However, the time factor demands that whatever corrections are necessary in range or deflection be made instantaneously and continuously. None of the standard methods of fire adjustment as used in seacoast or field artillery can be wholly adapted for use with antiaircraft. The methods described below are based upon conditions where the fire-control instruments are providing an accurate prediction of the target's future position and correctly calculating the necessary firing data. In this situation, such deviations as occur will be due to normal dispersion and to errors which could not be eliminated during preparatory fire.

c. The second step in adjusting fire is to place the center of burst as close to the line of position as possible. This is accomplished by the application of vertical and lateral deflection corrections. This adjustment should be instantaneous and continuous, for unless and until the center of burst is on or very close to the line of position, spotting from the flank is apt to be somewhat unreliable and stereoscopic spotting from the battery position will be impossible. The spotting telescope on the director measures the lateral deviations in an inclined plane; that is, along a horizontal line through the target and perpendicular to the line of position. Lateral deflection corrections, however, are applied to the director in the horizontal plane. It is therefore necessary to convert deviations measured in an inclined plane to corresponding values in the horizontal plane in order that they may be applied correctly as adjustment corrections in the data computor. In order to simplify the calculation of the magnitude of the lateral deviation in the horizontal plane, it is sufficiently accurate to accept the full value of the lateral deviation for angular heights from zero to 600 mils. For other angular heights, the deviation should be multiplied by factors as indicated below:

600 to 1,000 mils	1.5
1,000 to 1,200 mils	2.0
1,200 to 1,400 mils	4.0

The deviations observed are multiplied by the proper factor and then applied to the data computor in the opposite sense. Vertical deflection corrections are made by applying in the opposite sense the full value of the deviations observed.

d. The third step in adjusting fire is the determination and application of range adjustment correction. Range adjustment corrections are made by altitude corrections (dH_o spot). A change in altitude moves the center of burst along the line of position, increasing or decreasing the slant range. (See fig. 49.) The altitude of the center of burst is H_b and that of the target is H. The application of an altitude correction equal to (H_b—H) will move the center of burst along the line of position and place it on the target. The center of burst should be placed on or just short of the target. When lateral and vertical deflections are correct, the most favorable position for the center of burst is from 20 to 50 yards short of the target. Fire may be considered adjusted when mixed overs and shorts with a preponderance of shorts are obtained on the

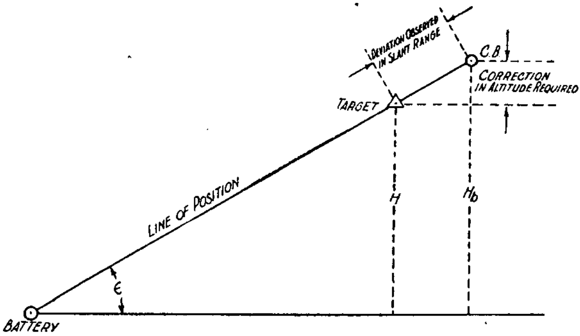


FIGURE 49.—Altitude and angular height.

line of position. While altitude corrections can be applied to the altimeter, M1920, and height finders, it is preferable in all cases to apply them during fire for effect directly to the director in order to secure more prompt adjustment. As a general rule, no attempt should be made to adjust the range by the application of corrections in fuze range. Range adjustments are always applied in a sense opposite to that of the reported deviation. A decrease in altitude decreases the range, and an increase in altitude increases the range. The value of the range adjustment correction (in terms of altitude) is obtained by any one of the following methods which are described in detail in paragraphs 149, 150, and 151.

(1) Angular unit.
(2) Fuze range pattern.
(3) Modified bracketing.

e. Adjustment corrections for a particular target will probably hold good for another target in the same general area and with the same approximate altitude and direction of flight. For other targets, however, it is generally preferable to readjust.

■ 149. ANGULAR UNIT METHOD OF FIRE ADJUSTMENT.—*a.* This is the most rapid and dependable method of range adjustment and should be used when practicable.

b. In this method, the distant observer determines the range deviation in mils, over or short of the target, using the flank spotting instrument, M1 (par. 195).

c. In order to make an adjustment correction, the angular deviation read by the observer must be converted into an altitude correction in yards. Since the magnitude of the correction factor is dependent upon the position of the observer relative to the gun–target line, we must have a quick, practical method of determining the correction factor in the field. The flank spotting rule, M1 (par. 195) converts the deviations from the flank station in mils to altitude correction in yards.

d. Instructions for use of the flank spotting rule M1 are given on the face of the rule. (See par. 195*c*.) Either a correction factor or the altitude correction can be calculated by the rule.

■ 150. FUZE RANGE PATTERN METHOD OF FIRE ADJUSTMENT.—*a.* In the fuze range pattern method, the bursts are made to occur at different intervals along the trajectory by specified variations of the fuze settings. One gun will fire with fuze greater than normal, two guns with normal fuze, and one gun with fuze less than normal. This variation in fuze setting

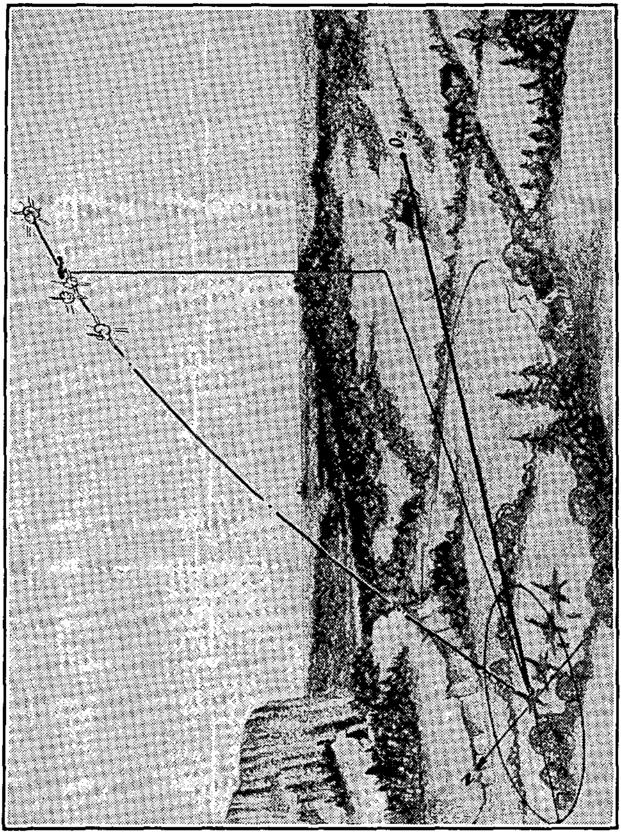


FIGURE 50.—Fuze range pattern.

will cause the pattern of the bursts of the battery to assume a form similar to that shown in figure 50. The distance, seen by the observer, between the burst of greatest range and least range, forms a unit of measure by which the deviation of the center of the pattern from the target may be estimated. The only practical advantage of this method lies in the fact that the unit of measurement of deviations is independent of the position of the observer, since both the fuze range pattern and the deviation observed are distorted in the same ratio. This obviates the necessity of determining the length and direction of the gun–observer line. The following disadvantages weigh heavily against using this method:

(1) It may be impossible to definitely identify the pattern due to fuze errors or to a failure of the guns to fire simultaneously. This method also requires a greater expenditure of ammunition and is generally slower than the angular unit method of adjustment.

(2) Only half the fire volume of the battery is directed at the target until the adjustment is completed. This distinct loss of initial fire volume violates one of the rules formulated in paragraph 7.

b. The firing tables give for each combination of quadrant elevation and time of flight the probable error (*PE*) in time of flight in seconds. These values multiplied by four will give the value of one fork expressed in time of flight. For practical purposes, the numerical value of a fork in seconds of time of flight may be considered equal to the value of a fork in units of fuze range or corrector divisions. For example, table D–1, Part 2a, of firing Tables 3 AA–J–2a (see table XXI, paragraph 257) gives, for a *MV* of 2,600 f/s, a quadrant elevation of 700 mils and a time of flight of 10 seconds, a probable error of 0.10 second in time of flight. The fork for these data is 0.40 second or four corrector divisions. Under the normal service conditions a change of 4 percent in altitude moves a burst along the line of position approximately one fork or four probable errors in fuze range. This relationship is utilized in the fuze range pattern method of adjustment.

c. Assuming that a difference of X_f divisions in fuze range will produce a difference of one fork, a "fuze range pattern" is established at the target by firing two guns with the fuze setting determined by the data computor, one gun with this setting reduced by one-half the value of X_f, and the remaining gun with the setting increased by one-half the value of X_f. The length of the pattern will then be equal to X_f divisions in fuze range, or one fork.

d. Values of X_f will be constant only within certain limits of fuze range and quadrant elevation. Instead of changing X_f to meet these varying conditions, X_f is made constant equal to four corrector divisions. Then the dH_o correction is the variable as fuze range and quadrant elevation change.

e. An expression of the above relationship is the following simple proportion:

$$\frac{0.4 \text{ (actual setting)}}{X_f \text{ (true)}}=\frac{dH \text{ (actual)}}{0.04\,H\text{(true)}}$$

This may be simplified to

$$dH=\frac{0.4\times 0.04H}{X_f}$$

but $X_f=4\ PE$ (seconds) PE=Probable error

hence:

$$dH=\frac{0.4\times 0.04H}{4PE\text{(seconds)}}=\frac{0.004H}{PE\text{(seconds)}}$$

Extracting values for altitude (H) and probable error (PE) from firing tables for various values of fuze range and quadrant elevation, a table of dH directions may be computed. Extracts of Firing Tables 3 AA–J–2a will be found in paragraph 257.

Values of altitude corrections for 1 fork

φ (mils)	200	400	600	800	1,000
Fuze range	Altitude corrections				
8	40	80	110	120	130
10	35	80	105	115	125
12	30	70	95	110	120
14	25	65	90	100	110
16	----------	55	80	90	105
18	----------	50	70	85	95
20	----------	40	60	75	85

This table is to be used with an offset of +0.2*F* on the fuze receiver of one gun and a −0.2*F* on the fuze receiver of another gun. The other two guns of the battery are fired with no fuze offset. A simple means to apply the fuze offset is to place a piece of adhesive tape on the inner fuze dial. Make a mark + or $-0.2F$ from the zero pointer. The gunner then matches the new (offset) pointer on the fuze receiver at a proper signal from the range officer. In this way, a fuze pattern may be immediately applied or taken off at the will of the adjusting officer.

f. This standard variation from normal fuze setting by two of the guns establishes the fuze range pattern in the sky (called a "fork"). The spread of the pattern in range is a unit of measure by which the observer at the flank station estimates the deviation of the center of the pattern over or short of the target. Estimation of deviations are made to the nearest one-half fork. The range officer receives the reports of deviations by telephone. Using the table in *e* above he is able to extract directly the altitude correction for the range deviation. The table gives altitude corrections for deviations of one fork at different fuze ranges and quadrant elevations.

Example: Assume the target is at quadrant elevation 800, and fuze 14. The flank observer reports, "Over one." The value of the altitude correction from the table is 100 yards. The correction applied to the dH_0 dial of the director would be "Down 100 yards."

g. Under certain conditions such as for maneuvering targets, it may be better to maintain the spread of the guns in fuze range, merely moving the pattern along the line of position by corrections in altitude. Under other conditions, as soon as the target has been bracketed, all guns should be fired with the same fuze setting.

■ 151. MODIFIED BRACKETING METHOD OF FIRE ADJUSTMENT.—*a.* In the modified bracketing method of adjustment, the range deviations are determined by the stereoscopic height finder observed. As was pointed out in paragraph 142, the deviations are sensings. It is impossible for the observer to obtain reliable sensings of the bursts until the bursts are on or very close to the line of position. The method is slower than the angular unit method of adjustment. If the range adjustment must be delayed until the vertical and lateral corrections take effect, the method is even slower. It is used only when the other methods are impractical.

b. Since the observer determines only the sense of burst (over or short) with reference to the target, and cannot give measured deviations, the adjusting officer must apply corrections in terms of a "fork" (approximately 4 percent of the altitude), which is the unit of adjustment in this method. (See fig. 51.) Corrections should be made according to the following:

Way over	Down 3 forks.
Over	Down 2 forks.
Hit	No change.
Doubtful	No change.
Short	Up 1 fork.
Way short	Up 2 forks.

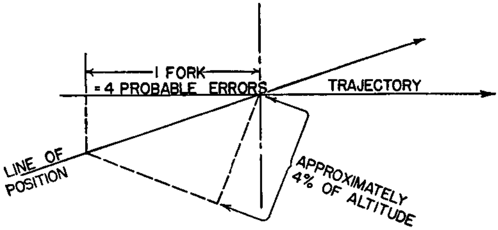


FIGURE 51.—Determination of fork.

c. When the sense is reversed, apply a correction of one-half of the adjusting unit in the opposite direction. When the center of burst has been sensed short, however, the correction should not be such as to place it beyond the target. When the center of burst is over, the correction should be of such magnitude as surely to reverse the sense.

■ 152. LOCATION OF FLANK SPOTTING STATIONS.—*a*. *Length of spotting base line*.—The length of the spotting base line is a very important consideration in locating the flank spotting stations. In order to determine just what effect length of base line had on correction factors, a number of courses were analysed using different length base lines and various ranges and altitudes. Correction factors were plotted for each course and base line. Figure 52 shows one set of curves of correction factors for a base line of 3,000 yards and a target altitude of 3,000 yards. (The altitude correction in yards is the correction factor multiplied by the range deviation in mils.) From a study of the curves for various altitudes, ranges, and base lines, the following deductions are made:

(1) For all courses, values of correction factors are greatest and change fastest when a short base line is employed.

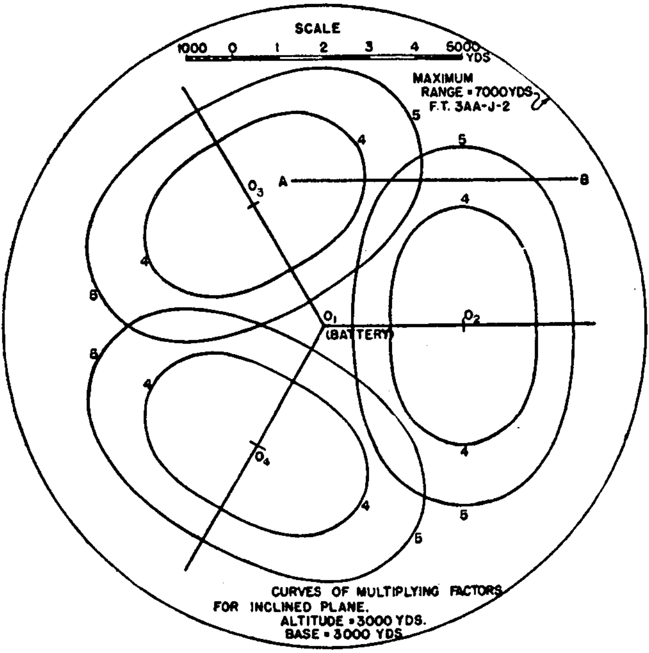


FIGURE 52.—Curves of multiplying factors.

(2) For most courses, these values are prohibitively large when using the 1,000-yard base line.

(3) Using three base lines, each 3,000 yards or more in length, accurate spotting results should be obtainable at all altitudes throughout the field of fire.

(4) Improvement in magnitude and rate of change of factor values when the base line is lengthened from 3,000 to 5,000

yards is so slight as scarcely to warrant the additional effort involved in installing and maintaining communication.

b. Effect of lateral and vertical deviations.—An unavoidable weakness in any system of flank spotting is the loss in spotting accuracy which will result when the bursts occur far off the line of position. The effect of such deviations is particularly noticeable when a spotting base line as short as 1,000 yards is employed. For example, in figure 53, which represents the firing situation in the inclined plane, it will be noted that with a 1,000-yard spotting base line and a slant range of 5,000 yards, a burst which is correct for range but is 3 mils right (observed from the battery) will appear from the flank as being 76 yards over in slant range. At an angular height of 800 mils, such an observation would thus call for an erroneous altitude correction of down 54 yards. Using a 3,000-yard base line under similar conditions, the burst would

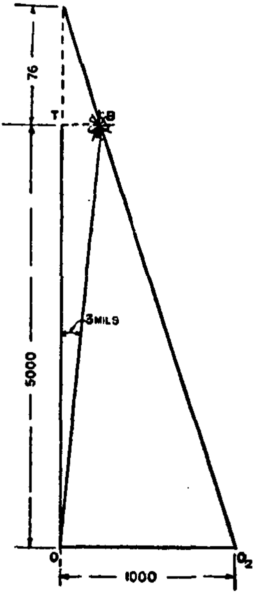


FIGURE 53.—Effect of lateral and vertical deviations.

appear as being 25 yards over in slant range. At an angular height of 800 mils such an observation would require an erroneous altitude correction of down 18 yards. This consideration indicates the necessity for a spotting base line of at least 3,000 yards in length. Lateral and vertical deviation from the line of position will each result in spotting errors of varying amounts, depending on the target angle, slant range, and inclination of the slant plane. When the inclination of the slant plane is less than 800 mils, the effect of lateral deviations will be the more serious. When the inclination of the slant plane is greater than 800 mils, the vertical deviation will be the more serious. In any case, it should be accepted as a definite doctrine of antiaircraft gunnery that only when the center of impact of a group of bursts is within 5 mils of the target both laterally and vertically (with a spotting base line of 3,000 yards or more), can full reliance be placed on flank observations. It may be noted that errors due to lateral and vertical deviations have exactly the same effect on spotting accuracy when using the fuze range pattern as when using the angular unit method. Thus, in the example cited, if the burst as plotted is considered as the center of the fuze range pattern, a similarly erroneous altitude correction will be called for. It appears, therefore, that the flank spotting station must be at least 3,000 yards from the battery position when either the angular unit or fuze range pattern method of spotting is used.

c. Number of flank spotting stations.—Consideration of figure 52 will show that any number of flank stations less than three will not be satisfactory as the multiplying factors become too great for accuracy in certain parts of the field of fire. The inherent accuracy of the spotting method employed varies inversely with the correction factor used. It is important, therefore, that these factors be kept as small as possible for all points in the field of fire. On the other hand, more than three flank spotting stations will complicate the problem by the inclusion of additional equipment, observers, and lines of communication to maintain, and at the same time, decrease only slightly the correction factors in certain parts of the field of fire close to the maximum limit of the guns. The base lines are arranged approximately

120° apart, thus giving a fairly even coverage of all parts of the field of fire.

■ 153. **Comparison of Methods of Fire Adjustment.**—Present accepted doctrine, confirmed by certain tests, ranks these methods of adjustment in order of effectiveness as angular unit method using magnitude spots obtained from a flank station on a measured base line; fuze range pattern method using observations from a flank station, no measured base line being required; and modified bracketing method using a stereoscopic height finder at the battery to obtain spots by sensing only. The last-named method is generally regarded as being far less accurate than the other two and ordinarily would be used solely in those situations where one of the more effective systems is not available.

a. The angular unit method is admittedly the most accurate of the three standard spotting methods. It requires the use of at least three flank spotting stations for accurate fire adjustment in all parts of the field of fire. The length and azimuth of the spotting base lines must be known. Map measurement is sufficiently accurate for these data. The flank spotting station must be equipped with a suitable instrument to measure the range deviation along the line of position from the battery (flank spotting instrument, M1), The battery commander's telescope measures lateral deviations along a horizontal line perpendicular to the line of position from the station. It also measures vertical deviations in the vertical plane including the line of position. (Therefore, it cannot be used as a flank spotting instrument for fire adjustment in conjunction with the flank spotting rule, M1, as described in paragraph 149*d*.) The range officer or his assistant must convert the angular range deviations, as read at the flank station, to altitude corrections.

b. Adjusting fire by the fuze range pattern method results in a considerable loss in fire effectiveness particularly insofar as the first few rounds are concerned. The spread may be removed after an adjustment has been secured, but by that time the destructive effect of a number of bursts has been sacrificed to provide the necessary yardstick for spotting purposes. The method is weak in that it provides for spotting only in terms of range forks. It is manifestly incapable of the accuracy obtainable with the angular unit method. Furthermore, it involves almost as difficult a problem for the range officer as does the angular unit method in determining corrections in terms of yards altitude. No special type of spotting instrument is required when spotting is done by the fuze range pattern method, observations being made either with the naked eye or with the assistance of such binoculars as may be available. The advantage claimed for this method, that is, that it requires no measurement of base line length, would seem to bear little weight since map measurement is sufficiently accurate for a base line used with the angular unit method. Hence the advantages claimed for the fuze range pattern method are practically nonexistent; whereas its disadvantages have become by comparison more serious than before, in view of the increased accuracy of the angular unit method with the recently developed devices for inclined plane spotting.

c. It is believed that the possibilities of stereoscopic spotting have never been fully exploited by the service. In its present state of development, stereoscopic spotting should still be regarded as an emergency method for use when failure of communication, difficulties of target identification, or other unforeseen troubles render flank-spotting facilities unavailable. Moreover, it appears likely that the angular unit method of flank spotting will always be potentially more accurate and will provide a quicker adjustment than ever will be possible with a unilateral system.

■ 154. **ADJUSTMENT OF FIRE AGAINST MANEUVERING TARGETS.**—*a.* Since the adjustment of fire is the process of bringing the center of burst onto the target or adjusting point and keeping it there, it is necessary to include a consideration of maneuvering targets. Actually, maneuvering targets do not require adjustment of fire but rather an adjustment of data which will serve to bring together the computed and the actual future position of the target. Since the fire-control instruments provide a linear prediction of the target's course at constant speed, it is clear that any deviation of the target from a rectilinear course, during the time of flight of the projectile, will result in an erroneous calculation of its future position. Any deviation observed will include not only the deviation due to dispersion and ballistic errors but also the error in prediction due to the target's maneuvers. The only tools provided to meet this situation are the various facilities for correcting firing data which are utilized in adjusting fire. This necessitates combining adjustments to correct for two different classes of errors. The adjustment for target maneuvers is purely a temporary one and must be removed as soon as the target resumes rectilinear flight, taking care not to remove any adjustment corrections that may have been properly made.

b. (1) As in the case of adjustment of fire, adjustments for maneuvering targets must be carefully planned beforehand so that when a distinctive type of maneuver or combination of maneuvers is recognized, corrections may be applied promptly. In planning, it is essential that the capacity of the target for maneuvers is known. Exact figures on the maneuverability of the most modern airplanes are not available. However the values stated in paragraph 5 give basic data for the analysis of specific problems.

(2) One basic assumption is made for the purposes of analysis as follows: In executing a turn, the airplane follows the arc of a circle whose radius is proportional to the speed of the airplane. For turns of not more than 90° the speed of the airplane remains unchanged.

c. All maneuvers of an airplane can be classified as—change in direction, change in altitude, change in speed, and combinations of the three.

(1) *Change in direction.*—(*a*) Sudden changes in direction are readily observed from the battery or flank station. As soon as a change in direction is apparent, estimated lateral, vertical, and fuze corrections should be applied. These corrections should be removed when the target resumes rectilinear flight.

(*b*) Corrections should be computed for various curved courses in order to obtain a general picture of the direction and magnitude of the corrections required under various conditions of altitude, speed, and angular height. When a specific maneuver is recognized, corrections based on the study of the general characteristics can be applied.

(*c*) The simplest method of computing the corrections is by a combination of graphical analysis and static problems set in the director. The course of the target is plotted to scale. Tangents are drawn to the plotted course at definite time intervals from the beginning of the maneuver. The coordinates of the points of tangency are set in the director as A_o, R_o and H_o. The E–W and N–S component rates of the target flying along the tangent are computed. These E–W and N–S rates are set in the director on the problem setting dials. The director will predict along the tangents and the values A_f, ϕ, and F can be read and recorded.

(*d*) It is necessary to know the time of flight for each of the predictions along the tangents. In the case of mechanical fuzes, fuze range equals time of flight. In the case of powder train fuzes, time of flight can be obtained from the firing tables or trajectory chart using F and ϕ as arguments.

(*e*) Multiplying the time of flight by the speed of the target results in the linear travel of the target during the time of flight. Lay off the linear travel of the target on the curved course from each point of tangency. This will locate the actual or true position of the target for each prediction made along the tangent.

(*f*) Place the coordinates (azimuth, horizontal range, and altitude) of the predicted position along the true course in the director. (The problem setting dials are set at zero.) The A_f, ϕ, and F dials will now indicate the firing data for the true predicted position of the target. The difference in the values of A_f, ϕ, and F as computed by the director for the two different problems will be the required corrections for the maneuver.

(*g*) As it will take an appreciable interval of time for the adjuster to note that the target is turning, to apply the corrections, and for the corrections to take effect, the adjuster must take into consideration this dead time when estimating the corrections. It will be found that the magnitude and direction of corrections will fluctuate greatly throughout the maneuver.

(2) *Change in altitude.*—(*a*) Consider next a decrease in altitude, or more commonly a "dive." Well-trained and experienced height finder observers should be able to maintain stereoscopic contact on a diving target. Thus the present position of the target will be continuously determined.

(*b*) The director, M4, is equipped with a mechanism to predict the altitude of the future position. As soon as this maneuver is discovered, an estimated altitude rate is set into the director by operating the altitude rate knob and the altitude follow-up motor is turned on. The indices of the altitude dial are kept approximately matched by changing the altitude rate. When the target "levels off," the altitude rate is removed.

(3) *Change of speed.*—It is not unreasonable to assume that a bomber traveling at a rate of 300 miles per hour may reduce its speed to 100 miles per hour in approximately 10 seconds, with a somewhat longer period required to again resume a speed of 300 miles per hour. Changes in speed affect the prediction problem in varying degrees, depending upon the angular height, altitude, and angle of approach of the target. When the angle of approach is approximately 90°, the principal error will be a lateral one. When the angle of approach is approximately 0°, the principal error will be a vertical one. When the angle of approach varies between 0° and 90°, errors will result both laterally and vertically. There is no reliable rule as to the magnitude of corrections to be applied. Again, it is a question of working out specific problems for varying changes in speed and for different speeds of airplanes.

d. The specific examples considered above are simple and each involve but one type of maneuver. Normally, a fully loaded bomber will not execute extreme maneuvers but will usually maneuver on wide curves or on a sinuous course of short curves, the main axis of its course being in the general direction of the target to be bombed discussed above. A maneuvering target may combine any of the changes. The corrections to be applied under such conditions of flight will ordinarily consist of a combination of the separate corrections involved.

e. A target maneuver which is completed in less than 10 seconds will render unnecessary, in the usual case, any effort to apply corrections, as the fire-control instruments will again make correct calculations as soon as the maneuver is completed. When the target pursues a zigzag course (sine curve) consisting of a series of changes of short duration, no corrections should be applied as the director will predict a mean course and the paths of the target and the bursts will repeatedly cross. It devolves upon the antiaircraft artilleryman to carefully plan his actions in applying corrections to the end that a target maneuver will not render completely ineffective the fire from his battery. Careful planning demands a thorough knowledge of the manner in which his fire-control instruments function, a well-trained group of operating personnel, and the analysis of various classes of maneuver which may be encountered under different conditions of range, altitude, and target speed. In analysis, the graphical method offers a guide as to the magnitude of corrections to be applied.

The approximations which are inherent in the method may be justified when the burst pattern, the normal dispersion of a four-gun battery, and the danger volume of a bursting shell are considered. Bombardment tactics should be carefully studied with a view toward anticipating what maneuvers may be employed. While the artilleryman is unable to apply corrections before a maneuver starts, close observation of a target's movements and prompt action will usually prove valuable. It is too much to expect that the center of burst will follow a maneuvering target continuously and large deviations must be expected at times. The real problem is to reduce these deviations as promptly as possible and to improve the director's calculations. If the target does not maneuver as expected, the only course open is to remove the correction as soon as possible.

CHAPTER 3

INSTRUMENTS AND ACCESSORIES FOR ANTIAIRCRAFT GUNS

SECTION I

DIRECTORS

■ 155. GENERAL.—*a.* Directors may be defined as combined observing and predicting instruments which determine firing data pertaining to the future position of the target (T_p). There are three general types of directors. The ballistic type contains the means for computing firing data corrected for variations from "standard" conditions, that is, variations from standard muzzle velocity, atmospheric density, and wind. The semiballistic type contains the means for computing firing data corrected for certain, but not all, variations from "standard" conditions. The nonballistic type merely computes uncorrected firing data. Data computors are also classified as to whether their design is based upon the linear speed or angular travel methods of solving the problem. This manual does not differentiate between data computors and directors. Both names are used and refer to the same instruments.

b. It is beyond the scope of this manual to include complete handbook instructions regarding every type of instrument which may be encountered. The standard director, M4, only, is described. For further information on all types of directors, reference is made to the appropriate instruction handbook.

■ 156. **DESCRIPTION OF DIRECTOR, M4.**—*a.* The director, M4 (figs. 54 to 58, incl.), is the present standard antiaircraft director. It is of the semiballistic type and its predictions are based upon the linear speed method. The basic means of locating the present position of the target, predicting its future position, and computing firing data to hit this future position are unchanged from previous types of standard linear speed directors, but methods of achieving these data have been altered. Noteworthy features of this instrument which make it different from other linear speed directors are as follows:

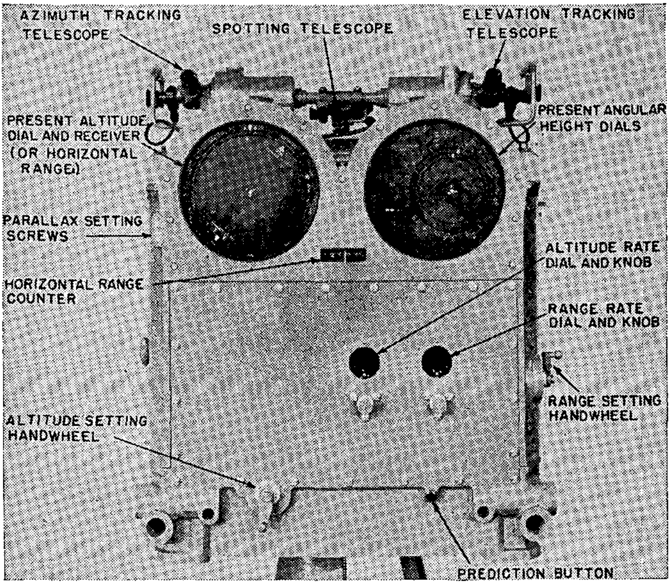


FIGURE 54.—M4 director (front).

(1) A means is furnished for predicting the future position of a gliding or climbing target.

(2) An automatic rate mechanism in altitude to apply the rate of decrease or increase in altitude as transmitted by the height finder to the director.

(3) A simple means, by matching pointers on proper dials, to compute the data required for fire at targets under 10° of elevation (horizontal fire).

(4) Automatic prediction.

(5) Ability to use the director for firing several different types of ammunition (including 105-mm ammunition). This change is accomplished by changing various cams and dials within the director.

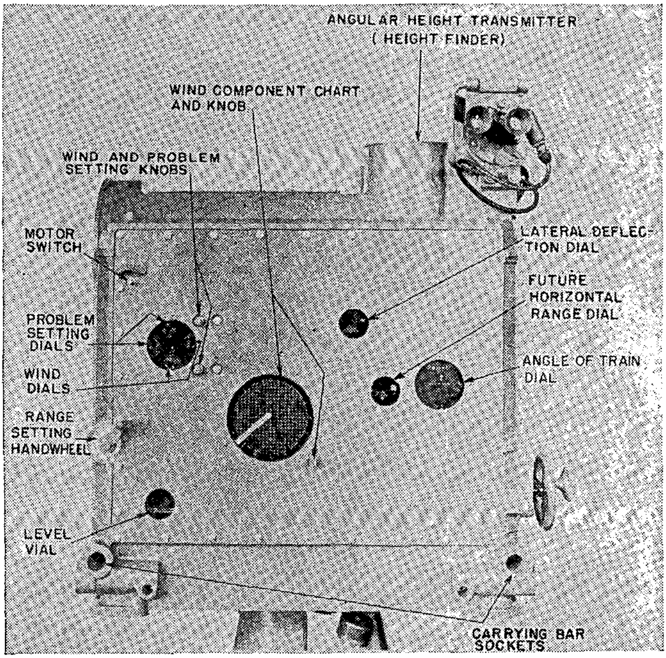


FIGURE 55.—M4 director (left side).

(6) Vertical and lateral deflections are computed and the data exposed on proper dials for case I firing.

b. This director weighs about 725 pounds. The scale of the azimuth and range disks is 4,000 yards to the inch. This scale permits the use of the director for 105-mm gun firing and for horizontal ranges up to 15,750 yards.

c. Twenty-four differentials are used in this director to—

(1) Equate rates.

(2) Cancel quantities.

(3) Perform algebraic addition.

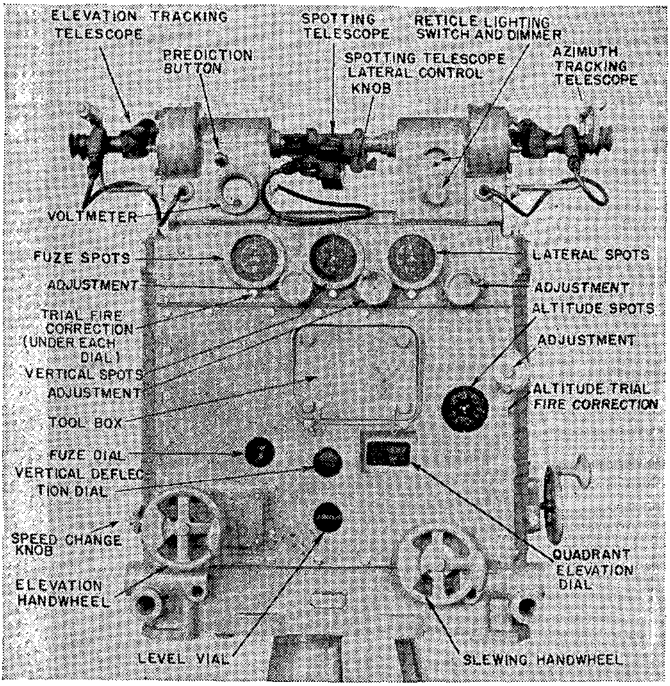


FIGURE 56.—M4 director (rear).

d. Eight ball and disk drives are used to—

(1) Set in rates.

(2) Perform multiplication.

(3) Change variable linear motion to rotary motion.

e. There are four 3-dimensional cams in the director. One cam solves the relationship $R_o=H_o \cot \epsilon_o$. The other three cams are cut from one piece of metal and give the proper quadrant elevation (ϕ), fuze (F), and time of flight $\left(\frac{1}{t_p}\right)$.

f. The data computed by this instrument are for use with guns equipped primarily for case III pointing. The lateral and vertical deflections shown on the dials may be used for case I pointing. The altitude and wind rates must be set into the director before firing. In case of horizontal fire, the slant range to the target is "set in" in place of the altitude. All other elements of data are solved within the instrument. The firing data obtained (for case III firing) are transmitted to the guns through the data transmission system, M4 (A. C. self-synchronous). In addition, the instrument is equipped to furnish the present angular height and present azimuth of the target to the height finder by means of two additional data transmitters. These latter data insure that the height finder is tracking the same target as the director. Space is provided for mounting double receivers for

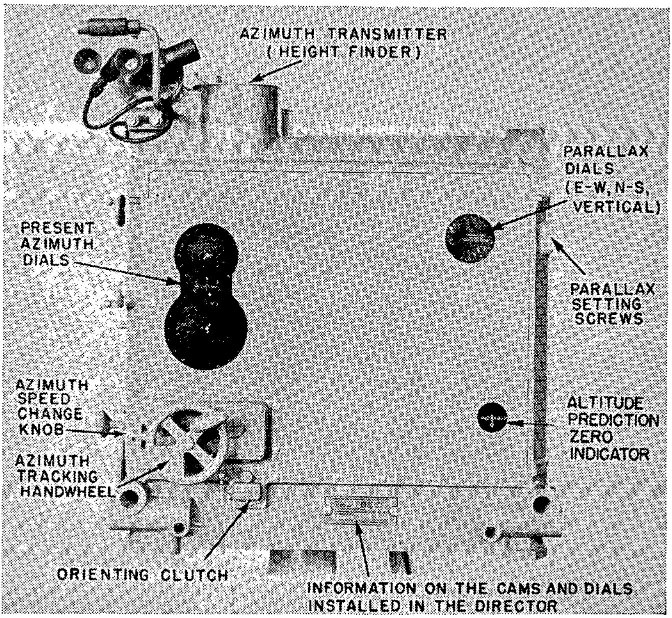


FIGURE 57.—M4 director (right side).

receiving present azimuth and angular height from an external tracking instrument. These receivers would be mounted directly behind the azimuth and angular height dials. The coarse receivers are graduated 6,400 mils per revolution and the fine receivers 400 mils per revolution. A "dummy" mount is provided for each dial when tracking receivers are not installed.

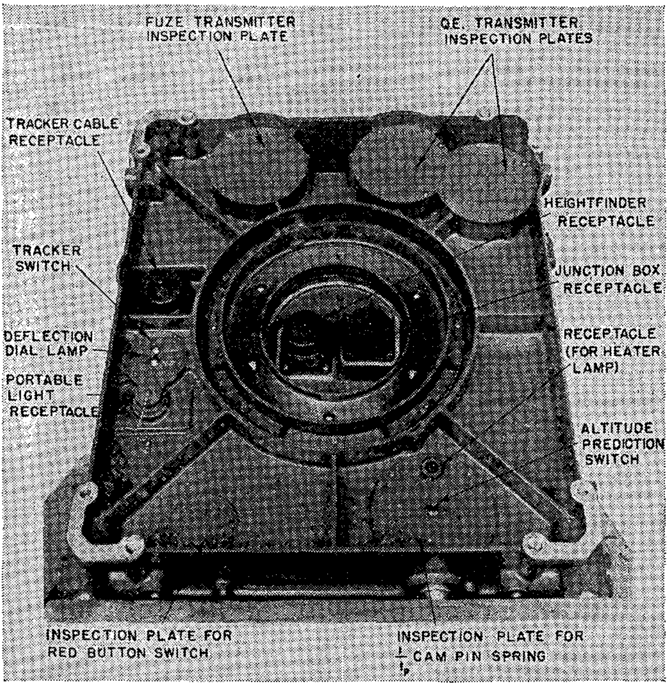


FIGURE 58.—M4 director (base plate).

g. At the cardinal directions, that is, along the N–S or along the E–W axes, and at a large time of flight (30 seconds), the director can handle target speeds up to about 400 miles per hour. At shorter ranges, or when the target is flying along other courses (not cardinal directions), greater target speeds can be accommodated.

h. The limits of operation of the director are as follows:

Present azimuth	No limit.
Present altitude	−320 to +8,350 yards.
Present angular height	−175 to +1,600 mils.
Present horizontal range	250 to 15,750 yards.
Target speed	0 to 200 yards per second.
Wind correction	0 to 50 m. p. h.
Time of flight	4 to 33 seconds.
Battery parallax	0 to 450 yards.
Future horizontal range	250 to 15,750 yards.
Present altitude spot	±450 yards.
Vertical parallax	±450 yards.
Lateral spot	±140 mils.
Vertical spot	±50 mils.
Fuze spot	±2.5 fuze numbers.
Future azimuth	No limit.
Quadrant elevation	−135 to +1,600 mils.

■ 157. MECHANISMS USED IN DIRECTOR, M4.—Before a clear understanding of the operations of the director can be obtained, a thorough knowledge of the operation, uses, and limitations of the different types of mechanisms listed below is essential.

a. Variable speed drives.—(See par. 55.)

b. Differential gears.—(See par. 56.)

c. Three dimensional cams.—(See par. 57.)

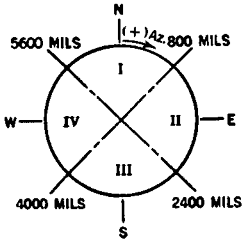
d. Disk and slide mechanisms.—(See par. 58.)

e. Automatic prediction mechanism.—(See par. 59.)

f. Ballistic wind mechanism.—(See par. 60.)

g. Quadrant switch and contact controls.—(1) *Quadrant switch.*—The predictions have been computed in N–S and E–W directions. Prediction is added to present position data to obtain future position data. Due to mechanical limitations, predictions must be set into future position mechanism in terms of plus or minus range or azimuth. The difference (or prediction) motors rotate the future azimuth or range disk proportional to the proper amount of prediction. The quadrant switch connects the N–S and E–W prediction mechanisms to either the range or azimuth difference motors and determines the proper direction of rotation of each. The quadrant switch is rotated in future azimuth and its motion controls the throwing of the three switches shown in figure 60. The tables (fig. 59) show which difference motor operates and in what direction for predictions (along the cardinal directions) in the four quadrants. For example, a north prediction in quadrant I causes the range difference motor to turn in a direction to increase the future range. Likewise, a west prediction in quadrant I causes the azimuth difference motor to turn in a direction to decrease the future azimuth.

(2) *Contact controls.*—Proper connections having been made by the quadrant switch, it is necessary to have another switch to control the amount of the operation of each difference motor, that is, to turn them on or off at the proper instant. These switches are called the N–S or E–W or altitude contact controls. When a prediction is computed, the prediction shaft (fig. 21) is connected to its contact control through a canceling differential (fig. 60). The closing of the contact control completes the circuit, through the quadrant switch, to the proper difference motor. When the motor has rotated the proper amount (prediction), the contact control is opened by the action of the other input to the canceling differential $(Y_p - Y_o)$, $(X_p - X_o)$ or ΔH and the difference motor is stopped. Suppose that the target is traveling from east to west in quadrant I. (See fig. 59.) There will be no N–S prediction and Y_o equals Y_p. As shown in fig. 59, the E–W contact controls are connected to the azimuth difference motor and the N–S contact controls are connected to the range difference motor. As A_p changes, R_p will remain constant (there being no N–S prediction). It follows, therefore,



Quadrant I	*Quadrant II*
North to (+) range	East to (+) range
South to (−) range	West to (−) range
East to (+) azimuth	South to (+) azimuth
West to (−) azimuth	North to (−) azimuth
Quardant III	*Quadrant IV*
South to (+) range	West to (+) range
North to (−) range	East to (−) range
West to (+) azimuth	North to (+) azimuth
East to (−) azimuth	South to (−) azimuth

(+) means increasing
(−) means decreasing

FIGURE 59.—Quadrant diagram.

that Y_p will change. It has been shown above that $(Y_p - Y_o)$ is zero. If Y_p changes $(Y_p - Y_o)$ is no longer zero. The position difference $(Y_p - Y_o)$ operates the range difference motor

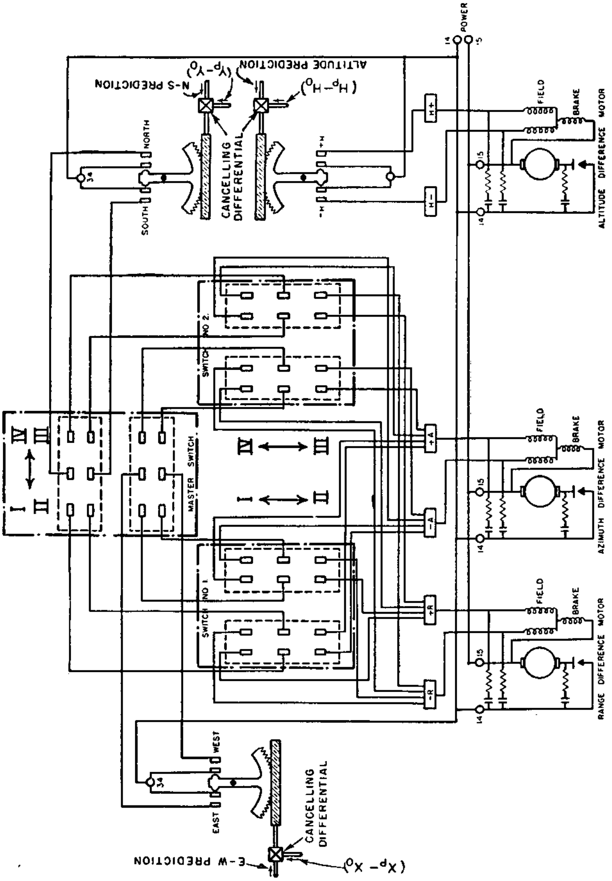


FIGURE 60.—Wiring diagram M4 director.

through the N–S contact controls causing R_p to increase or decrease so as to maintain Y_p equal to Y_o. When the position difference $(Y_p - Y_o)$ equals N–S prediction (ΔY) equals zero, the contact controls will open causing the range difference motor to stop. Y_p has been kept equal to Y_o by changing R_p. Normally, prediction through the canceling differential turns on the difference motors. This quantity is "backed off" in the differential by position difference, thereby shutting off the difference motors. Since the difference between the present and future position mechanism is set in by the difference motors to position the future slides, by rotating the future range and azimuth disks, the motor selection and direction of rotation will be different for each quadrant. (See fig. 59.) In quadrant I, for example, an E–W prediction is controlled by the E–W contact control, which is connected through the quadrant switch to the azimuth difference motor. Similarly, a N–S prediction is controlled by the N–S contact control and the quadrant switch connects it to the range difference motor. In quadrant II, it can be seen that an E–W prediction requires the operation of the range difference motor to control the position of the future slides instead of the azimuth motor. When passing from quadrant I to quadrant II, the quadrant switch, therefore, switches the connections between the contacts and the motors.

(3) *Magnetic brakes.*—Each difference motor is equipped with a magnetic brake which functions to lock the armature of the motor at the instant the control contact opens. The brake is operated by a solenoid in series with the field coils. (See fig. 60.) When the control contact is closed, the field coils are energized, the solenoid operates to release the brake against spring pressure, and the armature circuit is closed. The difference motor then operates. When the control contact is opened, the solenoid is no longer energized and the spring immediately applies the brake, opening the armature circuit and stopping the motor. The functioning of the magnetic brakes causes the clicking sound heard when the director is in action. This applies particularly to directors of low serial numbers.

(4) *Summary.*—To summarize, it is seen that a N–S or E–W prediction must be transformed into proper range or azimuth motion. The quadrant switch mechanism, including the motors and contact controls, performs the following functions:

(*a*) Selects the range or azimuth motor to be energized.

(*b*) Transforms a N–S or E–W prediction into range or azimuth prediction.

(*c*) Determines whether a plus or minus range or azimuth prediction will be transmitted.

(*d*) Starts or stops the range or azimuth difference motors at the proper instant.

■ 158. FUNCTIONING OF DIRECTOR, M4.—Figure 61 represents schematically a general explanation of how the individual mechanisms previously described are tied together within the director. To understand this operation and the following explanation, reference should be made to this figure. Starting at the various handwheels, their movements are traced through the diagram.

a. *A_o handwheel*.—Following it to the right, it passes to the A_o dial. The first shaft up rotates the director. Follow the second shaft "up" to the azimuth transmitter to the height finder. The next shaft "up" turns the present position azimuth disk in azimuth, and through a differential, the present range disk. Follow the shaft up the diagram to the future position disks. The future azimuth disk is rotated and the future range disk is given its added motion. Follow the same shaft to the right as it goes to the transmission motors, to the guns, and to the dials. When no prediction has entered into the data, the present azimuth would follow the above outline. Now consider that prediction is being made in azimuth. The azimuth prediction motor (marked A. D. M. in diagram) starts to turn. This motion passes to the right, enters the differential, is added to A_o, and becomes future azimuth or A_p. When drift or other corrections are added, A_p becomes firing azimuth or A_f. The differential just below lateral deflection dial, subtracts $(A_f - A_o)$ which equals lateral deflection.

b. *H_o handwheel (lower right corner)*.—Follow to the left, matching the present altitude coming from the height finder on the altitude dial. Then going to the left and up, the present altitude passes through a differential where corrections may be added. Then, through a train of gears, it passes down and positions the ϵ_o cam in rotation. Following it up through a differential (where altitude prediction may be

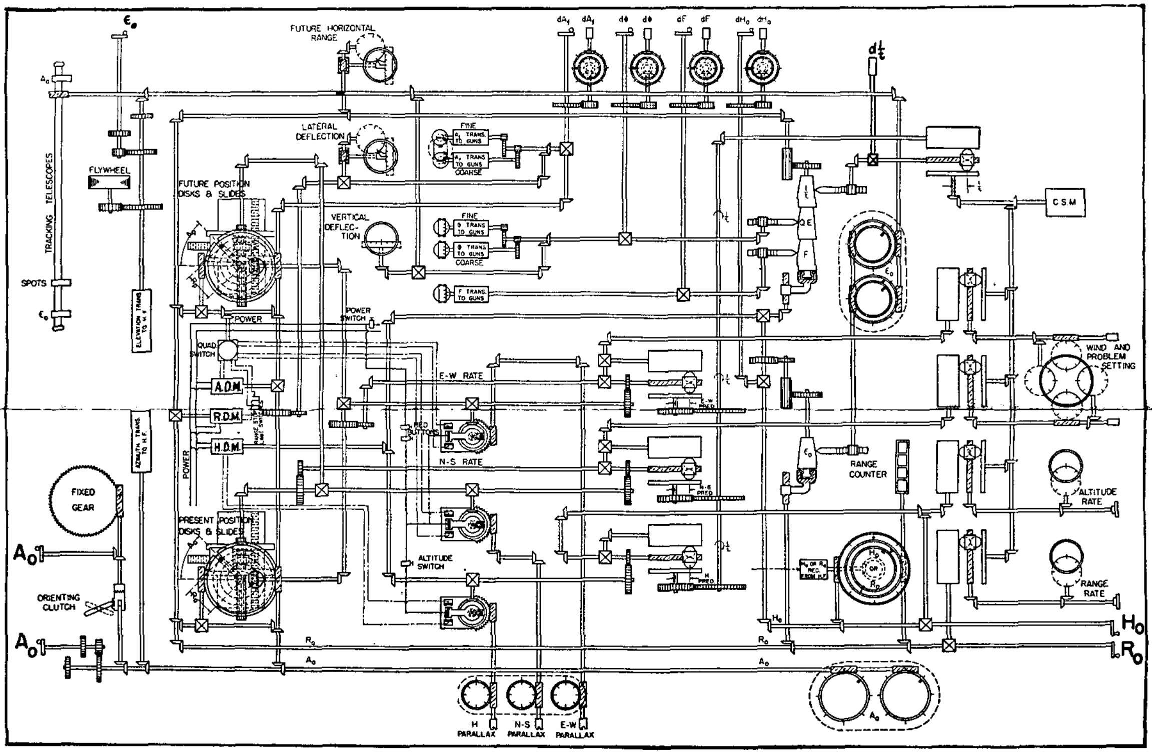


FIGURE 61.—Schematic diagram of M4 director.

added), present altitude may be seen to be positioning the ballistic cams $\left(F, \phi, \text{and} \frac{1}{t_v}\right)$ in translation.

c. R_0 handwheel—(lower right corner).—Follow it to the left. At the first differential a range rate is added. This is the mechanical method of putting into the director a smooth range rate, which supplements the range rate put in by the handwheel. The next "up" shaft goes to the range dial (from height finder). This dial is used during "horizontal fire." The next shaft "up" goes to the ϵ_0 cam and positions it in translation. The R_0 handwheel is turned continuously so that the pointers on the ϵ_0 dial are constantly matched. Follow the R_0 shaft farther to the left and it passes through the differential to rotate the present range disk proportional to present range. Follow up to the future range disk where it positions the future range disk in present range (neglecting for the moment any prediction). Continue up and find that it passes into the future horizontal range dial. To the right it rotates the three ballistic cams $\left(\phi, F, \frac{1}{t_p}\right)$. When a prediction is being computed, the range follow-up motor (marked R. D. M.) begins to turn; its motion is transmitted to the differential to the left and range prediction is added to R_0 giving R_p. The ballistic cams then, in normal operation, are rotated in R_p.

d. Time of flight data.—Start at the $\frac{1}{t_p}$ ballistic cam. The lift of the pin passes to a ball and disk drive which converts the linear motion $\left(\frac{1}{t_p}\right)$ to a rotary motion. Follow from the cylinder to the left and down. These $\frac{1}{t_p}$ data pass into three sets of ball and disk drives. The top set computes E–W prediction, the middle one computes N–S prediction, and the bottom one computes altitude prediction. (See *e* below.)

e. Prediction.—(1) Follow through the N–S prediction. (The E–W and altitude predictions are similar.) Start at the N–S shaft of the present position disk. The N–S data shafts in both the present and future disks are the vertical long pinions. The N–S component is called Y_0 (present) and Y_p (future). The E–W component is X_0

(present) and X_p (future). Follow Y_o (vertical) shaft from the present position disk. This shaft carries both rate of movement as well as amount of movement, proportional to the movement of the target in present position. At the large set of gears, Y_o "rate" passes up and to the right, while Y_o "amount" passes directly to the right, into the differential. From the vertical shaft of the future disks comes Y_p, which enters the differential just mentioned. Here, algebraic addition is performed and the result is "position difference" (Y_p-Y_o), which passes to the right and enters another differential just above the N–S contact switch. Now follow the Y_o rate up and to the right from the set of gears mentioned, along the shaft marked N–S rate into and through the "equating" differential. This rate is the observed rate, being the rate set up by the actual tracking of the target. Paragraph 59 explains how the observed rate is equated with a generated rate by the automatic prediction mechanism, which sets up the N–S prediction. The N–S prediction is transmitted through a shaft into the right side of the canceling differential just above the N–S contact control.

(2) When the prediction first passes into the canceling differential, it causes the N–S contact switch to make contact. This turns on either the range or azimuth difference motor, as determined by the quadrant switch (par. 157*g*). On the left of the canceling differential (Y_p-Y_o) enters, while on the right the prediction from the automatic prediction mechanism enters. (Y_p-Y_o) actually backs off, through the differential, the amount of prediction and when the two are equal, the electrical contact is broken and the prediction motor is shut off. Thus, it is seen that the prediction motor (range or azimuth) is started and stopped by the N–S contact switch, to set in the proper amount of either range or azimuth prediction.

(3) The E–W and altitude predictions are set into the instrument in a similar manner.

f. Firing data.—(1) It has been seen from *e* above that the prediction is obtained and added to present data to obtain future data. The future azimuth (corrected) is transmitted directly to the guns as previously described. The future range is used to rotate the ballistic cams, while the future altitude is used to translate the ballistic cams.

(2) The pin from the quadrant elevation (ϕ) cam transmits its motion to the left through a differential, where spots may be added. ϕ then passes into the fine and coarse transmitters to the guns. Before arriving at the transmitters, this quadrant elevation is also taken to one side of a differential (located just below the ϕ transmitters). Into the other side of this differential comes a value proportional to ϵ_0 (from the tracking telescopes). The two are subtracted algebraically and the result is placed on the dial as vertical deflection ($\phi - \epsilon_0$).

(3) The motion of the pin from the fuze (*F*) cam is transmitted to the left, where it passes through a differential for adding spots then to the fuze transmitter to the guns.

■ 159. OPERATION OF DIRECTOR, M4 BEFORE FIRING.—*CAUTION: Always set both N–S and E–W target velocity dials to zero with power "ON" after completing check problems. If this caution is not strictly observed, adjustment of the N–S or E–W contacts may be disturbed if the handwheels are indiscriminately turned with the power "OFF." After tracking always allow an interval of approximately 10 seconds or more before shutting off power to bring prediction to zero in the director.*

a. Setting-up and leveling.—(1) Set the pedestal in place on a firm surface and level approximately by means of the three leveling screws.

(2) Place the director on the pedestal, using the eight porter bars supplied, and rotate the director very slowly until the locking pin is heard to click in place. (When this pin is in place, the three clamping holes in the director base are lined up with the clamping screws in the upper part of the pedestal.)

(3) Tighten these three clamping screws, thus firmly holding the director large azimuth gear to the pedestal.

(4) Rotate the director until one of the sides carrying a level is parallel with any two leveling screws. Adjust these two screws to center the bubble.

(5) Adjust the third screw to center the bubble of the second level carried on the adjacent side of the director.

(6) Traverse the director and note at approximately each quarter revolution any deviation of the level bubbles from

center. If the bubbles move off the center more than one division, repeat the leveling operation until satisfactory leveling is obtained.

(7) Before connecting the cable plugs, place several coils of the cable inside the pedestal to permit several revolutions of the director in azimuth without causing undue twisting strains on the cable. Plug in the cables from the height finder and junction box in their respective receptacles at the center of the base of the director. (When an external tracking instrument is used, plug its cable in the base also.)

CAUTION: See that power is "OFF" when plugging in cables.

b. Orienting.—(1) Remove the cover over the orienting clutch lever and turn to the "IN" position.

(2) Turn the azimuth tracking handwheel until the present azimuth dial reads the azimuth angle of the assigned reference point.

(3) Turn the orienting clutch lever to the "OUT" position without disturbing the setting of the present azimuth dial. (With the orienting clutch in the "OUT" position, the azimuth tracking handwheel is disconnected with the traversing drive.)

(4) Rotate the director by means of the sluing handwheel until the vertical line of the azimuth telescope intersects the reference point.

(5) Turn the orienting clutch lever to the "IN" position and check to see that the present azimuth dial reads the assigned azimuth of the reference point.

(6) Make a few settings to check the performance of the director, as outlined in the "inspection report" problems, for the ammunition being used. These problems are included in the rear of the manual director M4, part I.

CAUTION: Before making check settings, pull the altitude follow-up motor switch to the "ON" position for several seconds and then push it "OFF." This takes out any altitude prediction that may have been left in the director. The switch is to be kept in the "OFF" position for targets flying at constant altitude.

c. Wind correction.—(1) Obtain the azimuth from which the wind is blowing and the wind velocity in miles per hour from the meteorological message.

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(2) Rotate the wind velocity scale (on the radial arm of the wind component solver on the director, left side) to this azimuth by means of the knob at its lower right.

(3) Read the N–S and E–W components of wind velocity from the chart and set these values on the respective wind dials on the left side of the director.

Example: A 10-mile per hour wind from azimuth 533 mils would thus be set in the director as 8.7 miles per hour north wind and 5 miles per hour east wind.

Note that as long as the wind remains the same in direction and velocity, its components as set in the director are constant regardless of the direction in which the instrument may be pointed in tracking a target.

d. Synchronization.—(1) Apply power to the system and check the synchronism of all indicators and transmitters. This check includes firing azimuth, quadrant elevation, and fuze range as transmitted from the director to the guns. Check the transmission of altitude (or range) from height finder to director and present azimuth and angular height from director to height finder. If an external tracker is used, the transmission of present azimuth and angular height from the tracking instrument to the director also is checked.

(2) All indicator and transmitter units have been electrically zeroed at the time of manufacture and their dial readings should agree. It should not be necessary to reset any of these units.

(3) If the transmitters at the director and the indicators at the guns do not agree, make adjustment by means of the electrical synchronizing screws on the gun indicators.

(4) If the director and the height finder are not in synchronism, make the adjustment by rotating the housings of the self-synchronous units at the height finder.

(5) Refer to the Data Transmission System Handbook for instructions for synchronization adjustments. (See ch. 4.)

e. Parallax adjustment.—If the director is displaced from the battery directing point, an adjustment for parallax must be made. The method of adjusting for parallax is best shown by an example.

(1) With the orienting clutch lever in the "IN" position, sight on the directing point of the battery and read the present azimuth dial, say 1,973 mils.

(2) Measure the horizontal distance from director to the battery as, say, 220 yards. Resolve this distance into components along the N–S and E–W reference lines. In this example, it will be 79 yards north and 205 yards west.

NOTE.—The displacement must be measured as component distances from the battery to the director. (See fig. 62.)

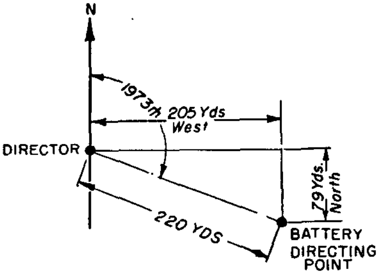


FIGURE 62.—Computation of parallax.

(3) Set in the component distances on the respective parallax dials.

(4) If there is a vertical displacement between the director and gun battery, set in this amount on the vertical parallax dial. For example, if the director is 30 yards higher than the battery, set in 30 yards "UP" on the vertical parallax dial.

NOTE.—When setting in a vertical parallax, it is necessary for the altitude follow-up motor to operate. To operate the motor, pull the altitude follow-up motor switch to the "ON" position. This switch is located in the base of the director behind the altitude handwheel. When the QE and fuze dials come to rest, the motor will have driven in the vertical parallax. *Push the switch to the "OFF" position.*

f. Handwheels.—Do not force any handwheel when its limit of movement at the stops has been reached. Altitude, range, and angular height handwheels are provided with couplings which slip to protect the mechanism when the limit of movement is reached. All other handwheels and knobs are provided with positive stops and therefore must not be forced when the limit of movement is reached. The elevation and azimuth tracking handwheels have two speeds; the "IN" position of the handwheel is low speed and the "OUT" position is high speed. When changing speeds, pull out the release knob (located at the left of the handwheel), shift handwheel, then allow release knob to snap back in place. *These two handwheels should be cleaned frequently to insure removal of any dust or sand that may have collected.* Oil after cleaning.

■ 160. **OPERATION OF DIRECTOR, M4, WHEN FIRING.**—*a. Normal antiaircraft fire (target flying at constant altitude)*.—(1) A manning detail of four operators is required for the director as follows:

(*a*) *Azimuth tracker*.—Tracks the target in azimuth.

(*b*) *Elevation tracker*.—Tracks the target in elevation (present angular height).

(*c*) *Range setter*.—Sets range by matching the angular height dial pointers.

(*d*) *Altitude setter*.—Sets altitude by matching the "AA" pointers on the altitude dial.

(2) Pull the motor switch located on the left side of the director to the "ON" position. This energizes the constant speed motor and the range and azimuth follow-up motors.

(3) In picking up a target for tracking, the open sight is used to direct the azimuth and elevation telescopes to the target.

NOTE.—When "sluing" the director to bring the telescopes on the target, it is advisable to keep the red button "pushed in" for a period of approximately 5 seconds after picking up the target. The red button operates a switch stopping the follow-up motors to "arrest prediction" during any rapid change of azimuth or range, thus avoiding a temporary excessive prediction being set in. There are two of these red buttons on the instrument, one on the front side and one on the rear, either one of which will perform the operation stated above.

(4) As soon as the target appears in the field of vision of the telescopes, the azimuth and elevation trackers bring their telescope reticle lines on the target and follow it. (The azimuth tracker keeps the vertical line and the elevation tracker the horizontal line on the target.) Smooth tracking is important, as any irregularity will cause the firing data to be erratic. Therefore, the trackers must be especially careful to maintain a uniform, steady motion of their handwheels.

(5) The altitude setter matches the pointers marked "AA" on the dial by using the altitude handwheel. The inner

pointer is positioned according to altitude received from the height finder.

(6) When the trackers report "On target," the range setter matches the pointers on the angular height dials with the range setting handwheel. The pointers of the coarse dial are matched first. Then after matching the pointers of the fine dial, he transfers the operation of range setting from the handwheel to the range rate knob. (One fine and one coarse adjusting knob are provided for range rate control.) Continuous adjustment of the range rate knobs is necessary during matching except on directly incoming and outgoing targets. The range setter should avoid making sudden changes in range and must match the angular height dial pointers smoothly in order to maintain as steady a change in range as possible.

(7) The range setter should push in the red button whenever the pointers separate sufficiently to require a rapid and appreciable change in range to rematch pointers.

NOTE.—The red button should not be released until approximately 5 seconds after the setting has been completed.

(8) During the performance of the above operations, the director is transmitting the required firing data to the guns.

(9) Spotting corrections are applied during the course of fire in accordance with the doctrines prescribed in this manual. Spotting corrections have different effects on the functioning of the M4 director. An analysis of these effects may readily be made by a study of the schematic diagram (fig. 61). In making this analysis, the various mechanisms should be visualized as being in motion and continuously computing and transmitting firing data to the guns.

(*a*) $d\phi$, dA, and dF corrections are set in through differentials in the gear train to the respective data transmitters, quadrant elevation, angle of train, and fuze. No other parts of the director are effected by these corrections.

(*b*) Present altitude (dH_o) corrections are set in through a differential in the altitude drive to the ϵ_o cam. Any dH_o correction will require a change in present horizontal range to keep the ϵ_o dials matched. The effect of this correction will be very apparent in the director. Hence, when applying any dH_o correction, the red button (prediction arresting) should be kept "pushed in" until approximately 5 seconds after the setting has been completed, in order to prevent a temporary excessive prediction with its corresponding erroneous firing data being transmitted to the guns.

(c) Setting in an altitude rate of change has two effects on the director. First, H_0 is changed at a constant rate depending upon the setting. Until the range rate is readjusted so that the ϵ_0 dials remain matched, there will be a temporary excessive prediction. Second, the altitude prediction mechanism will function and position the ballistic cams according to H_p. This will result in a new value for $\frac{1}{t_p}$ which in turn will result in a new prediction for T_p. Holding the red button "pushed in" until 5 seconds after the ϵ_0 dials are matched will prevent excessive predictions due to the combination of the two effects mentioned above.

b. Diving or climbing targets.—The operating procedure for diving or climbing targets is as follows: (The director provides for vertical velocities up to 50 yards per second.)

(1) The azimuth and elevation trackers and the range setter operate in the same manner as previously outlined for firing on a target flying at constant altitude.

(2) For diving or climbing targets, the altitude follow-up motor switch must be pulled to the "ON" position. This switch is located in the base of the director below the altitude handwheel.

(3) The changing altitude, as received from the height finder, is indicated by the movement of the inner "AA" pointer on the altitude dial. When the altitude change is smooth and regular, the "AA" pointers are kept matched by adjusting the altitude rate knob. This varies the speed of the outer matching pointer and drives the vertical velocity into the altitude prediction mechanism. For a smooth altitude rate during a dive, the height finder operator should keep continuous stereoscopic contact.

(4) In cases where smooth changes of altitude are not received, the altitude rate must be determined. This altitude rate must be set on the altitude rate dial by the altitude setter after setting in the altitude with the altitude handwheel. The changing altitude on the dial should be read at

frequent intervals, as a check. If the pointers do not remain approximately matched, change the altitude rate and rematch the pointers by means of the altitude setting handwheel.

c. Horizontal fire.—(1) The term "horizontal fire" as used herein includes low-angle firing between the limits of plus or minus 10° angular height. During horizontal fire, the range (slant range) is received at the director by the same receiver as used for altitude in antiaircraft firing and is set in by matching the "HOR" pointers (instead of the "AA" pointers).

(2) The elevation and azimuth trackers operate in the same manner as previously described for antiaircraft firing.

(3) In horizontal fire, the altitude setter must keep the angular height pointers matched with the altitude handwheel.

(4) The range setter must first match the "HOR" pointers on the range receiver dial (used for altitude in antiaircraft firing) with the range setting handwheel, and then keep the moving pointer matched with the range rate knob. The range setter must avoid making any sudden changes in range without first using the red button to arrest prediction. (Use of the red button in horizontal fire is the same as described for antiaircraft fire.)

(5) In cases where smooth changes of range are not received, the range rate must be determined. This range rate must be set in on the range rate dial after setting in the range on the horizontal range dial by the range handwheel. The changing range on the dial should be read at frequent intervals as a check. If the pointers do not remain approximately matched, change the range rate and rematch the pointers by means of the range setting handwheel.

d. Case I firing.—(1) means are provided in the director for the indication of vertical and lateral deflections on dials for use when the data transmission system is inoperative, and with guns equipped with a deflection sighting mechanism. The vertical deflection dial is located between the fuze and QE dials at the rear of the director. The lateral deflection dial is located on the left side of the director. The lamp switch for illumination of the deflection dials during night firing is located in the underside of the base at the left.

(2) The vertical and lateral deflections and fuze number are read on the dials and communicated (by telephone or other means) to the gun operators.

e. *Conclusion of tracking.*—(1) At the conclusion of tracking, push the motor switch on the left side of the director to the "OFF" position. This stops the constant speed and follow-up motors. Always allow about 10 seconds after tracking ceases for the prediction to return to zero before turning off the power.

(2) Place the canvas cover on the director when not in use.

f. Procedure in case of interlock.—(1) *Certain combinations of settings may lock the horizontal range drive to make the director inoperative. This condition will not occur during service use, but may occur through certain indiscriminate settings of target velocities or turning of handwheels which cause the future horizontal range to reach its minimum stop without restoring prediction to normal.* There are two cases of locked positions as follows:

(*a*) The first case of a locked position occurs when the future horizontal range is held at its minimum stop which opens the difference motor circuits and prevents the prediction from returning to normal after setting target and wind velocity dials to zero. This condition is indicated when the future horizontal range dial reads its minimum value of approximately 250 yards and there is a considerable displacement between angle of train and present azimuth. Verify this locked position by increasing present horizontal range (with the motor switch pulled to the "ON" position to apply power) three or four revolutions of the range handwheel and noting future horizontal range. If it returns to its minimum value, it is an indication of the locked condition.

CAUTION: Do not turn the range handwheel more than a few revolutions with power "ON" when in the first case of locked position.

(*b*) The second case of a locked position occurs when future horizontal range is locked at its minimum stop and present horizontal range is locked at its maximum stop causing the range handwheel to become completely inoperative. This condition can only be reached from the first case by turning the range handwheel to its maximum stop with the motor switch in the "ON" position or by turning to the maximum present range stop and then applying power.

(2) *If the first case of locked condition occurs, restore the director to normal as follows:*

(*a*) With power "OFF," turn the range handwheel to increase future horizontal range several thousand yards (if possible, 5,000 yards should be obtained).

(*b*) Set wind and target velocity dials to zero.

(*c*) Turn the slewing handwheel at about one revolution per second with the orienting clutch in the "IN" position, and, while turning, pull the motor switch "ON." Continue turning for approximately ten revolutions. The director will then clear itself from the locked position and be returned to normal.

(3) *If the second case of locked position occurs, restore the director to normal as follows:*

(*a*) Turn power "OFF."

(*b*) Remove front and right cover plates. (This should be done in a place free from floating particles of dust, care being taken to prevent dirt from entering the mechanism.)

(*c*) Block the N–S and E–W contacts with paper strips.

(*d*) Connect a wire jumper between terminals 14 and *R*1 on the quadrant switch.

(*e*) Watching the future range dial, turn power "ON" and close the right limit switch contact for a short interval to see that future range increases. After verifying this connection for direction, close the contact to run future range to approximately 5,000 yards and push the motor switch "OFF."

(*f*) Remove the wire jumper from the quadrant switch and the paper from the N–S and E–W contacts.

(*g*) Proceed as instructed in (*b*) and (*c*) above for the first case of locked position.

(*h*) When the director has been cleared from the locked position, replace the cover plates.

■ 161. ROUTINE MAINTENANCE OF DIRECTOR, M4.—The following instructions are provided as a guide for the routine maintenance of the director. Any servicing of the director should be done by authorized personnel. Detailed instructions for servicing are included in the manual, Director M4, part II.

a. Transport.—(1) The director base is provided with a "shock mounting" and means for bolting to the floor of the transporting vehicle. The telescopes are detachable and a carrying case is provided for their protection during transportation.

(2) The director is built to withstand all normal service conditions but undue rough handling should be avoided.

(3) The director should always be lifted by the eight porter bars provided in the carrying case, special care being taken to avoid dropping as severe jolts may cause damage.

(4) A canvas cover is provided which should be put on the director when it is not in use. Although the director is sealed to prevent rain and dirt from entering the mechanism, the case must not be set down in water or mud.

(5) Special carrying cases are provided for the ballistic cams and associated dials.

(6) A tool box, which contains, in addition to the tools, spare motors, electrical meters, and miscellaneous spare parts, screws, and taper pins, as listed in the cover of the box, is provided.

b. Cleaning.—(1) The surfaces of the telescope lenses should be kept clean. Ordinary dust that collects on these surfaces may be removed with a soft camel's hair brush. Grease may be removed with a soft piece of clean cloth moistened with alcohol. Any moisture collected on these surfaces may be removed with a soft piece of clean cloth. When cleaning any optical surface, care should be taken not to scratch the glass.

(2) Clean the windows with a soft piece of clean cloth slightly moistened with benzine or turpentine. The surface should then be wiped dry with soft linen, silk, or tissue, frequently using a fresh portion of the material so as to avoid scratching the glass with any grit that may have been collected. Cleaning cloths for glass should be kept separately and should not be used for any other purpose. They should be washed frequently, all soap being rinsed out.

(3) Metal surfaces should be cleaned with a dry cloth. Surfaces from which the paint has been worn off may be wiped with a slightly oily rag before being thus cleaned. Abrasives or metal polish *must not* be used.

(4) Rubber eyeguards should be removed periodically, washed in warm water and dusted over with french chalk, or equivalent, as a preservative.

(5) Plugs and receptacles should be kept clean and, when not in use, covered with their protecting caps.

c. Checks for operation.—Refer to the "inspection report" problems for the type of ammunition used for settings to check the adjustment of the director. These problems are included in the back of the manual, Director M4, part I.

d. Fitting for change in ammunition.—(1) To fit the director for a different type of ammunition from the one specified on the name plate (director right side), it is necessary to change the ballistic cam and certain dials.

CAUTION: This must be done in a closed room free from floating particles of dust, care being taken to prevent any dirt from getting into the mechanism.

(2) Remove rear cover plate, right cover plate, and left cover plate.

(3) Remove the cover plate in the base of the director behind the altitude handwheel. This cover plate supports the altitude follow-up motor switch, the heater lamp plug receptacle, and the heater lamp. Unscrew the heater lamp and allow the cover plate to hang supported by the wire leads to the altitude follow-up motor switch. This allows access to the $\frac{1}{t_p}$ cam pin spring and lever arm.

(4) For blocking cam follower pins for removal of the cam, obtain two pieces of ¾ inch diameter wooden rod 2¾ inches long and a third piece 6½ inches long. Cut a cone-shaped hole in one end of the long piece approximately ½ inch diameter by ¼ inch deep.

NOTE.—These blocks should be clean and smooth so that handling will not leave any splinters in the instrument.

(5) At the rear of the director, pull out the quadrant elevation and fuze cam pins and block them with the two short wooden blocks. This is done by pulling out the cam pin flanges on either side of the vertical deflection dial and inserting the blocks between the cam pin flanges and the brass guides.

CAUTION: In blocking the quadrant elevation cam pin, it will be necessary to pull the cam flange out ¼ inch beyond the end of the steel guide pin in order to insert the wooden block. Be very careful during this operation not to pull the cam pin out any farther than is absolutely necessary to insert the wooden block, as movement beyond this point may disengage the pinion gear from the rack and disturb the dial settings.

(6) Unhook and remove the $\frac{1}{t_p}$ cam pin spring. Push on the bottom of the cam pin lever arm to move the cam pin off the $\frac{1}{t_p}$ cam. Block the lever arm in this position with the long wooden block.

CAUTION: The cam pins must never be allowed to drop on the cams.

(7) To remove the cam, remove the hexagonal nut, washer, and clamping tube at the center of the cam carriage bearing. Take off the cam carriage flange held by the three screws and withdraw the cam. See that the cam is properly greased and wrapped in its oil paper as a protection from rust, before placing in its carrying case.

(8) Coat with grease the surfaces of the cam being installed and check to see that the end of the cam flange is clean before inserting. Insert the cam in the carriage, being sure that the slot in the cam flange engages the locating pin in the far end of the carriage.

(9) Replace the clamping tube, washer, hexagonal nut, cam carriage flange, and the three holding screws.

(10) Remove the blocks holding the three cam pins, gently releasing the cam pins on to the cams as a sudden release might indent the cam surface. Replace the $\frac{1}{t_p}$ cam pin spring.

(11) Replace the heater lamp in its socket and put on the base cover plate with its four attaching screws.

(12) Remove the instruction plate on the right side of the director and replace with the plate supplied with the cam installed.

(13) Check to see that the wind and problem target velocity dials are set exactly to zero. Remove the two wind dials and replace with the wind dials supplied with the cam in the carrying case.

CAUTION: When changing dials on the director, see that the part number of the dial corresponds with the part number engraved on the instruction plate for the particular cam being installed.

(14) Remove the glass cover and replace the lateral correction dial (ring). (This dial corrects for drift.)

(15) Check to see that the fuze spot dial is set to zero. Remove the glass cover and replace the fuze spot and fuze correction dials, lightly clamping the fuze spot dial in the zero position with its three screws.

(16) If cams are to be changed as shown in 3 of the table in (17) below, proceed as instructed in (19) to (22), inclusive, below. If, however, cams are to be changed as shown in 1 or 2 of the table, proceed as instructed in (17) below.

(17) Set in a fuze spot with the spot handwheel in accordance with the table. Reset the fuze spot dial to zero and clamp it firmly in this position with the three screws.

	Ammunition		Fuze spot dial setting [1]
	From—	To—	
1	3″ AA shrapnel, Mk. I, Scovil fuze, Mk. III or 3″ AA shell, Mk. IX and M42, Scovil fuze, Mk. III.	3″ AA shell, Mk. 42, with fuze, M43.	−0.75 FN, in changing back +0.75 FN.
2	3″ AA shrapnel, Mk. I, Scovil fuze, Mk. III or 3″ AA shell, Mk. IX and M42, Scovil fuze, Mk. III.	105-mm shell, Mk. 38, with Scovil fuze, Mk. III.	−0.75 FN, in changing back +0.75 FN.
3	3″ AA shrapnel, Mk. I, with Scovil fuze, Mk. III.	3″ AA shell, Mk. IX and M42, with Scovil fuze, Mk. III.	No fuze spot correction required interchanging these cams except as instructed in paragraph below.

[1] Theoretical computed correction. FN=whole fuze range numbers.

(18) Adjust the spring detent to fall in a detent at the zero dial position. To do this, loosen the three screws in the

flange ring back of the fuze spot handwheel and rotate the detent ring by means of the pin until the detent falls in place.

(19) Remove the fuze dial by removing the three screws and clamping plate with the offset screw driver contained in the tool box.

(20) Replace the new fuze dial, clamping plate, and screws, but do not tighten the holding screws at this time.

(21) Set all spot, wind, and parallax dials to zero and apply power to the director. Pull the altitude follow-up motor switch to the "ON" position for several seconds to take out any altitude prediction that may have been left in the instrument, and then push it "OFF." See that the motor switch on the left side is pushed "OFF."

(22) Set in 6,000 yards range on the future horizontal range dial by turning the range handwheel and 2,500 yards altitude on the altitude dial with with the altitude handwheel. Holding this setting, set the fuze dial as indicated below for the particular ammunition required and tighten its clamping screws.

Ammunition used:	*Fuze setting*
3'' shrapnel Mk. I, Mk. III fuze	16.36
3'' shell Mk. IX, Mk. III fuze	16.68
3'' shell M42, M43 fuze	12.96
105-mm shell M38, M2 fuze	10.38

Check this setting as follows: Increase and decrease range approximately 300 yards, each time coming "up" and "down" on 6,000, and note the fuze reading each time. Reset the dial if the readings are incorrect. Extend this check to various points on the cam by setting in several values of altitude and future range as given in the "inspection report" test problems in the manual, Director, M4, part I. Reset the fuze dial to the best average value.

(23) Replace the left, rear, and right cover plates, applying a sealing compound (*e* below) to insure watertightness.

NOTE: Before replacing cover plates, make an inspection of the director and the cover plates for cleanliness.

(24) Set in several problems contained in the manual, Director, M4, part I, as a check for data accuracy.

(25) It is possible that a slight error in quadrant elevation and in fuze may be found after changing the cams. Such errors, if present, may be corrected by turning the spot handwheels to indicate the correct amount on the dials and then resetting the spot dials to zero.

e. Storage.—(1) The director should be stored in a dry room at an even temperature and covered with its protective canvas cover. If there is any dampness present, however, or if the director is stored in the tropics, plug the socket on the heater lamp cord into its receptacle in the base of the instrument and connect to a 110-volt A. C. source of supply. This should be left on to suit the storage conditions. The heater lamp is a standard 40-watt incandescent bulb such as is used for lighting purposes and will require replacement occasionally.

(2) All moving parts, including handwheels, spot dials, range and altitude rate dials, prediction and constant speed motors, should be exercised at least once every two weeks. The moving part should travel from stop to stop or through one complete revolution if operation is not limited by a stop.

(3) For sealing the director cover plates, the instructions issued by the manufacturer should be followed. For coating the cam surfaces and lubricating the director mechanisms, the same lubricant should be used (1-pound can in tool box). Detailed instructions for lubricating the director are given in the manual, Director M4, part II.

■ 162. DIRECTORS M3, M3A1, T8E3, M2, M1A1, DATA COMPUTOR, M1917 (R. A. CORRECTOR).—A number of these types of data computors may be encountered in the service. Reference should be made to the appropriate manuals for information concerning these particular instruments.

SECTION II

HEIGHT FINDERS AND ALTIMETERS

■ 163. GENERAL.—There are two types of height finders in the service, the self-contained (stereoscopic) and the two-station (altimeters). The standard instrument of each type will be described in the paragraphs below.

■ 164. **Characteristics of Height Finder, M1.**—*a.* This instrument has the following general characteristics:

Type	Self contained (stereoscopic).
Base	4 meters (13.5 feet).
Magnification	12 and 24 power.
Range scale	550 to 50,000 yards.
Transmitter	0 to 10,000 yards.
Elevation	0° to 90°
Traverse	360°
Tracking telescopes:	
Magnification	8 power.
Field	6°.
Weight of component parts:	
Tube	575 pounds.
Cradle	160 pounds.
Tripod	185 pounds.
Weight of unit, packed	2,160 pounds.

b. The instrument is disassembled into three major loads for transporting: the tube, cradle, and tripod. These loads are packed separately in steel boxes. The cylindrical container for the tube is provided with shock mounting for minimizing the road shocks incidental to transportation, is also airtight, and is provided with the necessary valves for charging with dry air.

c. The main structural elements of the tube of the height finder consist of two concentric tubes; a double-walled body tube and an optical tube or bar. The purpose of the double-walled tube is to prevent sudden changes in temperature from affecting the accuracy of the instrument. This body tube consists of an inner and outer tube of such diameters that there is a space between them. This space, sealed at the ends, forms an air chamber which acts as a heat insulator. The entire instrument is also hermetically sealed, thus preventing the optical parts from becoming fogged due to condensation resulting from temperature changes.

(1) The outer tube constitutes the base of, and serves as a cover or housing for, the instrument proper. It is covered with a layer of heat insulating material, such as hair felt covered with canvas, further to prevent temperature changes in the instrument. It is supported by the cradle through two

ball bearing surfaces, one on each side of the center of the tube, allowing the height finder to rotate freely in elevation when in use. It is provided with end windows (fig. 64) through which the rays enter; the eyepiece unit; and other units which are not sensitive optical parts of the instrument. The end windows are slightly prismatic or wedge shaped, providing means whereby a final adjustment of the instrument may be made before leaving the factory. These windows should never be readjusted in the field except by an expert optical repairman. The eyepiece unit consists of two rhomboid prisms, the ray filter glasses, and the eyepiece lenses. The rhomboid prisms have two reflecting surfaces which offset the rays passing through them but do not change their direction. They are so mounted that, with the eyepiece lenses, they can rotate about the fixed centers of the central prisms thus permitting the eye lenses to be adjusted to the interpupillary distance of the individual observer. The eyepiece lenses may be focused to fit the observer's eyes. Various filters are provided for observing under different conditions of light or background.

(2) The inner or main tube has attached to it the end reflectors, compensator (measuring wedges), correction wedge height adjustment, and the internal adjuster system. (See TM 4–250.) It is suspended in the outer tube at two places. The end reflectors consist of two mirrors set at an angle of 45° with each other.

(3) The optical bar carries the objective lenses, reticles, erecting system, and central prisms, which are the most sensitive optical parts of the instrument. It is made of specially treated steel, is perfectly balanced, and is supported by the inner tube.

■ 165. **SETTING UP HEIGHT FINDER, M1.**—*a.* The tripod is unclamped and removed from its packing case. In order to secure the maximum stability, the legs of the tripod should be spread to the mechanical limit or as far as the conditions of the ground permit. The sleeve (fig. 64) on the tripod pivot arm is then clamped firmly in place. The tripod should be roughly leveled by eye by adjusting the ground plates with the hand wrench provided. Two men are normally required to set up the tripod.

b. The cradle is unclamped and removed from its packing case. The release lever (fig. 65), which disengages the azimuth gears, should be set at the release index. Two men lift the cradle, one at each end, and carefully set it in position on top of the tripod so that the locking bolts (fig. 65) engage their respective holes in the tripod top housing. The locking bolts are turned with the wrench provided until the cradle is securely fixed in position. The azimuth release lever is then turned to the engaged position. The protecting tubes of the level vials (fig. 65) are turned to expose the level bulbs, and the cradle is accurately leveled by adjusting the tripod ground plates. The cradle should be turned through 90° and the leveling checked and readjusted until the cradle is level at all azimuths. The data transmission system is plugged in by removing the plug cap (fig. 65) and inserting the plug on the end of the transmission line.

c. Eight men mount the tube on the cradle. The hinged end of the cylindrical carrying case is opened and the tube pulled out after the carriage clamps on the inside wall of the case are released. The tube is then removed from the traveling carriage by loosening the lock screws at each end and shifting the clamping brackets. Before placing the tube on the cradle, the elevation receiver should be set to read zero. The elevation index (fig. 65) should be set to match the zero line on the tube. If the index and the zero line do not match, the elevation drive can be turned by the fingers where it meshes with the elevation drive of the cradle until they match. Note that the elevation receiver should be zero and the index matched with the zero line whenever the instrument is disassembled. The tube is now lifted carefully by means of the porter bars and seated in place on the cradle. When the tube is accurately seated, the locking knobs (fig. 65) are turned down. The plug for the lighting circuit (fig. 64) is engaged with the socket on the cradle. The light switch (fig. 65) is turned to the proper setting depending upon the source of power. All lighting fixtures should be checked for operation.

■ 166. **ORIENTATION AND SYNCHRONIZATION.**—In order that the azimuth and elevation receivers on the height finder may be used to put the height finder on the same target as the director, these two instruments must be oriented and synchronized as far as the azimuth and elevation indicators are concerned. Furthermore, in order that correct altitudes be transmitted, the altitude transmitter and receiver must be synchronized. (See ch. 4.)

■ 167. ADJUSTMENTS OF HEIGHT FINDER, M1.—*a*. Before the height finder can be operated, it is necessary to make certain adjustments. The operator should be trained to make these adjustments in the following sequence:

(1) Set in the proper interpupillary distance (par. 168).
(2) Adjust focus of each eyepiece (par. 169).
(3) Adjust headrest for comfort of the observer.
(4) Make height of image adjustment (par. 170).
(5) Determine and apply range corrector setting (*RCS*). This correction may be determined in one of three ways:
(*a*) By use of the internal adjuster (par. 171*a*).
(*b*) By sighting on a celestial body at night (par. 171*b*).
(*c*) By adjustment of a known datum point (par. 171*c*).
(6) Check height of image adjustment (par. 170).

b. Every precaution should be taken to insure that these adjustments are made as accurately as possible in order to prevent eye strain, fatigue, and inaccurate readings. Furthermore, *before using the height finder, the temperature within the instrument should be allowed to stabilize* if accurate results are to be expected. Under normal conditions, the time necessary will vary from 10 to 30 minutes, depending upon the difference in temperature between the storage space and firing position.

■ 168. INTERPUPILLARY DISTANCE.—*a*. An observer's interpupillary distance remains constant and should be predetermined under the supervision of an instructor or by an oculist when the soldier is first selected for observer's training. It can be determined by an interpupillary gage provided for the purpose. (See fig. 63.) The gage is used as follows: The scale side is placed upon the bridge of the nose and the observer faces the light with both eyes open. He looks into the mirror and sees the reflection of the scale on the gage and his eyes. The zero mark is alined with the center of the left pupil. The interpupillary distance is then read on the scale under the center of the right pupil. To obtain a more accurate value, the measurement should be repeated at least three times and the average used for the true interpupillary distance.

b. Before any attempt is made to obtain readings, the eyepieces of the height finder should be adjusted to this correct interpupillary distance by means of the lever provided. (See fig. 65.) When this distance has been correctly determined and applied, the eyepieces should be in the most comfortable position for the observer and the two circular fields should blend into one. *With an incorrect setting, it is not only difficult to fuse either target or reticle images, but it is also quite probable that erroneous readings will be obtained.*

FIGURE 63.—Interpupillary gage.

■ 169. FOCUS.—*a.* Each eyepiece should be focused separately. The adjustment should be made in the direction from plus toward minus readings. That is, the eyepiece should be screwed all the way out to the largest positive diopter setting possible and then gradually screwed in toward a negative setting until the correct focus is obtained. The eye is capable of an accommodation of approximately one half a diopter. As a result, when the proper focus is made from a positive setting toward a negative setting, the setting obtained is actually slightly too much in a positive direction. Thus, if the eyes become tired after continuous operation, the diopter setting becomes more nearly correct. If, on the other hand, the original setting is obtained by turning the focus from the negative direction toward the positive, the resulting setting will be slightly too much in a negative direction. Then, as the eyes become tired from operation, the eyepieces will become more and more out of focus, which may result in eye strain and consequent errors unless the eyepieces are refocused.

b. When focusing the individual eyepieces, it is desirable to keep both eyes open as this usually gives better results than covering one eye while focusing with the other. Until the observer becomes trained, this may be done best by covering the end window of the eyepiece not being focused. The focus or diopter setting for any one observer will remain fairly constant. However, due to different conditions of fatigue or health of the observer, this setting may vary slightly. For this reason, the diopter setting for each eyepiece should be checked frequently.

c. The height finder proper is permanently focused at infinity. This focus of the eye pieces is merely an adjustment to suit the observer's eyes so that the image observed will be clear and distinct.

■ 170. HEIGHT OF IMAGE ADJUSTMENT.—If a vertical error in collimation of the two sides of the height finder exists, the target will not be viewed the same distance above the main symbol on both the right and left reticles and it will be difficult to fuse the target images and reticle symbols at the same time. In this instrument, the height of image adjustment plate is located in the left side and, therefore, the image for the left eye is moved by the adjusting plate. The right-hand target image should be brought very close, vertically, to the main symbol, using the elevation and azimuth drives. The left-hand target image is brought to the same height by means of the height adjusting knob (fig. 65). This adjustment should be checked frequently as in some instruments the height of image adjustment will change slightly with changes in angular height. *This adjustment should always be made both before and after an internal adjustment is made.*

■ 171. DETERMINATION OF RANGE CORRECTOR SETTING (*RCS*).— A number of factors such as temperature, range, visibility, and physical condition of the observer affect the accuracy of the range or altitude readings. The combined effect of all these variations is corrected by the *RCS*. It should be checked at least once each half hour during the operation of the height finder under normal conditions of temperature. If the temperature is changing rapidly, it should be checked more frequently. Furthermore, it has been found that the first 20 or 30 readings of an observer are likely to be irregular. Hence, the initial *RCS* should be determined only after the observer has had a chance to "warm up" and stabilize his readings. This setting may be determined in one of the ways given below. Then, before being applied by the *RCS* knob (fig. 65), it should be corrected under the supervision of the range officer based on the observer's curve "B." (See TM 4–250.)

a. The *RCS* may be determined by use of the internal adjuster after the proper lever (fig. 64) has been turned to switch-in this system. The range scale is set to read infinity and the observer then makes stereoscopic contact with the internal adjuster target and reticle symbol, using the *RCS* knob instead of the observer's measuring knob. The range scale does not move but remains at infinity. The *RCS* is read from its proper scale. At least ten readings should be taken and the average determined for the correct setting.

b. The *RCS* may also be determined in a similar manner by making stereoscopic contact on a celestial body at night.

c. The *RCS* may also be determined by adjustment on a known datum point by setting the range to that point on the range scale and making stereoscopic contact on the point by turning the *RCS* knob.

NOTE.—*A record of temperatures, RCS used, method of determining such settings, and errors resulting when reading ranges or altitude should be kept for each combination of observer and instrument in order that a careful analysis of the results may be made.*

■ 172. **Other Adjustments to Height Finder, M1.**—Under certain circumstances, other adjustments must be made to this instrument.

a. Selection of the magnifying power to be used will depend upon the visibility. Theoretically, the accuracy of the instrument increases with the power. The observer's accuracy depends upon the brightness and sharpness of the target image. Brightness decreases with an increase in magnification. The effects of heat waves, poor visibility, and vibration due to wind are increased with magnification. Observers should use the higher power whenever sharp definition will permit.

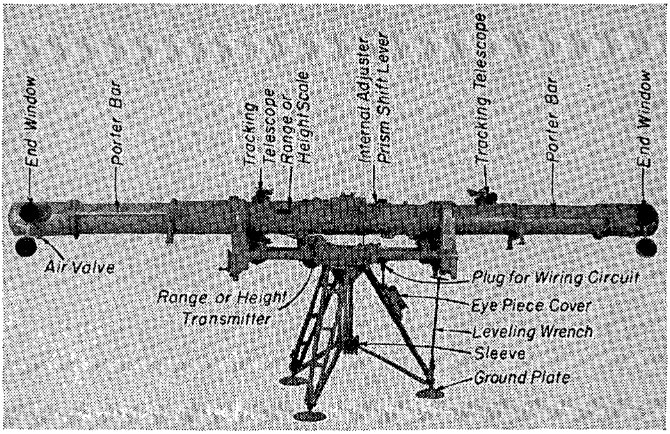


Figure 64.—Height finder M1 (front).

b. The range height lever (fig. 65) must be positioned depending upon whether ranges or altitudes are to be read. For ranges, the lever is locked at the index labeled "RANGE". For altitudes, the lever is locked at the index labeled "HEIGHT". The change over from ranges to altitudes or vice versa can be accomplished at any angular height. The range height lever is kept locked in the "RANGE" position during transportation of the instrument.

c. Filters are provided to aid the observer when light conditions or background are bad. The lever, which inserts the various filters in the optical system, is located just above the right eyepiece. (See fig. 65.) The choice of filter to be used is largely a personal preference of the observer.

CAUTION: It has been noted in many cases, that the introduction of a colored filter causes the observer to make errors in the determination of altitudes. The RCS should be determined, using the desired filter inserted in the eyepiece unit.

■ 173. **MANNING DETAIL, HEIGHT FINDER, M1.**—A minimum manning detail of four men is required to operate this instrument. Each member of this detail should be a trained stereoscopic observer. The duties to be performed are listed below:

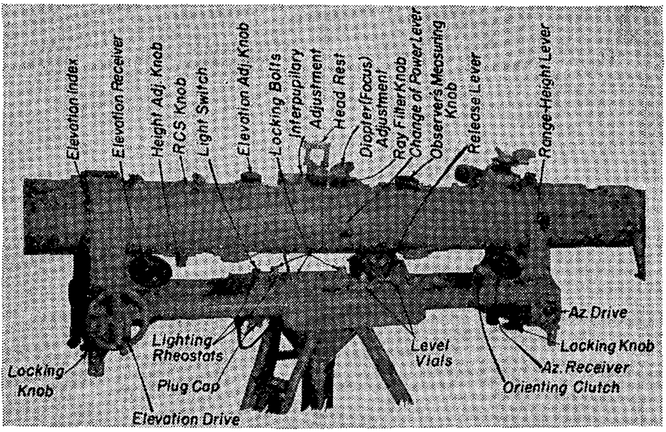


FIGURE 65.—Height finder M1 (rear center).

a. Elevation tracker.—Identifies target by matching pointers on the elevation receiver. Tracks the target in the vertical plane (angular height).

b. Azimuth tracker.—Identifies target by matching pointers on the azimuth receiver. Tracks the target in azimuth.

c. Stereoscopic observer.—Measures range or height by maintaining stereoscopic contact with the target.

d. Height or range setter.—Reads height or range on the scale and continuously resets the values in the range or height transmitter.

■ 174. OPERATION OF HEIGHT FINDER, M1.—*a.* For ease in getting the director and the height finder on the same target, a target identification system consisting of an azimuth and elevation receiver is incorporated in the height finder. Present azimuth and angular height are transmitted from the director to the height finder.

b. When the director gets on the target first, the height finder observer is aided in getting on the target by matching the azimuth and elevation receiver pointers on the height finder. Frequently, however, the height finder will pick up a target before the director. When this occurs, it is often advisable for a member of the height finder crew to watch these azimuth and elevation receivers and notify the director trackers the direction to turn. With practice, the director can be put on the target rapidly.

c. The tracking observers should track the target with the utmost care and smoothness. Slight unevenness in tracking by these observers will be multiplied several times in the field of view of the stereoscopic observer. This results in flickering of the target over the field, thus making stereoscopic contact difficult or even impossible to obtain.

d. There are two methods in general use for an observer to establish stereoscopic contact when reading ranges or altitudes. The first method, in which the observer breaks contact between successive readings, is the method most used and which should be used by all observers in the early period of training. In obtaining stereoscopic contact by this method, the observer should oscillate the range knob so that the target appears to pass in front of and then in rear of the main reticle symbol, thus obtaining a stereoscopic bracket. He then reduces the amount of oscillation until finally the target comes to rest in the same apparent plane as the main symbol where stereoscopic contact is obtained. The observer then calls "Read," the reader reads the range or altitude, contact is broken and then remade as before. In the second method, the observer after once establishing stereoscopic contact maintains it throughout. Sufficient data have not yet been obtained to determine which, if either, of these two methods is more accurate. However, the latter method is the only one whereby continuous altitudes may be sent to a director when firing on a diving target and a rate of change of altitude established without introducing a time altitude board or some similar outside means. If the observer's accuracy is adversely affected by the method of continuous contact after a fair test, he should go back to the method of breaking contact between observation. Regardless of which method is used, it is advisable for the observer to obtain his first contact by making the last motion of the range measuring knob in the direction for increasing the range. As soon as the observer makes stereoscopic contact, he calls "Read." The reader sets the altitude transmitter to the proper value and the reading is recorded for future comparison and analysis. The readings normally are not read aloud as it has been found that, frequently, if the observer has knowledge of the readings resulting from his observations, his performance is affected adversely.

■ 175. STEREOSCOPIC SPOTTING.—*a*. The stereoscopic observer may be called upon to furnish range sensings in addition to altitudes. A well-trained, experienced observer can do this successfully provided the deviations of the burst are not too great. Theoretically, the angular separation of the target and the burst in the apparent field must not exceed 2°. The angle in the true field then would be $\frac{2\times 17.8}{24}$ (angle in true field$=\frac{\text{angle in apparent field}}{\text{magnification}}$) or 1.5 mils for 24 power, and 3 mils for 12 power. Actual experience has indicated that the angular separation of the target and burst in the true field must not exceed 5 mils for 24 power and 10 mils for 12 power. If sensings are made when the angular separation exceeds the above limits, the results are entirely unreliable. The lateral "fence posts" of the reticles are 2.5 mils apart.

b. When spotting is done in addition to altitude determination, the method of maintaining continuous stereoscopic contact described in paragraph 174*d* will give the best results.

■ 176. GENERAL CARE OF HEIGHT FINDER, M1.—*a*. This instrument is of stury construction and will withstand normal handling in transportation and setting up. Care should be taken, however, to avoid any unnecessary jolting or mishandling. The life of the instrument and the satisfactory service that it will give depend upon the handling it receives.

b. The height finder proper, the cradle, and the tripod are provided with steel carrying cases. When the instrument is not in use, the units should be replaced in their respective cases. Whenever it is possible, protect the instrument from the direct rays of the sun and be sure that at no time the rays of the sun fall directly on any exposed optical surfaces, such as the eyepiece lenses. Cover the eyepiece with the eyepiece cover whenever the instrument is not being used. It is injurious to the observer and to the instrument to sight directly at the sun.

c. Temperature changes cause an unstable condition inside the instrument which will make reading with the instrument both difficult and inaccurate. It is advisable, therefore, to avoid any sudden changes in temperature. It is essential for accurate results that both ends of the height finder tube are exposed to the same temperature conditions when in operation; that is, do not allow one end of the tube to be in the sun while the other is in the shade, or do not allow a cool wind to blow on one end of the tube while the other is protected.

d. It is good practice, especially if the instrument is not in regular use, to turn all the handwheels and knobs from one stop to the other at least once a month to prevent gumming or sticking. Do not force any of the handwheels or knobs. If they cannot be moved, it is probably an indication that a stop has been reached. Persons who are not familiar with the operation of the instrument should not be allowed to manipulate handwheels or knobs.

■ 177. REPLACING ELECTRIC BULBS, HEIGHT FINDER, M1.—*a*. The electrical system of the height finder has been designed so that the replacement of bulbs does not involve exposing any vital part of the instrument. Standard automobile type double-contact lamps with bayonet sockets. (Mazda No. 64 6-volt, 3 C. P.) are used throughout. See manual, Height Finder, M1, for location of the various bulbs and the method of replacement.

b. Ordinarily, if the illumination on the right side is faulty, the lamp on the right side requires replacing. In the case of the internal adjuster, however, the source of light for the target seen through the right eyepiece is in the left internal adjuster mount and vice versa.

■ 178. CARE OF EXPOSED OPTICAL SURFACES, HEIGHT FINDER, M1.—The exposed optical surfaces are the end windows and the eye lenses on the main instrument, and the objective lenses and the eye lenses on the tracking telescopes. These should be kept clean in order to obtain the most satisfactory results since dirt or moisture collecting on the eye lenses will annoy an observer. Ordinarily dust that collects on any of these surfaces must be removed with a soft camel's hair brush supplied in the cradle carrying case. If moisture has collected on any of these surfaces, use the selvyt cleaning cloth that is supplied. Keep the selvyt cleaning cloths clean and in the dustproof can provided. Grease may be removed if the selvyt cloth is moistened with alcohol. Care should be taken when cleaning any optical surface to avoid scratching the glass.

■ 179. CARE OF CRADLE AND TRIPOD, HEIGHT FINDER, M1.—These parts of the instrument will need lubrication at various intervals. If the instrument has been out of service for a considerable time, lubricate it upon reentering service. See manual, Height Finder, M1, for further instructions on lubrication.

■ 180. MISCELLANEOUS ADJUSTMENTS TO HEIGHT FINDER, M1.—*a.* See manual, Height Finder, M1, for instructions on the checking of alinement of tracking telescopes and their adjustment.

b. See manual, Height Finder, M1, for the method of checking level vials and adjustment.

c. Except for the adjustments specifically mentioned in the preceding paragraphs, all repairs, dismantling, and adjustments will be made by ordnance maintenance personnel.

■ 181. STORAGE, HEIGHT FINDER, M1.—*a.* Temperature changes cause an unstable condition inside the instrument, making readings inaccurate and the operation of the instrument difficult. It is advisable, therefore, to avoid any sudden changes of temperature. During short periods of storage, the storage temperature should be as near that of the outside as possible. This will permit the immediate use of the instrument upon taking it from storage and setting it up in the field without repeated checking of the internal adjuster settings. When the temperature change is 3° or less an hour, or 12° or less in 4 hours, the temperature is considered stable. If an instrument has experienced a sudden change of temperature greater than the conditions of stable temperature, frequent checks of the internal adjuster setting must be made. As the changes between successive adjuster readings decrease, the time interval between readings of the internal adjuster may be increased.

b. The large steel carrying tube for the height finder, M1, is equipped with air valves which are similar to those found on the instrument proper. During prolonged periods of storage, these valves may be used to desiccate the interior of the carrying tube and thus prevent deterioration. The carrying tubes for the height finder, M1, serial numbers 1 to 32, inclusive, do not have air valves, and for prolonged periods of storage, a tray of calcium chloride should be placed inside each case before sealing it. This will absorb any moisture that is present when the case is sealed and help in the prevention of deterioration.

■ 182. **ADDITIONAL REFERENCES TO STEREOSCOPIC HEIGHT FINDING.**—Further detailed information on the theory of optical principles of the height finder, operation, and methods of training will be found in TM 4–250.

■ 183. **ALTIMETER, M1920.**—*a. General.*—The altimeter, M1920, consists of two instruments which determine altitudes by means of the two-station system (roof principle) described in paragraph 50. The two instruments are designated *B′* and *B″*. Figure 66 shows the principal features of the *B′* instrument. Normally, an identical instrument is used for the *B″* station, though a few instruments designed only for use at the secondary station have been used.

b. Functioning of the system.—(1) Both instruments are constructed so that the sight on each has but two movements. The first motion consists of swinging the support (22) of the sight (20) in the vertical plane containing the base line (in effect rotating a plane about a horizontal line perpendicular to the base line at the altimeter station). The second motion is accomplished by rotating the sight about its inclined axis (22) (in effect swinging the line of sight in the rotated plane). Both instruments must be oriented to insure that the axes of rotation of the planes are perpendicular to the base line and that the zeros of the vertical angles (ϕ_1 and ϕ_2) are in the same direction (the direction of the line from *B′* to *B″*).

(2) The solution of the altitude formula by the altimeter is automatic. In operation, the ballistic correction slide (7) is moved until the base line index (9) is set opposite the proper base line length on scale (8). This setting moves the altitude index (4 or 5) on the left edge of the slide (7) a distance from the origin of graduations (30) equal to log *b*. On the *B′* instrument, the curve disk carries curves of ϕ_2 (10). (See note below.)

NOTE.—The curves are plotted logarithmically from the formula

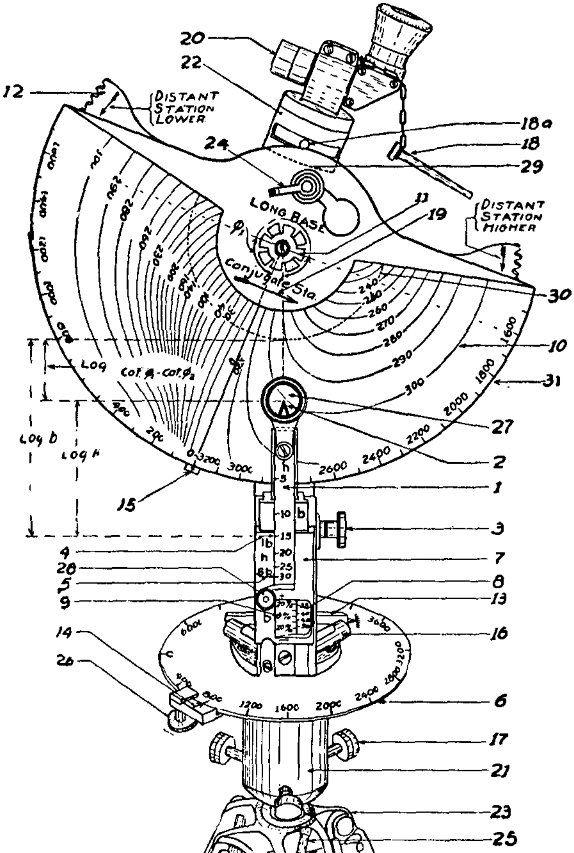
$$\log H = \log b + \log \left(\frac{1}{\cot \phi_1 - \cot \phi_2}\right)$$

$$= \log b - \log (\cot \phi_1 - \cot \phi_2)$$

The reference circle of graduations (30) is arbitrarily placed ((5) below) and is established by the conditions when $\cot \phi_1 - \cot \phi_2 = 1$, in which case $b = H$. All plotting of logarithmic values above the reference circle is positive in direction and below, negative. Whenever ($\cot \phi_1 - \cot \phi_2$) becomes less than unity, the logarithm becomes negative, from a consideration of plotting, and the negative sign in the logarithmic formula causes the value to be plotted positively. As an example of the positive and negative plotting, consider two points on the $\phi_2 = 1{,}200$ curve, for conditions of $\phi_1 = 500$ and 900 mils, respectively, the constant of construction being log 10 = 3 inches.

($\cot \phi_1 - \cot \phi_2$)	$\phi_1 = 500$
$\log (\cot \phi_1 - \cot \phi_2)$	$(1.871 - 0.4142) = 1.4568$
$-\log (\cot \phi_1 - \cot \phi_2)$	0.16340 positive
distance from reference circle (inches)	0.16340 negative
($\cot \phi_1 - \cot \phi_2$)	0.49 negative
$\log (\cot \phi_1 - \cot \phi_2)$	$\phi_1 = 900$
$-\log (\cot \phi_1 - \cot \phi_2)$	$(0.8207 - 0.4142) = 0.4065$
distance from reference circle (inches)	$9.60906 - 10 = 0.39094$ negative
	0.39094 positive
	1.17 positive

ϕ_1 is determined by pointing the *B′* instrument (fig. 66). The ϕ_2 curves (10) on the *B′* disk are so plotted that when the pointer (2) is raised or lowered until it intersects the curve of the synchronous value of ϕ_2, telephoned from *B″*, the vertical distance from the origin of graduations to the pointer will be log ($\cot \phi_1 - \cot \phi_2$). The distance from pointer (2) to altitude index (4 or 5), therefore, will be $\log b - \log (\cot \phi_1 - \cot \phi_2)$ which, as will be seen from the formula, equals log H. In the figure, the values of ϕ_1 and ϕ_2 are such that the log ($\cot \phi_1 - \cot \phi_2$) is positive. The altitude scale (1) is graduated in values of log *H* but marked to read *H* directly. When $(\cot \phi_1 - \cot \phi_2) = 1$, the $\log (\cot \phi_1 - \cot \phi_2) = 0$. *H* is then equal to *b* and the pointer will be at the origin of graduations.



See opposite page for legend.

1. Altitude scale (*H*) (numbered in hundreds of yards).
2. Altitude scale pointer (ϕ_2).
3. Altitude scale pointer knob.
4. Altitude index (*lb*), long base.
5. Altitude index (*sb*), short base.
6. Azimuth circle.
7. Base line and ballistic corrections slide.
8. Base line scale (*b*).
9. Base line index (0%).
10. Curve disk. ϕ_2 angles. Reverse side short base.
11. Curve disk retainer.
12. Curve disk support.
13. Declinator.
14. Azimuth index.
15. Elevation compensating index (slope).
16. Level.
17. Leveling screw.
18. Locking pin.

18a. Locking pin hole.

19. Orienting arrow.
20. Sight.
21. Spindle bushing support.
22. Telescope support.
23. Tripod head.
24. Wing nut (curve disk).
25. Spindle bushing support clamp screw.
26. Azimuth clamp nut.
27. Magnifying glass.
28. Base line slide clamp screw.
29. Line of separation between telescope supports, upper and lower.
30. Reference circle ($H=b$).
31. ϕ_1 or ϕ_2 graduated in 10 mils.

FIGURE 66.—Altimeter, M1920

(3) No graduations are required on the *B''* instrument except the mil scale (31) on the periphery of the curve disk. For the *B''* instrument the values of ϕ_2 are read opposite the pointer (2) which is depressed for this purpose to the mil scale on the periphery. It should be noted that the orienting arrow (19) on the *B'* type of instrument is based on its use as a *B'* instrument only. When used at *B''* the arrow should point away from *B'*.

(4) From the basic formula it can be seen that if ϕ_1 and ϕ_2 be held constant, *H* will vary directly with *b*. Therefore, if it be desired to use a false altitude a certain percent higher or lower than the actual altitude (for example, in applying a correction based on trial shots), it may readily be accomplished by applying a false base line greater or less than the actual base line by the same percent. The ballistic correction scale on slide (7) accomplishes this purpose.

(5) There are two altitude indices (4 and 5) on the left side of slide (7), the upper marked "*lb*" and the lower "*sb*." These indices correspond to the two sets of curves on the disk, one on either side, marked "LONG BASE" and "SHORT BASE," respectively. The two sets of curves are made available in order that greater accuracy may be obtained under

varying conditions. The long base side of the curve disk (and the *lb* index) should be used in all situations when the base line length will be greater than the expected altitude. Conversely, the short base side of the curve disk (and the *sb* index) should be used when the base line will be shorter than the expected altitude. It is manifestly unsound to change plates after a target appears, but experience and meteorological conditions, particularly cloud heights, will enable expected altitudes of targets to be foretold to some extent in most cases. (See note below.)

NOTE.—It has been stated that the situations plotted above the origin of graduations are those in which $\cot\phi_1 - \cot\phi_2$ is less than unity. In the formula

$$H = \frac{b}{\cot\phi_1 - \cot\phi_2},$$

it can be seen that whenever $\cot\phi_1 - \cot\phi_2$ is less than unity, the altitude will be greater than the base line. On the short base curve disk, the origin of graduations is 1 inch farther from the center than in the long base curve disk, and hence there is greater space for plotting and more inherent accuracy in the short base curve disk for those situations plotted above the reference circle; that is, when the altitude is greater than the base line. The converse is true of the long base disk which gives greater accuracy when the altitude is less than the base line.

■ 184. MANNING DETAIL, ALTIMETER, M1920.—The personnel required to operate an altimeter system consists of a noncommissioned officer and three men as follows:

a. No. 1.—The *B'* reader is the noncommissioned officer in charge of the detail. He is equipped with a head set and takes post seated and facing the curve disk of the *B'* instrument.

b. No. 2.—The *B'* observer takes post at the sight of the *B'* instrument.

c. No. 3.—The *B''* reader is equipped with a head set and takes post seated and facing the curve disk of the *B''* instrument.

d. No. 4.—The *B''* observer takes post at the sight of the *B''* instrument.

■ 185. SELECTION OF ALTIMETER BASE LINE.—*a.* The length of the altimeter base line is of importance. A short base line will give intersections at the higher altitudes and at the outer limits of horizontal range which are too acute for the desired accuracy. On the other hand a very long base line has the disadvantages of increased difficulty of control and communication, and a proportionately longer time is required for its establishment. It is obvious that, within limits, the longer the base line the more accurate the result for normal altitudes of antiaircraft gun targets.

b. The most favorable intersections on a target at any position in the field of fire of the battery are the controlling factors in determining the most efficient length of base line. Other factors are the desirability of having the *B′* instrument at the battery position and the *B″* instrument at approximately the same elevation. Modifying considerations will be concerned with the topography of the immediate locality, the time available for preparing the battery to open fire, and other considerations such as roads, routes, features of the terrain, and most probable direction of approach of targets.

c. Considering the usual altitudes of targets for antiaircraft artillery gunfire, a base line of from 3,500 to 4,500 yards in length is desirable.

d. The direction of the base line is relatively unimportant, but local, tactical, and topographical considerations may dictate one direction as being more desirable than another since, practically, better intersections result when the course of the target is approximately normal to the base line at its center. All other things being equal, a direction which affords intervisibility between the two base end stations facilitates orientation of the two instruments.

e. When the positions of the two instruments have been selected, the distance between them and the direction from the primary to the secondary station must be determined. It is sufficiently accurate to scale the distance and azimuth from an accurate large scale map. The length of the base line should be accurate to the nearest 10 yards and the azimuth should be measured to the nearest 5 mils. When the two stations are intervisible or when a marker can be erected on the base line in a position which is visible from both stations, the azimuth of the base line need not be determined.

■ 186. SETTING UP THE B′ AND B″ INSTRUMENTS.—*a.* The tripods are set up at the points designated. The lengths of the legs are adjusted so that the top will be approximately level and so that the instrument will be at a convenient height when assembled.

b. The reader places the stem of the spindle bushing support in the tripod head and tightens the wing nut. He loosens the leveling screws to prevent the spindle bushing striking them.

c. The observer removes the instrument from its carrying case and lowers the spindle bushing carefully into the spindle bushing support. He holds the instrument as nearly vertical as possible while the reader tightens the leveling screws until all three bear firmly.

d. The reader loosens the azimuth clamp nut and turns the instrument about until one level is parallel to a line joining two leveling screws. He turns these two leveling screws simultaneously and in opposite directions until the bubble over them is centered. The second bubble is then centered by turning the third leveling screw. In order to accomplish this, it will be necessary to loosen or tighten the first two screws by an equal amount. After both bubbles are leveled, the instrument is turned through 180° and checked for level. If both bubbles do not remain centered, the necessary adjustment must be made to correct the position of the bubble tubes. Adjustment of the level tubes should be done by competent Ordnance Department personnel.

■ 187. **ORIENTATION OF ALTIMETER, M1920.**—The altimeter is oriented when the curve disks on the two instruments are fixed in the same vertical plane, when the arrows on the disks point in the same direction (which must be in the direction *B′* to *B″*), and when a correction for difference in elevation of the two stations has been applied. Any one of the three methods below may be used to place the curve disks in the vertical plane of the base line:

a. Stations intervisible.—(1) *B′ instrument.*—(*a*) The observer inserts the locking pin in the telescope support so that the sight points in the same direction as the arrow on the curve disk.

(*b*) He releases the azimuth clamp nut and rotates the instrument until the *B″* instrument is on the vertical cross hair. He then tightens the azimuth clamp nut.

(2) *B'' instrument.*—(*a*) The observer inserts the locking pin in the telescope support so that the sight points in the same direction as the arrow on the curve disk.

(*b*) He loosens the azimuth clamp nut and sets the azimuth at 3,200. He then tightens the azimuth clamp nut.

(*c*) He loosens one leveling screw and turns the entire instrument about until the *B'* instrument is on the vertical cross hair. He then tightens the leveling screw, checks the level of the instrument, and verifies the sighting on the *B'* instrument.

(*d*) He then loosens the azimuth clamp nut, sets the azimuth at zero, and tightens the azimuth clamp nut.

(*e*) This method may also be used if the stations are not intervisible but when a sighting pole or marker can be erected on the base line in a position so that it is visible from each end.

(*f*) The arrow on the plate should point in the direction *B'–B''*.

b. By known azimuths (*B' and B'' instruments*).—(1) The observer inserts the locking pin as previously described.

(2) He loosens the azimuth clamp nut, sets off the azimuth of the datum point, and tightens the azimuth clamp nut.

(3) He then loosens one leveling screw and turns the entire instrument about until the datum point is on the vertical cross hair. He tightens the leveling screw and verifies the level and pointing of the instrument.

(4) He loosens the azimuth clamp nut, sets off the azimuth of the base line, and tightens the azimuth clamp nut. The azimuth of the base line (to be set on both instruments) is the azimuth from *B'* to *B''*.

c. By compass (*B' and B'' instruments*).—(1) The observer sets off the proper magnetic declination on the small scale near the end of the declinator ((13) fig. 66).

(2) He loosens the azimuth clamp nut, sets the azimuth at zero, and tightens the azimuth clamp nut.

(3) He loosens one leveling screw and turns the entire instrument until the compass needle rests opposite its index. He then tightens the leveling screw and checks the level of the instrument.

(4) He loosens the azimuth clamp nut, sets off the azimuth of the base line, and tightens the azimuth clamp nut.

NOTE.—This method of orientation is not accurate and should be used only when no other method is available.

d. Orientation of instruments.—Orientation of the instruments must be most carefully performed. The orientation may be verified by taking simultaneous readings on a celestial body with the altitude pointers of both instruments completely depressed. The ϕ_1 and ϕ_2 angles read should be identical.

■ 188. PREPARING ALTIMETER, M1920 FOR OPERATION.—*a. B' instrument.*—(1) The reader sees that the "long base" or "short base" curve disk is set on the instrument as ordered. If necessary to reverse the disk, he loosens the wing nut, turns the disk until it disengages from the curve disk retainer, removes the disk, and replaces it with the proper face exposed.

(2) He sets the elevation compensating index ((15) fig. 66) at zero unless otherwise ordered by the battery commander. If the stations are not at the same level, he sets off half the angular difference between stations by loosening the wing nut and turning the curve disk in the direction indicated by the arrows on the curve disk support until the correction ordered is set opposite the elevation compensating index. (See par. 43*d*.)

(3) The value of the %*H* correction is set on the ballistic correction slide opposite the length of the base line. If no correction is ordered, the zero mark on the ballistic correction slide is set opposite the base line length.

b. B'' instrument.—The reader sets the elevation compensating index as described for the *B'* instrument. It must be remembered that the words "distant station" refer to *B''*.

■ 189. OPERATION OF ALTIMETER, M1920.—*a.* The *B'* and *B''* observers remove the locking pins. They find the target by means of the collimator attached to the sight and follow it continuously by rotating the sight about its axis and elevating it by means of the elevating handwheel. They warn their readers "On target" when the target has been found in their sight. If for any reason the target maneuvers out of the field of view, they will warn the readers "Off target." If the target disappears behind clouds or other obstructions, they will indicate that fact by saying "Target obscured."

b. The *B''* reader depresses the altitude scale pointer completely. He repeats to the observer the target designations received over his telephone. When his observer is "On target," he notes the graduation on the periphery of the curve disk which will be under the pointer in about 5 seconds, for example 150, and warns the *B′* reader "Ready for one-five-zero." He again warns, "Ready" when the graduation is almost under the pointer, and calls, "Take" when the two coincide. After the *B′* reader has announced the altitude or "Reading lost," he repeats the operation, continuing until CEASE TRACKING has been given or the target has disappeared.

c. The *B′* reader repeats to the *B″* reader all designations of targets. If his observer is "On target," he notes the warning received from the *B″* reader, for example, "Ready for one-five-zero," and elevates the altitude scale pointer until it coincides with the 150 curve on the disk. He continues following that curve until "Take" is given by the *B″* reader at which he holds the pointer motionless and reads the altitude of the target on the altitude scale opposite the index corresponding to the face of the disk in use (*sb* or *lb*). If for any reason an altitude is not obtained, he calls "Reading lost" to the *B″* reader to indicate that he is ready for a new reading.

SECTION III

OBSERVATION INSTRUMENTS

■ **190. OBSERVATION INSTRUMENT, AA, BC, M1 (BC TELESCOPE).**—*a. General.*—(1) This instrument enables the battery commander to study and identify possible targets and to follow the course of firing on a target. It is also used to determine the coordinates in space of trial shot bursts. It may be used in lieu of a transit for orienting the battery.

(2) The instrument consists of three parts, the telescope unit, mount, and tripod. It is packed for transportation in three wooden carrying cases, one for the telescope unit, one for the mount, and one for the tripod. The weights of the parts are as follows:

	Pounds
Telescope unit	18.0
Mount	27.5
Tripod	10.0

b. Description.—The description below, refers to the instrument as shown in figure 67.

(1) *Optical systems and control.*—(*a*) The instrument is controlled by the battery commander's observer by means of an elevating handwheel and a traversing handwheel. These two handwheels drive the instrument through the usual worm and worm gear train. The azimuth train is provided with a disengaging lever for rapid changes in azimuth.

(*b*) The instrument comprises two separate optical systems; the observer's telescope by means of which he follows the target, and the battery commander's telescope available to the battery commander at all times. The observer's telescope is a standard M2 elbow telescope with the eyepiece set along the horizontal axis of rotation. It is an 8-power telescope with a field of 8°45′ and is provided with an amber filter. To aid the observer in locating the target in his field initially, an open sight is provided.

(*c*) The battery commander's telescope is also of the elbow type with the eyepiece on the horizontal axis of rotation. This telescope has two powers (10 and 20), the shift being made by a revolving nut. When set for 20 power, the telescope has a field of 3°5′ and an exit pupil of 0.125 inch. When set for 10 power, it has a field of 6°9′ and an exit pupil of 0.25 inch. The eyepiece is focused by means of an exterior knurled ring. Two internal filters are provided, one amber and one blue, which may be thrown into position by an exterior lever. The reticle bears graduations in mils along vertical and horizontal axes, the least reading being 5 mils.

(2) *Mount.*—(*a*) The instrument is carried on the base of an azimuth instrument, M1918, with a special trunnion support attached rigidly thereto. The cap squares of the trunnion support are hinged on one side and fastened down with screws on the other, holding the telescope in place. The mount is screwed onto the tripod in the usual manner and is provided with four leveling screws and two spirit levels for leveling the instrument.

(*b*) The main elevation scale, bearing graduations of 10 mils, is attached to the elevating rack and passes over an index held by two set screws, permitting a small adjustment. The elevation subscale, bearing graduations of 1 mil, rotates on the end of the elevating shaft and is read at a fixed index on the mount.

(*c*) The main azimuth scale, bearing graduations of 20 mils, appears in a window in the mount and is read opposite a fixed index. The azimuth subscale rotates on the shaft of the traversing handwheel and is read at a fixed index. The subscale is graduated in tenths of a mil, there being 200

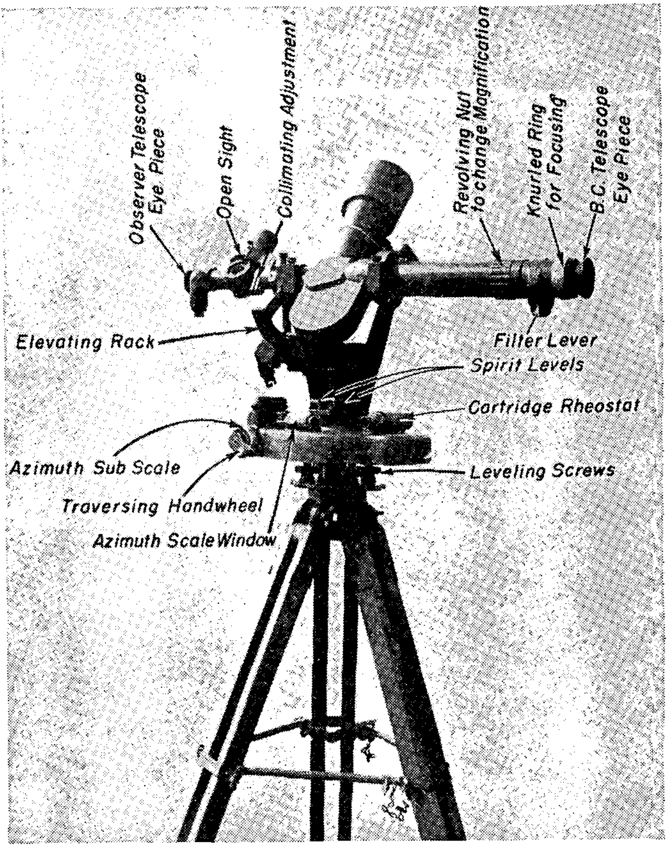


FIGURE 67.—Observation instrument, AA, BC, M1 (BC telescope).

graduations, or 20 mils to one complete revolution of the handwheel. For orienting the instrument, the azimuth release clamp is provided, and, for fine setting, the tangent screw and the tangent clamp screw are provided.

(3) *Lighting circuit.*—A 4-volt circuit is provided with sockets for illuminating the azimuth scale, the elevation scale, the observer's cross hairs, and the battery commander's cross hairs, and mil graduations. The amount of illumination may be varied by a cartridge rheostat.

(4) *Tripod.*—The tripod is the common wooden type with threaded head on which the mount is screwed. A tripod cap is provided for protection of the threads when the instrument is disassembled. A spirit level in the head provides a means for setting up the tripod so that the head is approximately level.

■ 191. **SETTING UP AND ORIENTING BATTERY COMMANDER'S TELESCOPE.**—*a.* The tripod is removed from its carrying case, tripod cap removed, and tripod set up with the legs well spread to give stability and pushed into the ground to a firm bearing, the head of the tripod being approximately level.

b. The mount is screwed firmly onto the head of the tripod. The trunnion clamp screws are unscrewed and the cap squares of the trunnion support opened so as to receive the trunnions of the telescope unit.

c. The telescope unit is removed from its carrying case, being grasped at the elbow junction of the battery commander's telescope, and placed carefully in the trunnion beds in such a manner that the objective end of the telescope is on the same side of the trunnion support as the elevating handwheel. The trunnion cap squares are folded down and the trunnion clamp screws are screwed up to a firm bearing, securing the telescope to the mount.

d. In order to facilitate operation of the instrument, the traversing handwheel must be to the immediate right of the observer. To bring the telescope and the mount in the proper relation, release the azimuth release clamp and turn the telescope unit until the traversing handwheel is in a convenient position at the right when standing in position for observing through the observer's telescope. Then tighten the azimuth release clamp.

e. Set the instrument to read the approximate azimuth of the datum (or orienting) point on the main azimuth dial. For large changes of azimuth, use the azimuth disengaging lever.

f. Loosen the leveling screws, grasp the instrument firmly with both hands about the leveling screws, and rotate the whole instrument by sliding it on the leveling plate until the telescope is pointing approximately toward the datum point. Tighten the leveling screws, release the azimuth release clamp, and rotate the telescope until one spirit level is parallel to the line between two opposite leveling screws. Turn these two screws in opposite directions until the bubble of the spirit level comes in the center of the level tube, being careful to maintain a firm bearing of the screws on the plate. Perform the same operation with the other pair of leveling screws, bringing the bubble of the other spirit level to the center of its tube. Repeat these operations until the bubbles of both spirit levels are exactly centered and the four leveling screws screwed up to a firm bearing.

g. Set the main azimuth scale and the azimuth subscale to read the azimuth of the datum (or orienting) point. This is done by releasing the azimuth disengaging lever, rotating the instrument until the azimuth to the nearest 20 mils is set opposite the index in the window, reengaging the azimuth disengaging lever, and setting to the nearest mil and tenth on the azimuth subscale by the traversing handwheel. Center the vertical cross hair of the observer's telescope on the datum (or orienting) point using the tangent screw. Tighten the tangent clamp screw. The instrument is now leveled and oriented.

■ 192. MANNING DETAIL.—The instrument is manned by an observer and such other observers as may be assigned. The spare observers may be utilized for readers and telephone operators when necessary. The chief observer is responsible for setting-up, orienting, and preparing the instrument for use.

■ 193. ADJUSTMENTS OF BATTERY COMMANDER'S TELESCOPE.—*a*. To adjust the lines of collimation of the two telescopes—

(1) Set up and level the instrument.

(2) On a convenient vertical surface normal to the line of sight, draw a horizontal line at the same height as the trunnions of the instrument. Make two marks on this line separated by the distance between the lines of sight of the two telescopes.

(3) Adjust the cross hairs of the battery commander's telescope on the right-hand mark, both horizontally and vertically.

(4) Adjust the cross hairs of the observer's telescope on the left-hand mark, both horizontally and vertically. The elevation adjustment is accomplished by means of the clamp which holds the observer's telescope to the trunnion. The azimuth adjustment is made by adjusting the spring adjustment at the rear of the observer's telescope.

b. To adjust the elevation scale and index, with the battery commander's telescope centered on a target at the same level as the trunnions of the instrument, adjust the elevation scale index so that it is coincident with zero elevation (the holes in the index are elongated to permit adjustment). Set the micrometer knob on the elevation worm to zero by loosening the three clamp screws and slipping the graduated ring to the zero position.

■ 194. CARE OF BATTERY COMMANDER'S TELESCOPE.—This instrument should be given the same care as other optical instruments. (See par. 178.)

■ 195. FLANK SPOTTING INSTRUMENT, M1 AND FLANK SPOTTING RULE, M1.—Both these instruments are described herein as they are used together to obtain altitude corrections.

a. Theory.—Figure 68 is drawn out of proportion to emphasize the small triangles at the T or target position. Delta sub 2 (δ_2) in the figure is the range deviation as read in mils from the flank observing station. We wish to evolve a factor (C) such that, when multiplied by this deviation in mils, the result will be a deviation in yards of altitude. This deviation (h_1) with the sign reversed is the altitude correction necessary to move the burst along the line of position to the target. The expression of this correction is:

$$C\delta_2 = h_1$$

δ_2 lies in the slant plane containing the spotting base line and the target. A further expression of the C factor is:

$$C=\frac{D_2 \sin \epsilon_1}{\sqrt{1-\left(\frac{D_1^2+D_2^2-b^2}{2D_1D_2}\right)^2}}$$

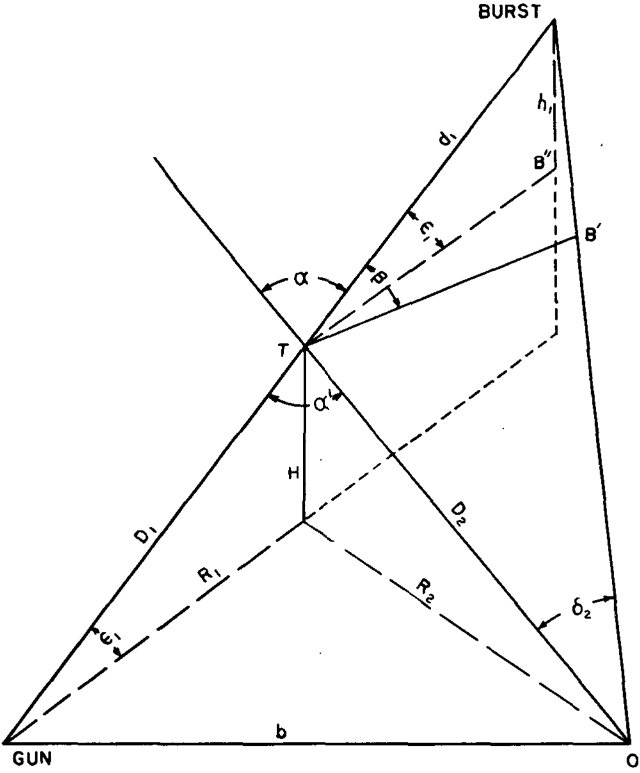


FIGURE 68.—Computation of conversion factor for deviations measured in the slant plane.

D_1 D_2 and b are expressed in thousands of yards. This may be expressed also as:

$$C=\frac{D_2 \sin \epsilon_1}{\sin \alpha}$$

Using the elements shown in figure 69, the above formula can be expressed as

$$C=\frac{H^2}{b \sin \epsilon_m \sin^2 \theta}$$

Expressed logarithmically, this equation becomes

$$\log C=2 \log H+\text{colog } b+\text{colog } \sin \epsilon_m+2 \text{ colog } \sin \theta$$

The flank spotting instrument M1 (fig. 71) obtains the angles ϵ_m and θ and the flank spotting rule M1 (fig. 72) solves the logarithmic equation.

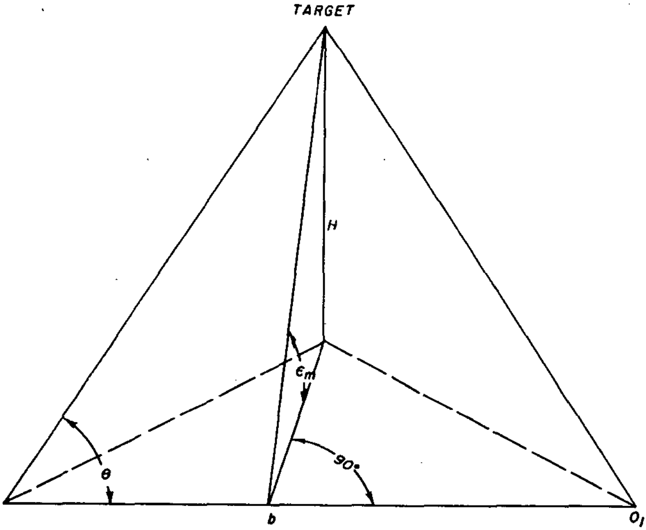


FIGURE 69.—Derivation of factor for inclined plane spotting.

b. Flank spotting instrument, M1.—This instrument was designed to provide a simple observing instrument which would enable the flank observer to spot in the inclined plane (O_1–O_2–T, fig. 69), and provides a means of determining the angles ϵ_m and θ, for use with the rule.

(1) The instrument (fig. 70) consists of a tripod, base, instrument proper, and telescope. The telescope rotates around two axes perpendicular to each other, one motion

being in the vertical plane of the ϵ_m scale (perpendicular to the spotting base line O_1–O_2), the second motion being in the inclined plane. The ϵ_m and the θ scales with their pointers provide means for measuring the amount of angular movement in these planes imparted to the telescope. For orienting purposes, a clamping knob is provided so that the instrument proper may be clamped to the base with the index of the ϵ_m scale at the zero setting. The telescope is an elbow type. The reticle is equipped with a mil scale.

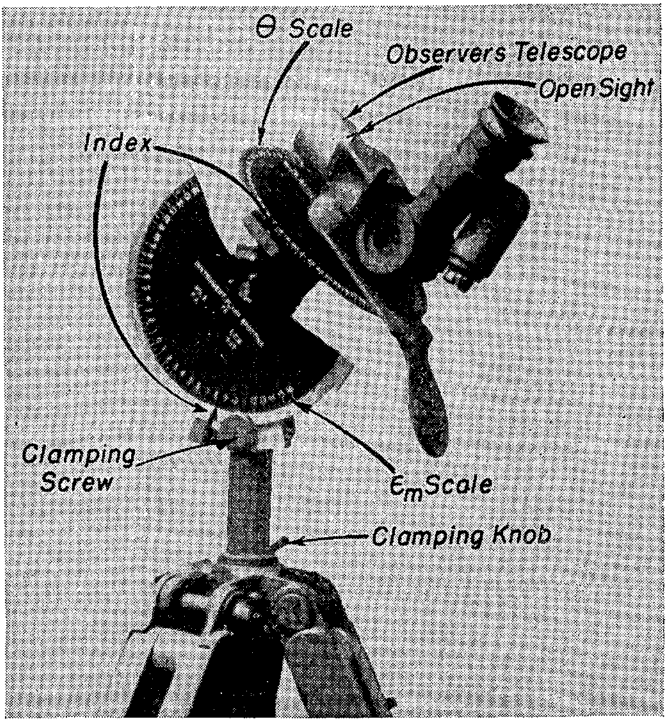


FIGURE 70.—Flank spotting instrument, M1.

(2) The instrument is set up and oriented as follows: Set up and level the tripod. Screw the base firmly in position.

Place the instrument proper on the vertical shaft of the base. Insert the elbow telescope in the bracket and tighten the clamp screws. Set the ϵ_m mil scale so that the zero mil graduation is opposite the pointer and clamp in position. This places the θ scale in a horizontal position so that it can be used to set off azimuths. Rotate the instrument proper on its vertical shaft until the pointer "To battery" on the θ scale is pointing in the direction of the O_1 (battery) station. Then clamp the instrument proper to its base by means of the clamping knob. This clamps the ϵ_m scale in a plane perpendicular to the base line. Loosen the ϵ_m scale clamping screw. The instrument is now oriented and ready for operation.

(3) For operation two men are required, an observer and a reader. The observer tracks the target by a combination of the two motions of rotating the main telescope axis in the plane perpendicular to the base line and sweeping the line of sight of the telescope in the slant plane. Both the observer and reader wear head sets connected in parallel to the range officer at the battery. When firing is about to start, the observer tracks the target and the reader continuously announces the instantaneous values of ϵ_m and θ as read from the proper scales. The observer keeps the target centered on the cross hairs of the telescope and, as soon as the bursts appear, announces the deviations of the bursts indicated by the mil values on the horizontal cross hair scale. From time to time, the reader may announce new values of ϵ_m and θ choosing his times so as not to interfere with the calling of the deviations.

c. Flank spotting rule, M1.—(1) This instrument (see fig. 71) consists of a circular base, a center disk on which is engraved an altitude scale. Around this disk is a movable ring on which is a base line scale and an ϵ_m scale; around this is another movable ring on which is a θ scale; around this is a fixed ring on which is the *C* scale. Covering the whole is a xylonite cover containing a duplicate of the *C* scale and an index line. All of the scales are logarithmic.

(2) Operation of the rule: Set the base line (*b*) opposite the altitude (*H*) of the target. Set the index of the θ scale opposite the value of ϵ_m. These latter two values are tele-

phoned by the reader at the flank station. Set the index on the top scale (xylonite) to the value of θ and read the correction factor (*C*) on the *C* scale under the index line, or read the *dH* correction in yards under the deviation on the top scale. These instructions are printed on the rule.

FIGURE 71.—Flank spotting rule, M1.

■ 196. THEODOLITE, PH–BC–33.—*a.* An analysis of the effectiveness of antiaircraft fire requires accurate determination, in three dimensions, of the positions of the bursts with respect to the target. "Camera spotting" is accomplished by photographing the target and bursts simultaneously with two synchronized motion-picture cameras (recording theodolites, fig. 72), set up at the ends of a surveyed base line. One recording theodolite (battery camera) is located at the battery and the lateral and vertical deviations are obtained by direct reading from its film. The other (flank camera) is located at a distant station and from its photographic data together with that of the "battery camera," the range deviation is obtained. In addition to the photographic record of the position of the bursts with respect to the target, each frame of the film bears a photographic record of the azimuth of the target in mils, the angular height in mils, a reference counter which indicates the instant of time of exposure, and serial number of the theodolite. The various angles necessary for the solution of linear deviations are thus recorded on each frame of the film.

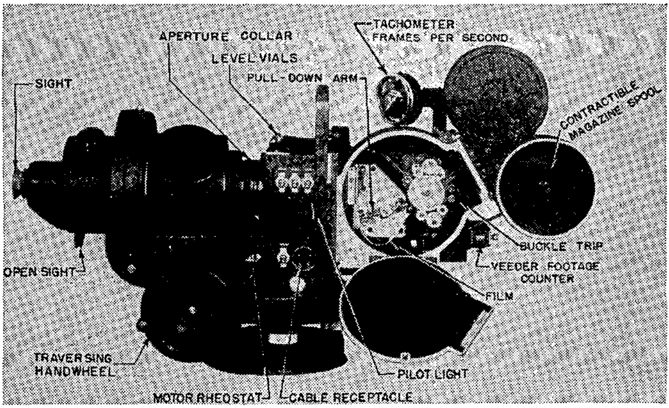


FIGURE 72.—Recording theodolite, PH–BC–33.

b. The battery and flank theodolites are identical. No tripods are furnished for the instruments. Pier mounts, preferably large iron pipes with flanged tops and set in concrete bases, must be constructed locally. The azimuth and angular height readings, in mils, are read from counters. A third counter, the time-interval counter, is located adjacent to the internal azimuth and angular height counters. Its reading increases normally one unit per second.

c. The film window in each theodolite has a peculiar form due to the presence of three projections or indicators which form shadows on the film. Two of these indicators are vertical and one is horizontal. The intersection of the vertical line through the two vertical indicators and the line through the horizontal indicator is the optical axis of the theodolite, and where the target's image should be recorded. When the target's image cannot be seen, all measurements to the bursts are taken from this intersection. The angular distance between the horizontal edges of the two vertical indicators is exactly 100 mils.

d. The time counter in each theodolite is actuated by a pulsating current through a solenoid. The current to operate the solenoid is furnished by a 12-volt storage battery located at each theodolite. A time-interval device (par. 197) operates a relay at each instrument which turns the operating current for the time counter on and off.

■ 197. **Time Interval Device, PH–103.**—This mechanism is designed to furnish electrical impulses at definite intervals of time. It is adjustable from about 32 to 75 impulses per minute and has an allowable variation of ±5 percent of the time interval. It is usually adjusted to 60 impulses per min-

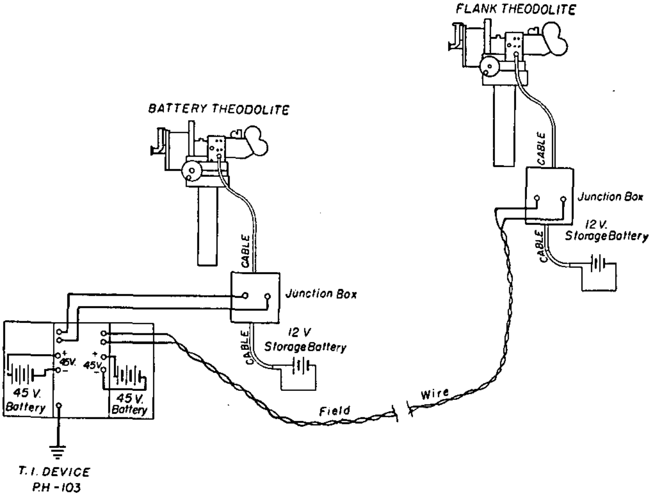


Figure 73.—Electrical connections, PH–BC–33 and T. I. device, PH–103.

ute. The impulses are created by the action of two slow acting relays which require about 65 milliamperes to operate. Figure 73 shows the electrical connections of the time interval device, PH–103 and the theodolites, PH–BC–33. Included on the switchboard of the instrument are connections for the leads from the junction boxes of the two theodolites; connections for the two 45-volt batteries; and a ground connection. A rheostat is provided for regulation of the line current. The relays at the theodolites operate on about 10 milliamperes. A rheostat is provided for regulating the number of impulses per minute. Switches and a milliameter

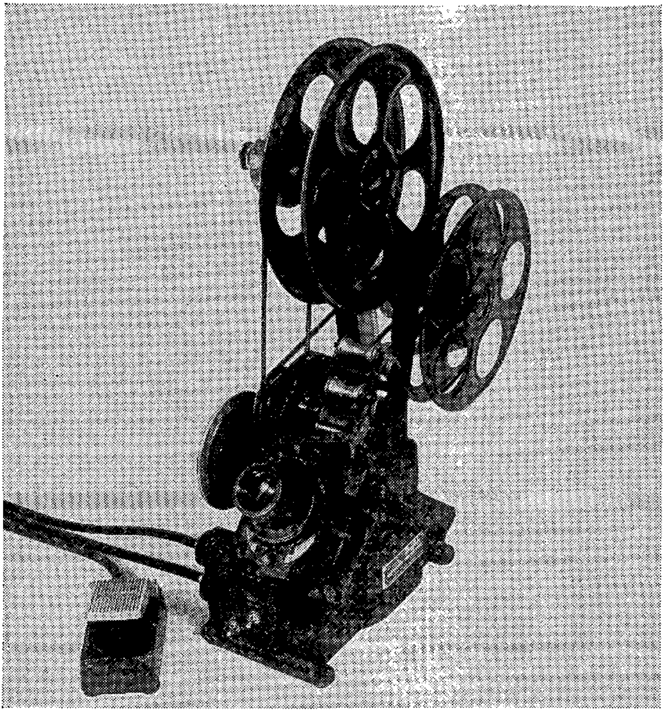


FIGURE 74.—Film viewer, PH–97.

are provided for testing for opens or shorts in the circuits. The ground test switch can be utilized to synchronize the time counters of the theodolites. Operating the ground test switch to the O_1 side will advance the counter in the O_1 theodolite one interval. Likewise, operating the ground test switch to the O_2 side will advance the counter in the O_2 theodolite one interval. Pushing the T. I. short button will advance both counters one interval each time. The T. I. device is started by turning the switch marked "T. I. START." It will function on one 45-volt battery by jumpering the 45-volt terminals on the board in parallel.

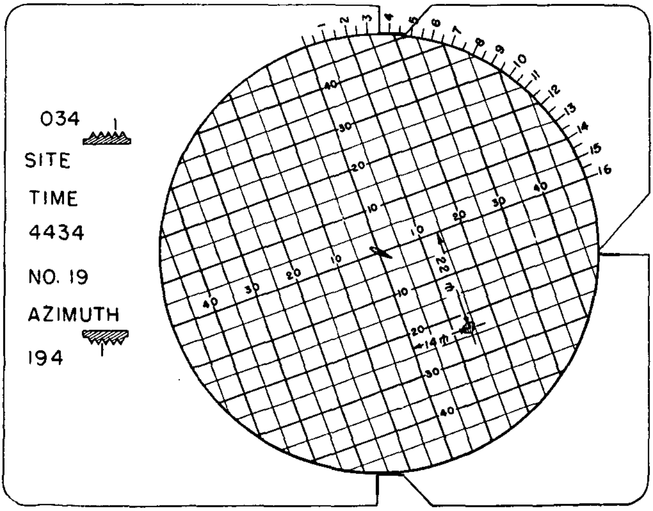


FIGURE 75.—Reticle of eyepiece, film viewer, PH–97.

■ 198. **FILM VIEWER, PH–97.**—*a.* The exposed film is developed and placed on reels for examination. A modified commercial film viewer and editing machine is used to read the deviations of the bursts from the target directly from the film. Figure 74 shows the film viewer, PH–97.

b. A different eyepiece assembly from that shown in the figure is used. Figure 75 shows the reticle of the eyepiece assembly. It can be adjusted laterally and vertically so that the center of the grid can be accurately superimposed on the target (or the center of the film frame if the target is not visible). The eyepiece can be rotated to set off the angular height of the target, as registered by the elevation counter on the left of the film frame, without removing the eye from the eyepiece. The deviations are read from the grid on the reticle.

c. The film viewer is equipped with a shutter so that distinct images of each frame are seen while the motor is running. Any particular frame can be examined for any length of time without danger of burning the film. The speed of the operating motor is adjustable and the motor is reversible. There is a foot switch which includes a rheostat for starting and stopping the motor and controlling the speed. There is also a toggle switch for operating the motor at constant speed.

■ 199. SPOTTING SET, PH–32.—*a.* This set, consisting of the recording theodolite, PH–BC–32, time interval device, projector, screen, combination rewinder and splicer, and spare reels, is still used in the service.

b. The recording theodolite, PH–BC–32 is similar to the one described in paragraph 196. The major differences are the operating switches are arranged differently, the camera does not have all of the refinements and safety devices of the PH–BC–33, the time counter is operated by the line current from the T. I. device, and only one ray filter is furnished.

c. The time interval device is a clock driven metronome. The current from the T. I. device actuates the counters in the theodolites. The electrical connections are different from those shown in figure 74. For further information, see the wiring diagram in the box containing the T. I. device.

d. The film is viewed by projecting it on a special grid screen which can be rotated to the angular height of the target as registered by the counter on the left of the film. The projector is hand-operated.

SECTION IV

LEWIS CHART

■ 200. GENERAL.—*a*. The Lewis chart is a nomogram furnished to make possible the rapid and accurate determination of trial shot data and of corrections based on preparatory fire. It is practically universal in application for all problems relating to preparatory fire for antiaircraft artillery. It is essentially a graphical representation of the law of sines used in the solution of triangles.

b. The problems relating to trial fire which may be solved by use of this chart are as follows:

(1) Knowing the horizontal range, azimuth, and altitude of the *TSP* from the battery position O_1 and the length and azimuth of the base line, it solves the azimuth and angular height of the *TSP* from the distant station O_2.

(2) Knowing the lateral and vertical deviations of the trial shots from O_1, and either the lateral deviations from O_2, or the altitudes of the bursts as measured at O_1, the center of burst *CB* may be located with respect to the *TSP* and the horizontal range O_1, to *CB* determined. This horizontal range is later used to plot the *CB* on the trial shot chart.

■ 201. THEORY.—*a*. In any triangle (fig. 76), the relation between the angles and the sides opposite them is given by the law of sines, which is—

$$\frac{a}{c}=\frac{\sin A}{\sin C} \qquad (1)$$

But $C=180°-(A+B)$, or

$\sin C=\sin (A+B)$, and equation (1) may be written

$$\frac{a}{c}=\frac{\sin A}{\sin (A+B)} \qquad (2)$$

Expressing equation (2) in logarithms, it becomes as follows:

$$\log a-\log c=\log \sin A-\log \sin (A+B) \qquad (3)$$

b. (1) The Lewis chart and its log range scale serve to solve equation (3). The chart gives the value of the right-hand side of the equation and the log range scale gives the value of the left-hand member. Using the chart and range scale together, we may solve equation (3) when any three of the four elements are known.

(2) To obtain a solution of the right-hand member of equation (3), the Lewis chart bears a group of curves which are graduated according to the size of angle *A*. These curves are plotted with angle *B* as abscissae and the corresponding value of the expression log sin *A*—log sin (*A*+*B*) as ordinates. (See fig. 78) When the values of angles *A* and *B* are known, the value of log sin *A*—log sin (*A*+*B*) may be scaled from the chart.

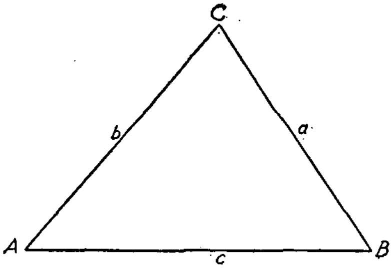


FIGURE 76.—Triangle

Conversely, when the values of angle *B* and the expression log sin *A*—log sin (*A*+*B*) are known, angle *A* is found by determining the curve which passes through the point whose abscissa is angle *B* and whose ordinate is equal to log sin *A*—log sin (*A*+*B*). Thus, in figure 78, if *B*=900 mils, and *A*=1,000 mils, the value of log sin *A*—log sin (*A*+*B*) is given on the chart as the vertical distance from the zero ordinate line to the point where the curve corresponding to angle *A* intersects the vertical line whose abscissa equals angle *B*.

(3) The log range scale furnished with the Lewis chart gives a means of obtaining the value of log *a*—log *c*. The scale is graduated according to ranges and the divisions are plotted logarithmically to the same scale as the ordinate scale of the Lewis chart. The distance between any two graduations represents the difference between the logarithms of the two ranges. Hence if *c*=6,000 and *a*=5,220, log *a*—log *c* is the vertical distance between the two graduations of the range scale as shown in figure 77, and is a negative quantity.

c. The purpose of the chart now becomes apparent. It may be used to solve for one of the four elements (side *a*, side *c*, angle *A*, or angle *B*) when the other three are known. The method of solving is illustrated by the following problems:

(1) *Problem 1.*

Given: $c=6{,}000$ yards
$a=5{,}220$ yards
Angle $B=900$ mils

What is the value of angle *A*?

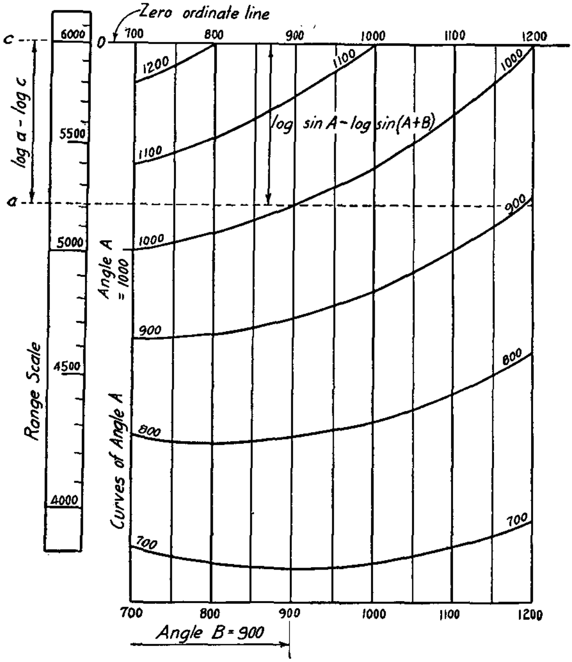


FIGURE 77.—Elements of the Lewis chart.

On the vertical line whose abscissa is 900 mils (angle *B*), measure down from the zero ordinate line a distance equal to log *a*—log *c* which is obtained from the range scale. The value of angle *A* is found to be equal to 1,000 mils.

(2) *Problem 2.*

Given: c=6,000 yards
Angle B=900 mils
Angle A=1,000 mils

What is the value of side a?

Determine the intersection of the vertical line whose abscissa equals angle B and the curve for angle A. Measure the vertical distance between this point of intersection and the zero ordinate line. Measure down from the 6,000-yard graduation on the range scale an equal amount and read the value of side a to be 5,220 yards.

d. In figure 77, the range scale is shown with the chart to clarify the discussion of its use. It is placed at the side of the chart so that no portion of the chart will be obscured. In practice, however, the 1,600-mil scale is placed on either side of the chart and the range scale is constructed on a separate piece of paper. In solving a triangle, the range scale is placed on the chart with its reading edge along the vertical line whose abscissa is angle B. The range scale is moved up or down until the zero ordinate line intersects the range scale at the graduation corresponding to side c. If angle A is known, then the length of side a may be read directly from the range scale at the point where the curve for angle A crosses the reading edge. Conversely, if side a is known, then the value of angle A is read, interpolating between curves, if necessary, opposite the graduation of the range scale corresponding to side a.

e. In order that this chart may be used to solve any triangle, the following general rules must be observed:

(1) In any solution, the data pertain to two angles and two sides of a triangle. The two angles include one of the two sides and the two sides include one of the two angles.

(2) The angle included between the two sides must be used as the abscissa on the chart.

(3) The range scale must be placed on the vertical line corresponding to this abscissa with the zero ordinate line of the chart intersecting the range scale at the graduation corresponding to the side included between the two angles.

■ 202. DESCRIPTION.—*a.* To insure accuracy and limit sections to a convenient size, the Lewis chart is issued in six sections. An overlap has been provided on each section. One section (2–s) of the Lewis chart with a log range scale is inserted in the manual opposite this page for the use of students in solving problems. The log range scale should be cut off and carefully pasted end to end in the proper order before attempting to use it in solving problems. The determination of trial fire corrections is made on a very small area of the particular section used.

b. For convenience in solving right triangles, that is, to determine the angular height when horizontal range and altitude are known or to determine horizontal range when angular height and altitude are known, a scale, called the 1,600-mil scale, is placed on each section of the chart. The scale is in two sections, one section on the right and one section on the left side of each section of the chart. (See chart facing page 218.) In reality, these scales are representations of the ordinate line of the chart when the abscissa (the angle included between the two sides) is 1,600 mils. One section of the scale represents the part above the zero ordinate line and the other the part below that line. If the range scale is placed on the proper section of the 1,600-mil scale with the horizontal range opposite the 800-mil graduation, the angular height may be read opposite the graduation corresponding to the altitude or the altitude may be read opposite the graduation corresponding to the angular height. Use of the 1,600-mil scale is illustrated in the following problem:

Given: $H=4{,}000$ yards
$R=5{,}200$ yards

Determine ϵ. Since R is greater than H, ϵ will be less than 800 mils; hence, use the section of the 1,600-mil scale reading down from 800 mils (on left side of chart). Place the range scale on the 1,600-mil scale with 5,200 yards opposite 800 mils. Opposite 4,000 yards on the range scale, ϵ is found to be equal to 667 mils.

c. In order to simplify the conversion of azimuths into angles used on the chart and of angles obtained from the chart into azimuths, two sets of numbers are used in graduating the curves and vertical lines of the chart. Each numbered curve and line bears two numbers. The upper set of figures on the vertical lines and the lower set of figures on the curves are the true angles. The other figures are the supplements of these angles. The utility of this method of graduation is illustrated in figure 78.

The O_1 and O_2 stations are located as shown in figure 78 with T representing the horizontal projection of the *TSP*. The length of the base line (O_1–O_2) is known as well as the horizontal range to the *TSP* (O_1–T). The azimuth of the base line and the azimuth of the *TSP* from O_1 are known. The interior angle at O_1 (O_2–O_1–T) is found by subtracting the azimuth of the base line (N–O_1–O_2) from the azimuth of the *TSP* (N–O_1–T). Using the Lewis chart with the double set of numbers, the angle (B–O_2–T) is determined. Use the exterior angle (B–O_2–T) at the left end of the base line, never the interior angle. Thus the rules (par. 203) hold in all cases, thereby eliminating sources of errors. To convert angle (B–O_2–T) into azimuth, it is necessary to add the azimuth of the base line (N–O_1–O_2) to angle (B–O_2–T).

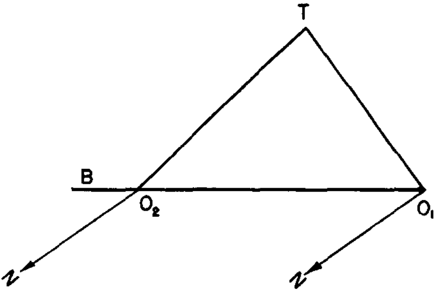


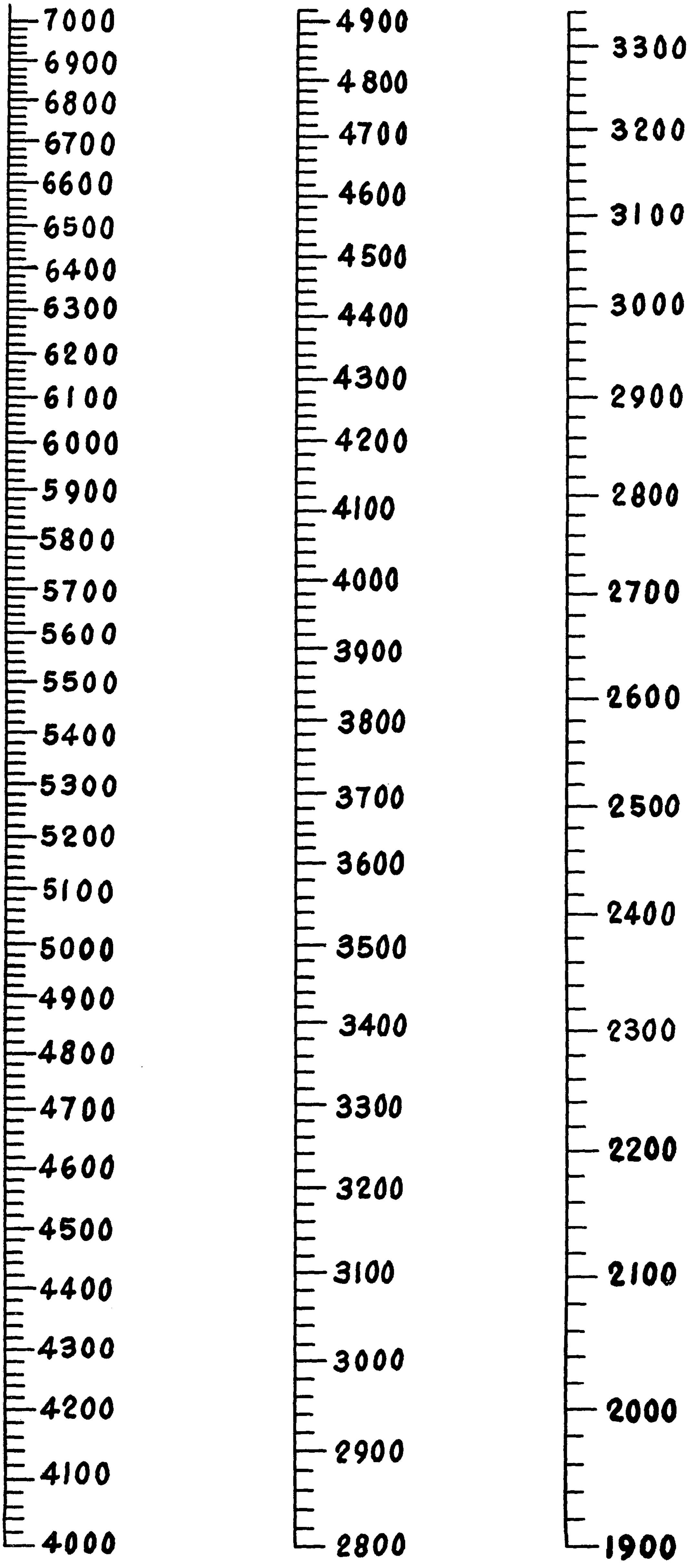
FIGURE 78.—Position sketch.

■ **203. RULES FOR OPERATION.**—*a*. When O_1 is on the right, subtract the azimuth of the base line from the azimuth of the *TSP* to determine the angle B with which to enter the chart.

b. When O_1 is on the left, subtract the back azimuth of the base line from the azimuth of the *TSP* to determine the exterior angle B with which to enter the chart.

c. The upper numbers are used when the included angle is on the right-hand end of the base line.

d. The lower numbers are used when the included angle is on the left-hand end of the base line.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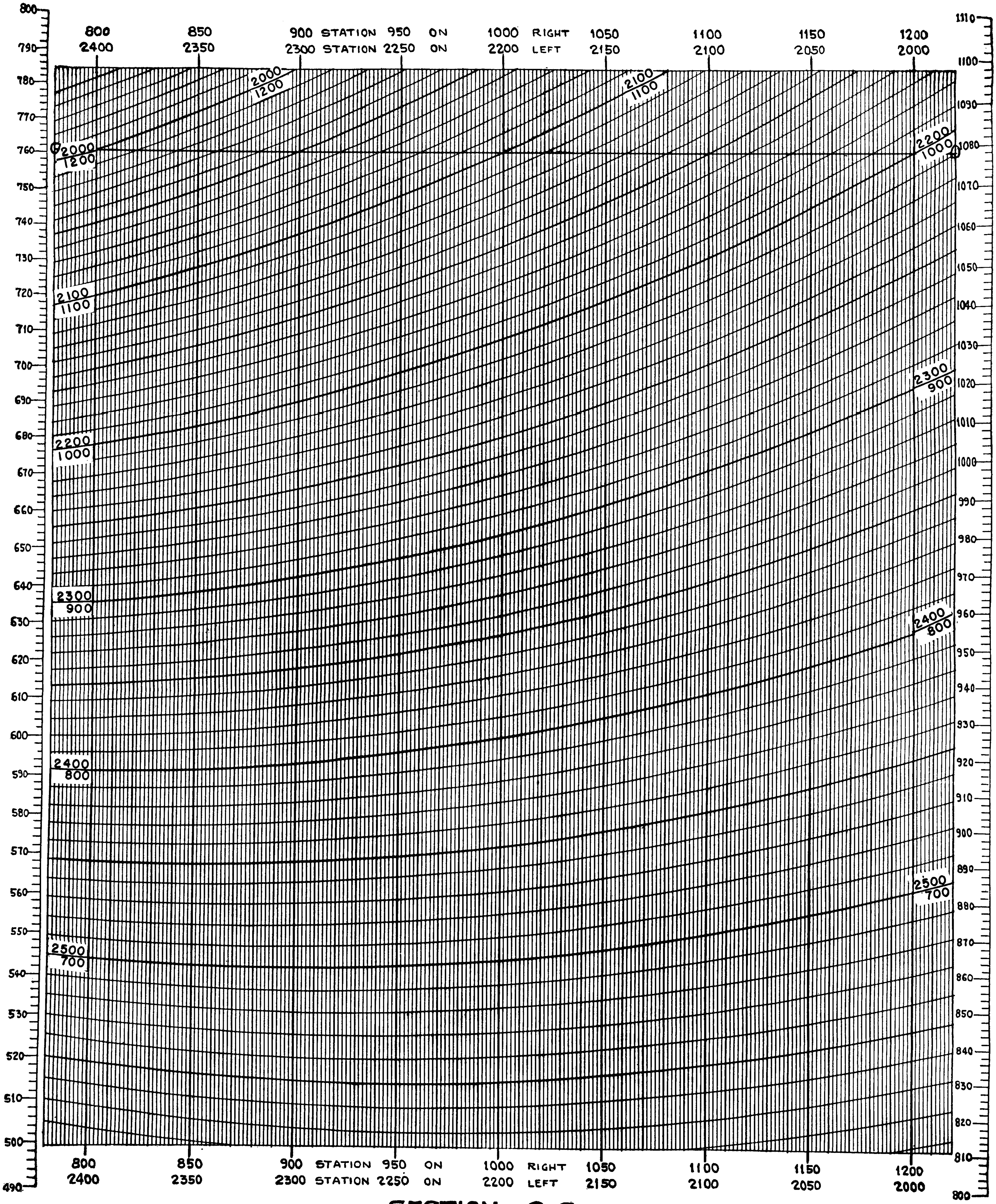
800 STATION 850 900 950 ON 1000 RIGHT 1050 1100 1150 1200
2400 STATION 2350 2300 2250 ON 2200 LEFT 2150 2100 2050 2000
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2300 900
2400 800
2500 700

SECTION 2-S

e. When O_1 is on the right, add the azimuth of the base line to the angle read on the Lewis chart in order to convert it to the azimuth of the *TSP* from O_2.

f. When O_1 is on the left, add the back azimuth of the base line to the angle read on the Lewis chart in order to convert it to the azimuth of the *TSP* from O_2.

g. In plotting the center of burst on the Lewis chart, a right deviation is added and a left deviation is subtracted from the respective *A* and *B* angles.

NOTE.—For a complete example showing the use of the Lewis charts, see paragraph 248.

SECTION V

CRICHLOW SLIDE RULE

■ 204. DESCRIPTION.—*a.* The Crichlow slide rule is a circular slide rule consisting of a series of concentric circular logarithmic scales used primarily for the solution of triangles. It has two arms, a long one, "L", and a short one, "S", which are pivoted at the center. The two arms are set with a certain angle (which represents a logarithmic quantity) between them. A flat spring at the pivot holds the arms at the angle set. Mathematical calculations are made by positioning the arms. (See fig. 79.)

b. The outside scale of the Crichlow slide rule is a 6,400-mil protractor. It was used in the construction of the rule and was left on the perimeter for convenience. All of the other scales are logarithmic and are lettered successively inward from A to E, as follows:

Name of scale	*Used with elements*
Scale A: $1/\sin \epsilon$	ϵ, *H*, and *D*
Scale B: $1/\cos \epsilon$	ϵ, *R*, and *D*
Scale C: Tan ϵ and cot ϵ	ϵ, *R*, and *H*
Scale D: $1/\sin$ O_1, O_2, or O_1+O_2	O_1, O_2, (O_1+O_2), base line.
Scale E: Logarithmic scale of numbers	Used with values obtained from scales *A, B, C,* and *D,* to solve triangles.
Scale F: Logarithmic scale of squares	Used with values on scale E.

From the instructions on the face of the slide rule, it will be noted that the rule may be used to solve both right triangles and oblique triangles.

■ 205. THEORY.—*a*. The following trigonometric formulas apply to the right triangle shown on the upper part of the Crichlow slide rule (fig. 79):

$$\left.\begin{array}{l}\text{Sin } \epsilon = H/D;\ H = D \sin \epsilon;\ D = H/\sin \epsilon \\ \text{Cos } \epsilon = R/D;\ R = D \cos \epsilon;\ D = R/\cos \epsilon \\ \text{Tan } \epsilon = H/R;\ H = R \tan \epsilon;\ R = H/\tan \epsilon\end{array}\right\} \quad (1)$$

In each of the above equations, three elements of the right triangle are used. If any two are known, the right triangle may be completely solved. The Crichlow slide rule furnishes the scales necessary for performing the mathematical operations required for the solution.

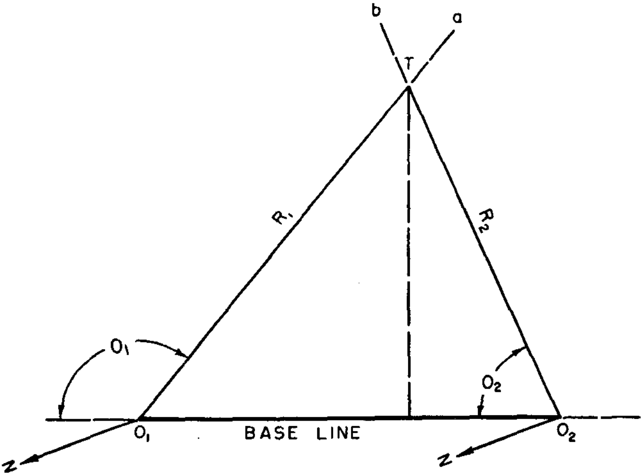
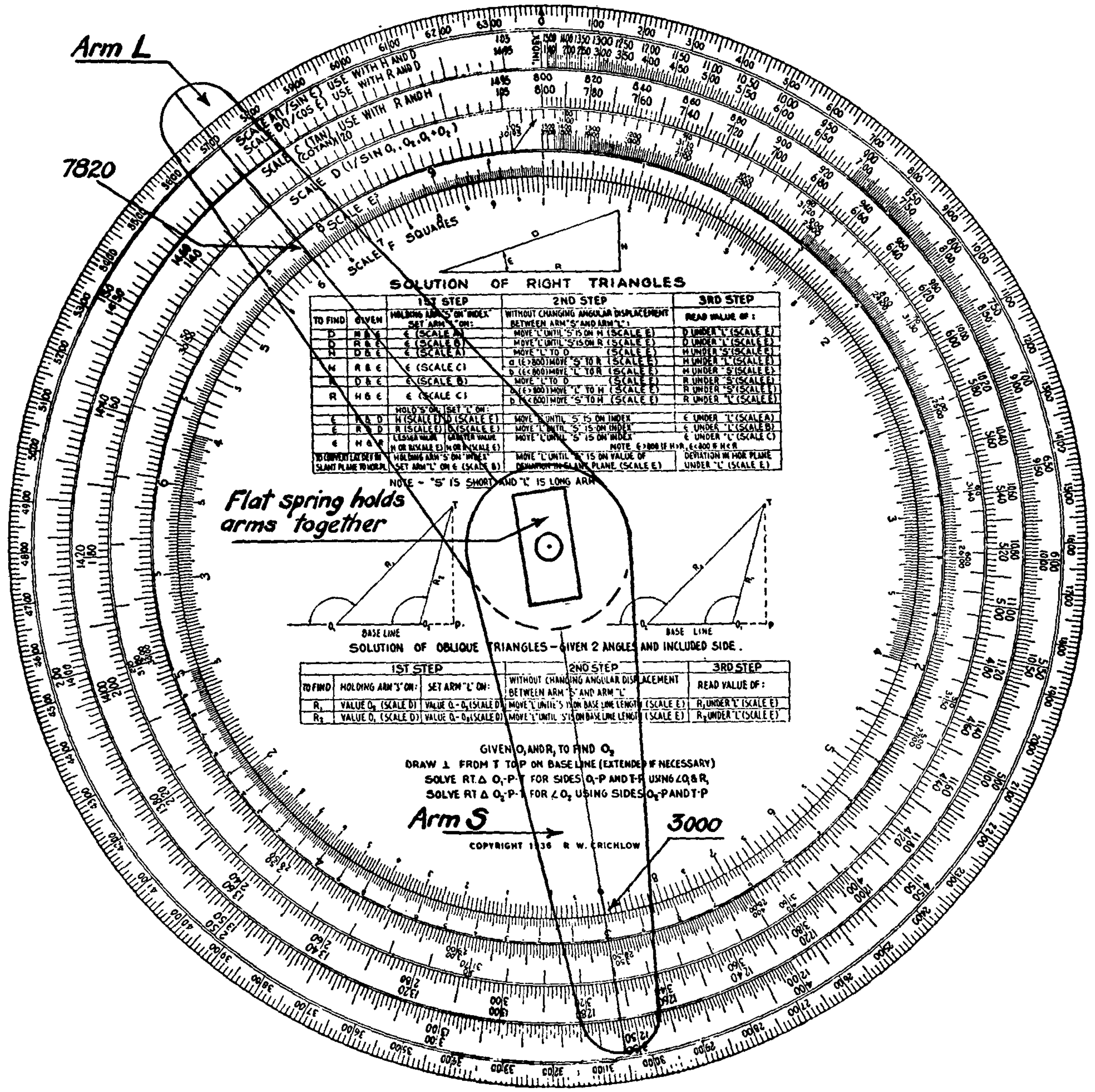


FIGURE 80.—Oblique triangle.

b. The oblique triangle is shown in figure 80. With certain exceptions, problems pertaining to the oblique triangle can be solved on the Crichlow slide rule by application of the law of sines. The exceptions are explained in *f* below.



SOLUTION OF RIGHT TRIANGLES

TO FIND	GIVEN	1ST STEP		2ND STEP	3RD STEP
		HOLDING ARM "S" ON "INDEX" SET ARM "L" ON:		WITHOUT CHANGING ANGULAR DISPLACEMENT BETWEEN ARM "S" AND ARM "L":	READ VALUE OF:
D	H & ε	ε (SCALE A)		MOVE "L" UNTIL "S" IS ON H (SCALE E)	D UNDER "L" (SCALE E)
D	R & ε	ε (SCALE B)		MOVE "L" UNTIL "S" IS ON R (SCALE E)	D UNDER "L" (SCALE E)
H	D & ε	ε (SCALE A)		MOVE "L" TO D (SCALE E)	H UNDER "S" (SCALE E)
H	R & ε	ε (SCALE C)		a (ε>800) MOVE "S" TO R (SCALE E) b (ε<800) MOVE "L" TO R (SCALE E)	H UNDER "L" (SCALE E) H UNDER "S" (SCALE E)
R	D & ε	ε (SCALE B)		MOVE "L" TO D (SCALE E)	R UNDER "S" (SCALE E)
R	H & ε	ε (SCALE C)		a (ε>800) MOVE "L" TO H (SCALE E) b (ε<800) MOVE "S" TO H (SCALE E)	R UNDER "S" (SCALE E) R UNDER "L" (SCALE E)
		HOLD "S" ON:	SET "L" ON:		
ε	H & D	H (SCALE E)	D (SCALE E)	MOVE "L" UNTIL "S" IS ON INDEX	ε UNDER "L" (SCALE A)
ε	R & D	R (SCALE E)	D (SCALE E)	MOVE "L" UNTIL "S" IS ON INDEX	ε UNDER "L" (SCALE B)
ε	H & R	LESSER VALUE H OR R (SCALE E)	GREATER VALUE H OR R (SCALE E)	MOVE "L" UNTIL "S" IS ON INDEX NOTE ε>800 IF H>R, ε<800 IF H<R	ε UNDER "L" (SCALE C)
TO CONVERT LAT DEF IN SLANT PLANE TO HOR PL		HOLDING ARM "S" ON "INDEX" SET ARM "L" ON ε (SCALE B)		MOVE "L" UNTIL "S" IS ON VALUE OF DEVIATION IN SLANT PLANE (SCALE E)	DEVIATION IN HOR PLANE UNDER "L" (SCALE E)

NOTE — "S" IS SHORT AND "L" IS LONG ARM

SOLUTION OF OBLIQUE TRIANGLES — GIVEN 2 ANGLES AND INCLUDED SIDE.

TO FIND	1ST STEP		2ND STEP	3RD STEP
	HOLDING ARM "S" ON:	SET ARM "L" ON:	WITHOUT CHANGING ANGULAR DISPLACEMENT BETWEEN ARM "S" AND ARM "L"	READ VALUE OF:
R_1	VALUE O_2 (SCALE D)	VALUE $O_1 - O_2$ (SCALE D)	MOVE "L" UNTIL "S" IS ON BASE LINE LENGTH (SCALE E)	R_1 UNDER "L" (SCALE E)
R_2	VALUE O_1 (SCALE D)	VALUE $O_1 - O_2$ (SCALE D)	MOVE "L" UNTIL "S" IS ON BASE LINE LENGTH (SCALE E)	R_2 UNDER "L" (SCALE E)

GIVEN O_1 AND R_1 TO FIND O_2
DRAW ⊥ FROM T TO P ON BASE LINE (EXTENDED IF NECESSARY)
SOLVE RT. △ O_1-P-T FOR SIDES O_1-P AND T-P USING ∠O_1 & R_1
SOLVE RT △ O_2-P-T FOR ∠O_2 USING SIDES O_2-P AND T-P

FIGURE 79.—Crichlow slide rule.

c. (1) Most of the oblique triangles encountered in antiaircraft position finding are associated with the use of azimuths. Hence, as a matter of convenience, it is desirable to use the exterior angle at the left end of the base line and the interior angle at the right end of the base line when solving triangles of this kind.

(2) In figure 80, by the law of sines:

$$\frac{R_1}{\sin O_2}=\frac{\text{base line}}{\sin O_1TO_2} \qquad (2)$$

If the figure is reversed by placing O_1 on the right and O_2 on the left, equation (2) is still true. From trigonometry, the sine of an angle is equal to the sine of the supplement of the angle. Therefore, either the exterior angle or the interior angle at the left end of the base line may be used in equation (2). Angle O_1TO_2 is called the "target angle" and in this discussion is designated as the angle T. By geometry, the angle T is equal to the difference between the exterior angle at the left end of the base line and the interior angle at the right end of the base line. It can be seen that equation (2) has four quantities: R_2, base line, O_1 angle, and the target angle T. If three are known, we can solve for the fourth. Since the target angle T is equal to the difference between the O_1 angle and the O_2 angle (exterior on left and interior on right), the O_1 angle can be determined when the target angle and the O_2 angle are known.

(3) Likewise we can set up another equation using the law of sines:

$$\frac{R_2}{\sin O_1}=\frac{\text{base line}}{\sin O_1TO_2} \qquad (3)$$

d. Equations (2) and (3) can be used to solve for O_1 and O_2 data for trial shot problems, and to determine the range to the center of burst after the trial shots have been fired. For use of the slide rule for this purpose, see paragraph 249.

e. The above equations (2) and (3) may be used with but slight modification when it is desired to use the interior angles at both O_1 and O_2.

From geometry: $\angle O_2Ta=O_1+O_2$ (interior angles).

From trigonometry: The sine of an angle=the sine of the supplement of the angle.

O_1+O_2 is the supplement of angle O_1TO_2.

By substitution in equations (2) and (3) (using interior angles at O_1 and O_2),

$$\frac{R_2}{\sin O_1}=\frac{\text{base line}}{\sin (O_1+O_2)} \tag{4}$$

$$\frac{R_1}{\sin O_2}=\frac{\text{base line}}{\sin (O_1+O_2)} \tag{5}$$

f. When R_1, base line, and O_1 angle are the known values and O_2 angle is the unknown (or when R_2, base line, and O_2 angle are known and O_1 angle is unknown), it may be seen from equations (2), (3), (4), and (5) that the value of O_2 (or O_1) angle cannot be determined by applying the law of sines. However, a solution can be obtained by dividing the oblique triangle into two right triangles and solving each right triangle in turn by the formulas given for the solution of right triangles.

g. Refer to the slide rule, figure 79. Scale D is a scale of logarithms of the reciprocals of the sines. Notice that it is similar to scale A except that it is graduated for values of angles from 14 mils to 3,186 mils, instead of from 105 mils to 1,600 mils.

■ 206. OPERATION.—The operation of the Crichlow slide rule can best be explained by the solution of a number of type examples.

a. To multiply two numbers, 2 times 3; set the arm "S" on the index and the arm "L" on the number 3 on scale E. The angle between the arms is proportional to the logarithm of 3 from the construction of the rule. Then, with the two arms clamped together by the flat spring at the intersection of the arms, move the arms until the arm "S" coincides with the graduation for 2 on scale E. The arm "L", having moved forward from the index an angular amount which is proportional to the sum of the logarithms of the numbers, 2 and 3, will indicate the product of the two numbers, or 6.

b. To determine the square of a number, set either of the arms to the number on scale E and read the square directly on scale F. To determine the square root, reverse the operation.

c. To determine the slant range *D*, having given the horizontal range $R=6{,}500$ yards, and the angular height, $\epsilon=750$ mils:

$$D=\frac{1}{\cos\epsilon}\times R$$

First step: Place the arm "S," on the index and then set the arm "L" on 750 on scale B. The angle between the arms is then proportional to the logarithm of the reciprocal of the cos 750 mils.

Second step.—Without changing the angle between the arms, move the arm "L" until the arm "S" is over the graduation for 6,500 on scale E. The logarithm of 1/cos 750 mils has then been added to the logarithm of 6,500, and the value of the slant range *D* appears under the index of arm "L." In this example, *D* is equal to 8,760 yards. Scales A and C are used in a similar manner with other elements of right triangles.

d. A type example illustrating the determination of the O_1 and O_2 data for trial shot problems is found in paragraph 249.

e. A type example illustrating the determination of horizontal range to *CB* from O_1 is found in paragraph 105*a*.

f. If the lateral deviations of the trial shots are measured in the slant plane instead of the horizontal plane, it will be necessary to convert the deviations into values in the horizontal plane. Conversion charts have been constructed for this special purpose. The value of the deviation in the slant plane divided by the cosine of the angular height is the deviation in the horizontal plane. The conversion is a simple operation on the Crichlow slide rule.

First step.—Hold arm "S" on the index and set the arm "L" on the value of the angular height on scale B.

Second step.—Without changing the angle between the arms, move the arm "L" until the arm "S" is on the value of the lateral deviation in the slant plane on scale E.

Third step.—Read the value of the deviation in the horizontal plane under the index on the arm "L" on scale E.

g. The Crichlow slide rule can be used in any mathematical operation requiring the solution of right and oblique triangles. Scale E is very convenient for performing ordinary multiplication and division problems. The rule will be found to be particularly useful in computing ranges and altitudes for checking the readings of stereoscopic observers within a very short time after the observations have been made.

■ 207. **Rules for Operation.**—*a.* The steps to be followed in the solution of the various problems will be found printed in tabular form on the face of each rule.

b. The successive steps to be followed in determining the O_1 and O_2 data when the O_2 angle is selected are stated below. These instructions should be placed on the back of the rule for convenient reference.

(1) Select the azimuth of the *TSP* from O_2.

(2) Make a sketch showing the relative positions of O_1, O_2, *TSP*, and lines toward North from O_1 and O_2.

(3) Subtract the azimuth of the base line from the O_2 azimuth of the *TSP* (adding 6,400 mils if necessary), if O_2 is on the left end of base line. If O_2 is on right end of the base line, subtract the back azimuth of the base line from the O_2 azimuth of the *TSP* (adding 6,400 mils if necessary).

(4) Determine the target angle T (interior angle at T) as follows:

First step		Second step	Third step
Holding arm "S" on	Set arm "L" on	Without changing angular displacement between arms "S" and "L"	Read value of
Value of base line (Scale E).	Value of R_1 (Scale E).	Set "S" on O_2 angle (Scale D).	*Target angle T under "L" (Scale D).

*Two values are indicated. See paragraph 249 for explanation of which value to select.

(5) Determine O_1 angle as follows:

(*a*) If O_2 is on the right, add the target angle to the O_2 angle.

(*b*) If O_2 is on the left, subtract the target angle from the O_2 angle.

(6) Determine azimuth of *TSP* from O_1 as follows:

(*a*) Add azimuth of base line (O_1–O_2) to the O_1 angle obtained in (5) above, if O_1 is on the right end of the base line. If O_1 is on the left end of the base line add the back azimuth of the base line to the angle obtained in (5) above.

(*b*) If the value obtained in (*a*) above is greater than 6,400, subtract 6,400.

c. The following rules are applicable when computing data to plot the *CB* on the trial shot chart:

(1) A right deviation increases both the O_1 angle and the O_2 angle.

(2) A left deviation decreases both the O_1 angle and the O_2 angle.

NOTE.—The Crichlow slide rule is being revised. The new rule will be slightly larger and the scales will be arranged in a different order. In solving problems, use the rules printed on the face of the particular slide rule.

SECTION VI

FUZE SETTERS

■ 208. **GENERAL.**—Fuze setters are devices at each gun for manually setting time fuzes on antiaircraft projectiles to the setting corresponding to the fuze range computed by the director. The fuze setter, M8, only, will be considered in this section. If other models are encountered in the service, the reader is referred to the appropriate handbook or TM 4–210 for further information. The M8 is a universal fuze setter for 3″ antiaircraft projectile. It is equipped with accessories for use when firing either powder train or mechanical fuzes or when drilling with dummy projectiles. The fuze setter, M9 pertains to 105-mm equipment.

■ 209. **DESCRIPTION.**—*a*. The fuze setter, M8, is mounted in an inclined position to the left rear and below the breech for convenience in the service of the piece. The fuze range receiver is mounted on and connected mechanically with the fuze setter. The fuze setter proper has two principal elements; the fuze-setting mechanism and the adjusting mechanism. The function of the former is to set the fuze in accordance with the setting indicated by the adjusting mechanism. The function of the latter is to adjust the setting to agree with the fuze range transmitted from the director as indicated by the electrical pointer on the receiver. Both mechanisms require manual operation. (See figs. 81 and 82.)

b. The fuze range receiver is mounted in the case in such a manner that its stator (field) may be rotated in either direction approximately 35°. The stator is rotated to effect synchronization by turning the slotted head of the shaft which protrudes into the lamp well on the right side of the receiver. The inner dial of the receiver is driven electrically by the director and indicates the computed fuze range.

c. The outer mechanical index of the receiver is geared to the adjusting mechanism and the adjusting handwheel and is, therefore, positioned at the fuze range being set by the fuze setter.

d. One turn of the setting crank causes the socket to make two revolutions. During the first revolution, the pawls in the setting ring engage the slot in (or the lug on) the body of the fuze and begin to rotate the round. During the next revolution, the adjusting ring pawls engage and position the lower cap of the fuze to the fuze range indicated on the receiver. The socket is restrained from rotation by two pawls. One is disengaged by striking the release lever adjacent to the bell mouth. This allows the setting crank to be turned in a counterclockwise direction. These pawls limit the rotation of the socket to one direction and to two complete revolutions, which will set the fuze regardless of the position of the round when inserted.

NOTE.—There is no device to hold the projectile in the fuze setter. Consequently, a cannoneer must hold the projectile by pressing with his right hand on the base of the round during the time the fuze is being set.

e. The body is supported on the case by a hinge and eyebolt. Loosening the eyebolt permits the body to be swung about, giving access to the adjusting and setting rings.

f. Illumination for matching the indices and the scale is provided by two 3 C. P., 6- to 8-volt, double contact, bayonet base lamps located in lamp wells on opposite sides of the receiver. The bell mouth is illuminated by light through a small hole from a similar lamp in a lamp well on top of the body near the upper edge. The current for these lamps is furnished by a step down transformer (115 volts to 6 volts) located in the gun junction box. The covers of the lamp wells are removed for access to these lamps.

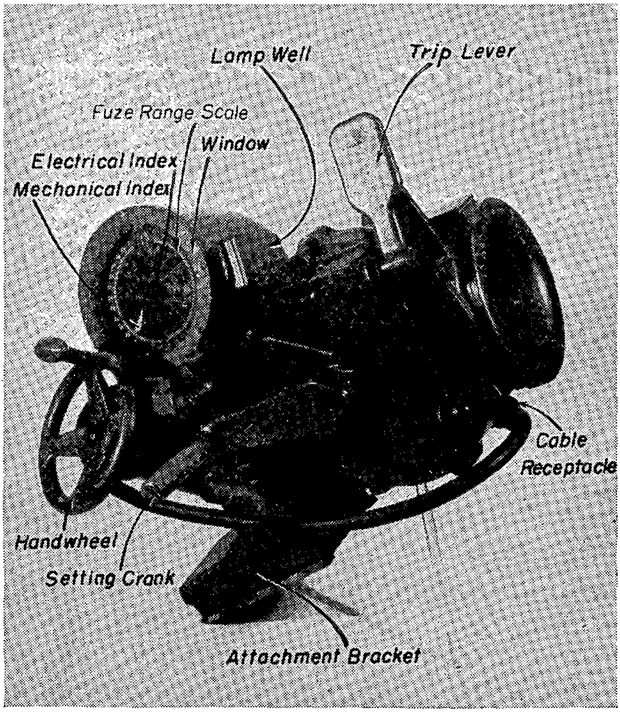


FIGURE 81.—Fuze setter, M8.

g. A 13-conductor flexible cable with a cable receptacle at one end is provided for connecting the fuze setter into the circuit of the data transmission system at the gun junction box. The conductors at the plain end of the cable are connected to the terminal block located in the recess in the lower portion of the case. This recess is closed by a plate on which is fixed a dummy receptacle for stowing and protecting the cable receptacle end of the cable when it is not connected to the gun junction box on the gun mount. For information on the wiring diagram, the reader is referred to the handbook on the M8 fuze setter.

h. An accessory chest is provided for storing extra lamps and the fuze indicator scale, adjusting rings, and setting rings which are not in use.

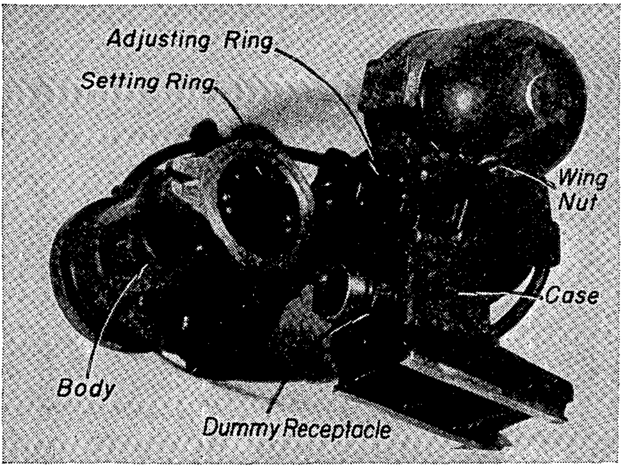


FIGURE 82.—Fuze setter, M8, showing adjusting and setting rings.

■ 210. OPERATION.—*a*. The drill is prescribed in FM 4–125. The following points in the drill should be carefully checked in order to insure proper functioning of the fuze setter.

(1) No. 4 must maintain pressure against the base of the round until No. 6 calls, "Cut."

(2) No. 4 should operate the tripping lever with a glancing slap so that it will recover and re-arm itself before No. 6 has completed a full revolution of the setting crank.

(3) No. 6 must maintain a tension on the setting crank in a counterclockwise direction so that it will start to turn as soon as the tripping lever is operated.

b. After a fuze has been set, it may be reset to any fuze range by reinserting the round and performing the ordinary procedure. As long as the round remains in the fuze setter, the fuze will change as the adjusting handwheel is turned.

c. The accurate setting of fuzes is dependent upon—

(1) Allowing the round to settle in position in the fuze setter before touching the tripping lever.

(2) Keeping the indices of the fuze indicator matched at all times while the fuze setter is in operation.

(3) Exercising care not to turn the round when removing it from the fuze setter until the round has been withdrawn sufficiently to insure that the pawls are no longer engaged with the setting elements of the fuze.

(4) Turning the setting crank until it is definitely stopped by the pawl. Care should be exercised when engaging the setting and adjusting lugs. If the setting crank is jerked too hard in the fuze setting operation or allowed to slam into the stop, the lugs on the fuze are deformed, resulting in erratic settings. The caution applies particularly to setting Mk. III Scovil fuzes.

(5) Keeping the pawls in the adjusting and setting rings lubricated and free of chips of metal, paint, or other foreign substances.

d. To set up the fuze setter, place the guides on the foot of its attachment bracket into slots in the support on the gun mount and make sure that it settles to the operating position. Remove cable receptacle from dummy receptacle and attach same to the gun junction box. Check the scale and rings installed on fuze setter to see that they conform with the ammunition to be fired.

■ 211. **Adjustments.**—The fuze setter is issued with the scale for the 21-second powder train fuze and rings for the dummy fuze installed. It will therefore be necessary to change rings, and possibly the scale, before fuzes can be set.

a. To equip fuze setter for 21-second powder train fuzes, remove rings for dummy fuze M42 by opening the body and removing screws and lock washers. Place adjusting ring marked "21 second AA fuze Mk. IIIA1" in lower portion of fuze setter. The setting ring marked "21 second AA fuze Mk. IIIA1" is placed in the body. The screw holes in these rings are differently spaced so that it is impossible to fit the rings improperly. (See fig. 82.)

b. To equip fuze setter for 30-second mechanical fuzes, remove rings and replace with rings marked "mech. time fuze M43." If a ring sticks in place after retaining screws have been removed, insert screws into tapped holes in rings and pull the rings off. In addition, the scale on fuze indicator must be replaced. Remove window on receiver, being careful not to injure the gasket. Remove the six screws and clamping ring which hold ring scale in place. Remove scale. Set 30-second scale in place with its outer rim in the groove in the bracket. Replace clamping ring and six retaining screws. Do not tighten screws but leave them loose enough to turn the scale. Place a shell in fuze setter, set fuze, and read setting as closely as possible. Insert a blunt point in the hole in scale over the zero and slide scale around under clamping ring until the value set on the fuze is opposite indicating marks on outer or mechanical index. Check with a different fuze setting. If the check is correct, tighten six retaining screws on clamping ring. Check, by operating through a complete cycle, that the dials do not bind at any place. Replace window.

c. If fuze indicator scale and actual setting of fuze do not agree, the procedure outlined in *b* above must be followed to adjust fuze indicator scale.

d. If the receiver at the fuze setter and the transmitter at the director are not synchronized, proceed as follows:

(1) In case of a small error, remove cover from lamp well on the right side of receiver and turn slotted head of protruding shaft until synchronization is accomplished. (See par. 234.) Replace cover of lamp well.

(2) In case of a large error, remove window of receiver. Loosen the three screws holding small clamping ring at center of dial. Rotate inner dial until synchronization is accomplished. (See par. 215.) Tighten the three screws holding clamping ring and replace cover.

e. For a complete discussion of trouble shooting, see section VII. The method of adjustment of synchronous units will be found in chapter 4.

■ 212. CARE AND PRESERVATION.—See FM 4–125 and manual, Fuze Setter, M8, for care and preservation of the fuze setter.

SECTION VII

DATA TRANSMISSION

■ 213. GENERAL.—The data transmission system, M4, is the standard data transmission system for antiaircraft guns.

■ 214. DATA TRANSMISSION SYSTEM, M4.—The principle of the A. C. self-synchronous data transmission system is explained in section VI, chapter 2. For further information on the data transmission system M4, see TM 4–210 or the manual, Data Transmission Systems, M3 and M4, issued with the equipment.

CAUTION: The cable connected to the gasoline electric generating unit must never be plugged into any other receptacle except the one of the main junction box marked "power plant" which is painted yellow. This power cable must never, under any circumstances, be connected to the director, to the height finder, or to the gun junction box. Failure to observe this precaution will result in burning out the synchronous transmitters and indicators in the director, height finder, and guns, and may otherwise severely damage the mechanisms in these units.

■ 215. OPERATING TROUBLES WITH PROBABLE CAUSES AND EMERGENCY CORRECTIVE ACTION.—The general procedure outlined in this section offers the quickest methods for eliminating certain difficulties that may arise in a data transmission system. However, the application of these methods will in many cases restrict the interchangeability of parts and complicate later installations of emergency cable systems. It is better practice to replace faulty equipment if possible.

Trouble	*Probable cause and remedy*
Transmitter and indicator readings do not agree. Indicators rotate in proper direction but a constant error exists between the two readings.	If an indicator is out of synchronism by 120°, it is probably due to an error in wiring, resulting from improper marking of terminals, or a mistake in following the color code in one of the cables. Check all connections to the indicator. If no errors can be found, it will be necessary to interchange the secondary leads 1, 2, 3, to terminal posts

Trouble	*Probable cause and remedy*
	2, 3, 1 or 3, 1, 2, respectively. This will not alter the direction of rotation, but will shift the index 120°. If an indicator is out of synchronism by 180°, this may also be due to an error in wiring. This error can be rectified by reversing the two primary leads 4 and 5 on their respective terminal posts. This will not alter the direction of rotation, but will shift the index 180°. If an M3 indicator is out of synchronism with its transmitter by a small constant amount, it may be adjusted by turning the black knob on the right side or the bottom of the indicator housing. (The power must be on when making this adjustment.) If it is impossible to synchronize with this adjustment, it will be necessary, in the case of the azimuth and elevation indicator, to remove the entire front cover plate. Before removing the front, set adjusting knob to its middle position. To do this, turn knob first to one end position, then count the number of turns necessary to reach the opposite end position, then turn back half this number of turns to middle position. Do not remove the smaller bezel which holds the glass to the cover, but remove the entire front cover plate, being careful not to injure the fibre gasket. Energize the indicator to help prevent the dial from turning during adjustment. Hold dial by gently pressing the fingers against it, and loosen, but do not remove, the three screws in the adapter at center of dial. The dial should now be free to rotate with respect to the armature shaft. Set dial to approximately the proper reading and tighten screws. This adjustment need not be made very accurately, since knobs for making final adjustments from the outside of the case are provided. *Turn the power off* and spin dial with the fingers to make sure that the dial has not been bent and is still free to turn. *Never do this with the power on.* Replace front cover plate. Turn the power on, vary transmitter readings, and check indicator readings at frequent intervals over one full revolution of each indicator. Final and small adjustments of the indicator readings are made by means of the adjusting knobs on the outside. If an M4 indicator is out of synchronism with its transmitter by a small constant amount, try to synchronize the indicator by adjusting shafts. If it is impossible to synchronize with adjusting shafts, set them to middle position and remove entire front cover

Trouble	*Probable cause and remedy*
	plate to gain access to the mechanism. Be careful not to injure the fibre gasket. Energize indicator to help prevent armature from turning during adjustment. Hold dial by gently pressing the fingers against it, and loosen but do not remove the three screws in adapter at center of dial. The dial should now be free to rotate with respect to the armature shaft. Set dials to approximately the proper reading and tighten screws. This adjustment need not be made very accurately since the slotted shaft ends which protrude into the cover recesses in the right and left sides of the case are provided for making the final adjustments. *Turn the power off* and spin dial with the fingers to make sure that dial has not been bent and is still free to turn. *Never do this with the power on.* Replace front cover plate. Turn the power on, vary transmitter readings and check indicator readings at frequent intervals over one full revolution of each indicator. There is no adjustment provided to electrically synchronize the elevation indicator of a height finder, T9E1 or M1. If electrical dial index does not agree with corresponding transmitter in the director, remove rear end of receiver housing by unscrewing it, back off clamping ring a little, and turn indicator case until index indicates the same elevation as the director. To synchronize the azimuth indicator electrically, the case must be open and adjustment made as described in preceding subparagraph. Small errors in the electrical synchronization of altitude transmitter with director may be compensated by means of a spot correction.
One or more indicators rotate in wrong direction.	Reverse the pair of leads involved as explained below: In the azimuth or elevation indicator M3 or M4, the terminal strip is made accessible by removing the plate held with six screws on right side of indicator housing. The fine indicator secondary leads are denoted by the numerals 1, 2, and 3. To reverse rotation, indicator leads connected to terminals 1 and 3 should be interchanged. The coarse indicator secondary leads are denoted by the numerals 6, 7, and 8. To reverse direction of rotation, indicator leads 6 and 8 should be interchanged. In the fuze indicator the terminal strip is made accessible by removing plate on which dummy receptacle is mounted. The indicator secondary leads are denoted by the numerals 1, 2, and 3. To reverse rotation,

Trouble	*Probable cause and remedy*
	indicator leads connected to terminals 1 and 3 should be interchanged. In height finder, M1, changes in transmission system wiring may be made only at the 19-pole receptacle. To reverse direction of rotation of azimuth indicator, the leads going to poles 1 and 6 must be interchanged with leads going to poles 3 and 8. Similarly, to reverse direction of rotation of elevation indicator, the leads going to poles 11 and 16 must be interchanged with leads going to poles 13 and 18. To reverse direction of rotation of height indicator in the director, the leads going to poles 9 and 19 (at the height finder) should be interchanged.
Indicators and transmitters do not remain in synchronism for a complete revolution of the dial.	If all the indicators behave similarly, the trouble is probably with the transmitter, director cable, or junction box. If not, the trouble may be due to the indicators, on-carriage wiring, gun cable, or junction box. If an indicator dial is binding at some point, it will affect the readings of all four indicators but the faulty indicator will show the greatest error. If the transmitter dial is binding at some point, its synchronization with the gearing in the director would be affected only if the transmitter dial remained stationary. If this is the case, the dial should be set to clear where it is binding and made fast to the rotor shaft. If one of the brushes on the transmitter does not make good contact with its collector ring at some point, thus opening the secondary circuit for part of a revolution, the indicators will all fall out of synchronism and remain out until the brush again makes good contact. If one of the brushes of an indicator does not make good contact with its collector ring at some point, thus opening the secondary circuit for part of a revolution, all four indicators will fall out of synchronism and remain out until the brush again makes good contact. The error of the good indicators will differ from the error of the faulty indicators in this case. The secondary circuits may be open intermittently by a loose contact at some point other than at the brushes. The effect would then be the same as if the secondary were open at the brushes. If a cable were at fault, shaking or twisting the cable should accentuate the trouble and give an indication of which cable is faulty and of the approximate position of the fault. Should the trouble occur while either the director or

Trouble	*Probable cause and remedy*
	height finder is being traversed, the fault probably lies in the cables in the vicinity of the instrument or in the plug contact between the cable and the instrument. Should the trouble occur while the gun is being traversed, the fault probably lies in the gun cable. These cables all contain at least one spare conductor which may be used if the faulty conductor is located. The trouble may arise from improperly connected or loose plugs and receptacles or from an intermittent open circuit in a primary winding in either the transmitter or one of the indicators. The trouble may be due to a short between two secondary leads. If this is the case, the indicators will tend to assume one of two positions, 180° apart, swinging suddenly from one to another as the transmitter is rotated. Also, in this case, the transmitter will be very noisy at certain positions, due to excessive currents. If this condition develops, the power should be turned off immediately and the short located and repaired, lest the excessive currents burn out the transmitter windings.
Indicator readings lag behind transmitter readings in either direction of rotation.	This indicates a lack of torque in the indicators. This may be due to a low voltage at the repeater or transmitter primaries. If the voltage at the repeater or transmitter primaries becomes less than 75 volts, or if the difference of voltage between the transmitter primary and the receiver primaries becomes greater than 40 volts, this trouble becomes very evident. The voltage should be correctly adjusted at the power plant. It may be due to an open primary circuit to either an indicator or the transmitter. Check the voltage between the 4 and 5 terminals at the indicator and at the transmitter. It may be due to frictional resistance, such as a tight bearing, applied at one indicator. In this case, all four indicators will be thrown out of synchronism; the faulty indicator, however, will show a greater lag than the others.
Indicator spins or "runs away."	*Cut off power immediately.* This fault is rarely encountered and will occur usually when the power is first turned on. If the indicator damper becomes inoperative and the indicator rotor has sufficient inertia to carry out beyond its synchronous position, the indicator will start running as an induction motor. After the power has been cut off, wait for the indicator to come to rest and again

Trouble	*Probable cause and remedy*
	apply power. The damper should be repaired or replaced.
Indicator fails to come to rest, but oscillates about its synchronous position.	This oscillation is characteristic of a defective damper. The damper should be repaired.

Summary

Symptoms	Indicator will not follow for a complete revolution but stops and reverses direction.
Check	Change data at director so that all transmitters will rotate through at least 180°.
Fault	Open phase lead.
Symptons	Low torque and two synchronous positions.
Check	Turn off power and change data at the director so that each of the transmitters (course and fine) differ by approximately 180° from their position when the power was shut off. Then turn on power and see if indicators are 180° from transmitters.
Fault	Open power lead.
Symptoms	Loud humming in both indicator and transmitter, erroneous data with probability that cam follower will be backed off to rearmost position.
Check	Lack of agreement between transmitter and indicator by varying amounts.
Fault	Two shorted phase leads in one of the gun indicators.
Symptoms	Indicator 180° from transmitter, same direction of rotation.
Check	Same as in open power lead above except that in this case the indicator will remain 180° out from transmitter.
Fault	Reversed power leads.
Symptoms	Indicator rotates in opposite direction to transmitter for a complete revolution.
Check	Same as in open phase lead above.
Fault	Two phase leads reversed.
Symptoms	Indicator 120° out of phase with transmitter, same direction of rotation.
Check	Lack of agreement between transmitter and indicator by a constant 120°.
Fault	All three phase leads interchanged.

■ 216. CARE AND MAINTENANCE.—*a.* The system requires ordinary care and attention to prevent damage. When not in use, the receptacles on the boxes and the plugs on the ends of the cables should have their covers screwed up tight to protect their interior parts from injury and to render them watertight.

b. When not in use, keep the plug on the end of the fuze indicator cable connected to the dummy receptacle, with the cable carefully coiled about the fuze setter and the collar screwed up tight to make it watertight.

c. When disconnecting the plugs and receptacles, grasp the bodies to pull them apart but do not pull on the cable or spring.

d. When not in use, the cables should be on the reels provided for them and protected from sunlight.

e. The rear gland followers on the cable plugs should be screwed up tight at all times. They are provided with locking springs to prevent their being backed off accidentally when the plugs and receptacles are disconnected. Considerable force, which may damage the spring, is required to remove these followers. Therefore, no attempt should be made to remove them unless it is necessary to repair the plug or cable. The best way to disassemble is by short and jerky rotation of the follower in a counterclockwise direction.

■ 217. CARE AND TESTING OF CABLE.—*a.* The multiconductor cable supplied with this system is the highest grade obtainable. However, no cable of this type will withstand repeated kinking or twisting. The importance of giving the cable the best possible care cannot be overemphasized. Avoid bending the cable on a short radius or allowing it to chafe against any moving object. Do not allow dirt of any kind to accumulate in the plugs or receptacles, as this would impair the connections. When the cables are not connected, all plugs and receptacles should be kept closed with the covers provided so as to exclude moisture from these units.

b. Oil and grease are detrimental to rubber of any kind and care should therefore be exercised to see that the cables are kept free of these materials.

c. Store cables in a cool, dark place, as heat and sunlight cause rapid deterioration of rubber products.

d. Friction tape should not be used to tape the end of any of the latox conductors of the 20-conductor flexible cable. Rubber tape only should be used, as the solvent in the saturated cloth of friction tape will in time dissolve the latox insulation.

e. To check cables for continuity and shorts, remove the cable from the system and connect one side of a battery or other power source to conductor No. 1 at one end of the cable. Connect one terminal of a suitable voltmeter to the other side of the battery or power source, and connect, one at a time, all the conductors of the cable (at the opposite end) to the second terminal of the voltmeter. If the given conductor (No. 1) is in good condition, the voltmeter will indicate the battery or power source voltage when, and only when, the No. 1 conductor is connected; in all other cases the voltage should read zero. If full voltage is not indicated when the No. 1 conductor (at the opposite end) is touched, the conductor is broken. If a voltage is indicated when any other conductor is touched, that conductor is shorted to No. 1. Each conductor should be tested in turn in the same way.

■ 218. **Alternate Source of Power.**—If the standard A. C. gasoline electric generating unit, M3 or M4 is not available to furnish power for the data transmission system, or if for some reason it is not desired to use this source of power, the data transmission system may be powered with any source of 115-volt, 60-cycle, single-phase alternating current. However, if the system is powered by any other source than the standard power plant furnished with the system, a special connection must be made in order to power both the director and the gun indicators. Connect one side of the A. C. line to pole No. 4 in the receptacle of the main junction box marked "Power Plant" and the other side of the A. C. line to both pole No. 5 and to pole No. 19 of this same receptacle.

SECTION VIII

STEREOSCOPIC TRAINING INSTRUMENTS

■ 219. **General.**—*a.* Stereoscopic training instruments are provided for the following reasons:

(1) They are used for the initial selection of individuals for further training.

(2) They are beneficial to any observer in assisting him to reach his maximum efficiency and to maintain that efficiency.

(3) They provide a means of training available at all times, being independent of such factors as weather conditions, suitable targets, and the availability of other members of the height finder detail or record section. The use of a stereoscopic trainer in no way obviates the necessity for actual practice on the stereoscopic range or height finder. A trainer

will frequently be the only available means of practice for an observer. A long period without practice will seriously affect the observer's ability. It is therefore essential that an observer can practice at all times of the year.

b. The battery commander should conduct the training of stereoscopic observers as given in TM 4–250.

■ 220. STEREOSCOPIC TESTER, M1.—This instrument consists of a small stereoscope and two sets of slides (stereograms). (See fig. 83.) It provides a simple and rapid means for the determination of stereo-acuity, muscle balance, and visual acuity. It is also suitable for the training of stereo-observers. A handbook containing a full description of the device and its uses is issued with each instrument.

■ 221. TARGET ASSEMBLY FOR STEREOSCOPIC TESTER, M1.—Figure 84 shows a target assembly for use with the stereoscopic tester. It is inserted in the holder and viewed through the stereoscope in the same manner as any stereogram. This device shows approximately what the observer will see through a height finder. It is adjustable so the target can be made to appear short, coincident, or over with respect to the reticle symbols. The adjustment is made by turning the adjusting nut which moves the target with respect to one reticle on one side of the stereogram only. Further instructions on its use will be found in the manual issued with it.

■ 222. STEREOSCOPIC TRAINER, M2.—*a. Use.*—The chief use of this instrument is the training and eye exercising of stereoscopic observers. It can also be used for testing vision.

It is a stereoscope equipped with several slides and reticles which may be used in various combinations to train an observer in making stereoscopic contact. (See fig. 85.)

b. Optical system.—The optical system consists of two low power microscopes. The eyepiece arrangement is substantially the same as that of the stereoscopic height finder. The optical characteristics are as follows:

Real field	6°.
Exit pupil	4.0-mm diameter.
Eye distance	Approximately 22-mm.
Interpupillary distance	Variable between 55- and 75-mm.
Focusing range	From +4 to —4 diopters.

c. Description.—A full description of the instrument and its uses will be found in manual, Stereoscopic Trainer, M2, issued with each instrument.

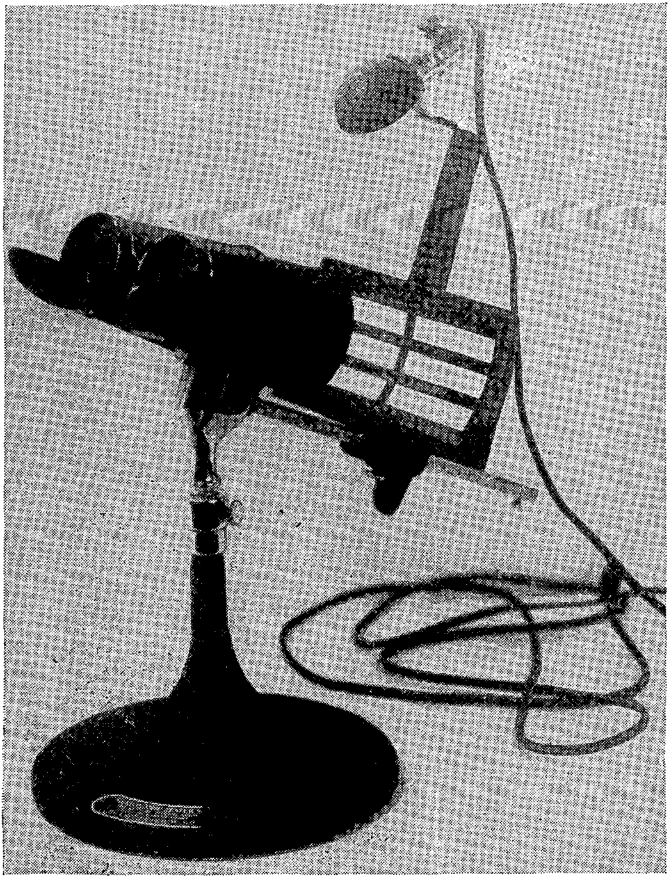


FIGURE 83.—Stereoscopic tester, M1.

d. Care.—(1) All movements are provided with positive stops. Do not force any knob if it turns hard or stops.

(2) Two handles are provided for lifting the instrument from its case.

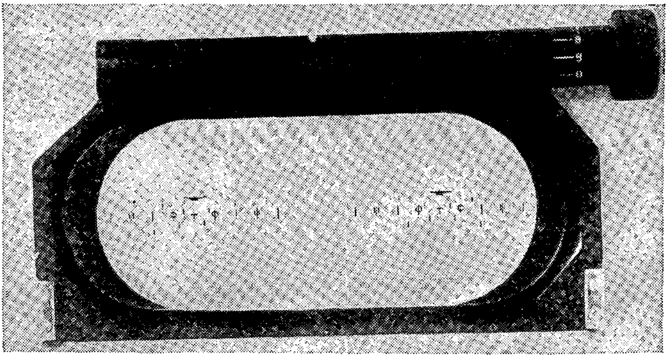


FIGURE 84.—Target assembly for use with stereoscopic tester, M1.

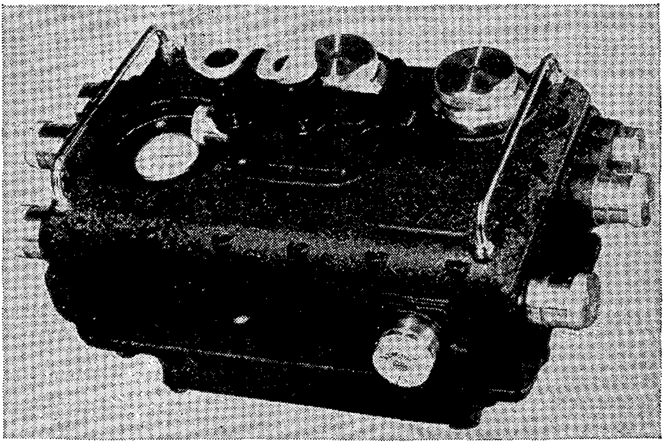


FIGURE 85.—Stereoscopic trainer, M2.

(3) Care should be exercised in placing and removing the target plates through the door on the right side of the instrument.

(4) The target plates are photographs on glass and are protected only by a transparent lacquer. Care should be taken to avoid scratching the film surface. Do not touch the film side with the fingers. Use the handle attached to each plate. The lower side of the plate can be cleaned with a lens cloth or paper. The upper or film side should be cleaned only by means of a very soft brush.

(5) The target plates are numbered. When not in use they should be kept in their numbered slot in the drawers in the instrument case.

CHAPTER 4

ORIENTATION, SYNCHRONIZATION, AND APPLICATION OF CALIBRATION CORRECTIONS

Section I

GENERAL

■ 223. **Orientation.**—*a.* Orientation of an antiaircraft gun battery includes—

(1) Adjustment of guns for azimuth, elevation, and fuze range.

(2) Adjustment of director, height finder, and observation instruments for azimuth and elevation.

b. It does not include synchronization of the electrical data transmission system.

■ 224. **Orientation Requirements.**—*a.* Orientation of a battery is accomplished when the following requirements are met:

(1) Instruments and guns are leveled.

(2) Guns and instruments being set at the same indicated azimuth, they point in parallel directions.

(3) Guns being set at a given elevation as indicated on the elevation indicators, the axis of each bore is at that elevation.

(4) Director being set at a given elevation as indicated on the ϵ_0 dials, the line of sight is at that elevation.

(5) Other instruments being set at a given elevation, the line of sight is at the indicated elevation.

(6) Fuze setter actually sets the fuze on a projectile to the fuze range indicated on the fuze indicator at the gun.

b. The method of orienting the gun battery is outlined in section II.

■ 225. **Synchronization.**—Synchronization is the process of making certain that the elements of data are being transmitted correctly between the various components of the battery. This includes the firing data from the director to the guns; altitude from height finder to director; and data for the target designating system from the director to height finder. This operation is entirely separate from and should not be confused with orientation. The method of synchronizing the data transmission system is outlined in section III. For further information on this subject consult the manual, "Notes on Matériel, Data Transmission Systems, M3 and M4."

SECTION II

ORIENTATION

■ 226. GENERAL.—The process of orienting the gun battery is divided into three parts; orientation in azimuth, orientation in elevation, and orientation in fuze range.

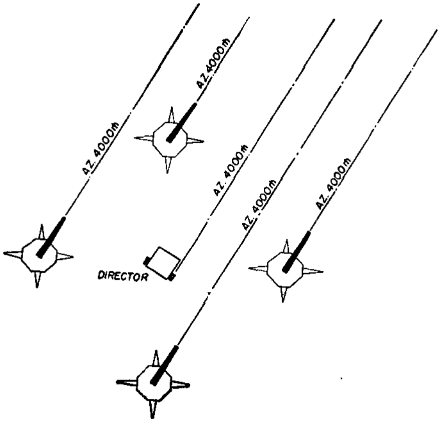


FIGURE 86.—Orientation in azimuth.

■ 227. AZIMUTH.—*a*. A battery is properly oriented in azimuth when, with all four guns and all the instruments pointed in parallel directions, the same azimuth is set on the azimuth indicators of each gun and the azimuth dials or scales of the instruments. (See fig. 86.)

b. Before orienting the matériel in azimuth, a datum point must be chosen and orientation data computed. Any prominent object on which a definite point can be located and which is visible from the director and all four guns (such as a church steeple or flag pole) may be chosen. It should be as far from the battery as practicable. The azimuth and range to that point from the director are obtained by survey, from an accurate map, or by using the compass azimuth and measuring the range with the height finder. Then the azimuth from each gun to that datum point is computed using the lateral parallax displacements of the guns. (See fig. 87.) The computations for computing lateral parallax are tabulated below:

Gun	No. 1	No. 2	No. 3	No. 4
Range displacement in yards	−25	+25	0	−45
Range—gun to datum point—yards	4,975	5,025	5,000	4,955
Lateral parallax displacement—yards	R 35	R 20	L 30	L 10
Perform indicated division	$\frac{35}{4.975}$	$\frac{20}{5.025}$	$\frac{30}{5.000}$	$\frac{10}{4.955}$
Lateral parallax in mils	−7	−4	+6	+2
Azimuth datum point from gun—mils	3,993	3,996	4,006	4,002

c. To orient a gun in azimuth proceed as follows:

(1) Level gun.

(2) Boresight gun on a datum point using boresight in the breech and a vertical string centered across muzzle of gun as a line of sight.

(3) Hold gun stationary with axis of bore alined on the datum point. Raise sliding cover on left side of azimuth indicator. Raise detent engaged in the toothed wheel. Turn toothed wheel until the mechanical (outside) dials read the azimuth from gun to datum point. Release detent and close cover. Check reading and alinement of gun on datum point and readjust if necessary.

d. Orientation of the director in azimuth is accomplished by making the present azimuth dials of the director read the azimuth of the datum point from the director when the vertical cross hair of the lateral tracking telescope bisects the datum point. Detailed instructions on the method of doing this are found in paragraph 159.

e. An alternate approximate method of orienting the guns and director in azimuth is to point the gun by means of a breech bore sight and vertical cross hair at the azimuth tracking telescope of the director. The director is traversed so that the azimuth tracking telescope is sighted along the

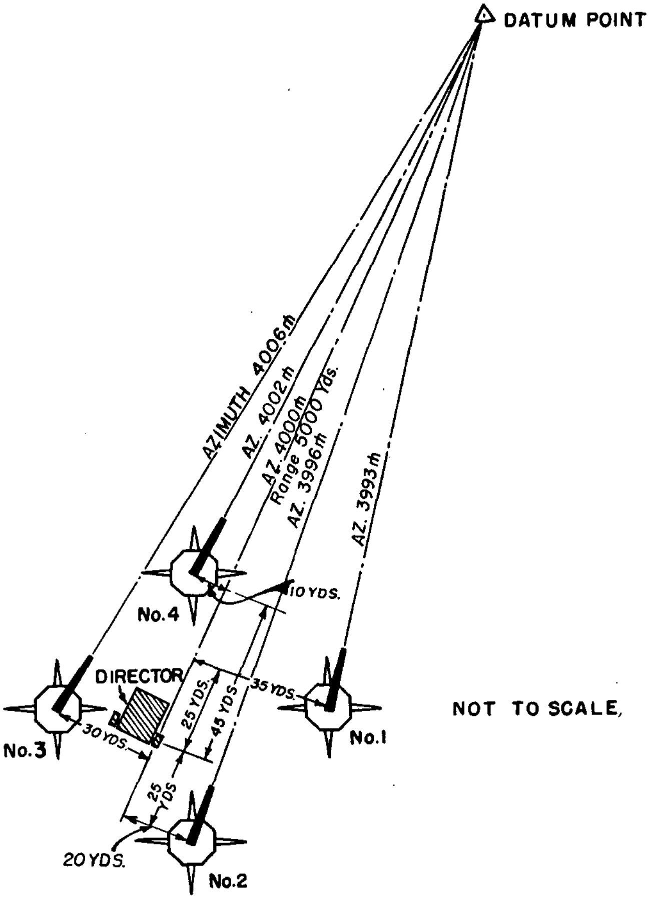


FIGURE 87.—Lateral parallax.

bore of the gun. The azimuth indicator at the gun is then changed so that it reads the back azimuth of the line of sight of the director. This method should be used only when a suitable datum point is not available.

■ 228. **Elevation.**—*a.* A battery is properly oriented in elevation when the elevation indicators on the gun indicate the true elevation of the axis of the bore and the angular height dials of the director indicate the true elevation of the tracking telescopes. A primary requisite is that the guns and the director are level.

b. To orient the gun in elevation proceed as follows:

(1) Level gun.

(2) Set gun at any convenient elevation, such as 800 mils, by means of the gunner's quadrant.

(3) Hold elevation wheel stationary. Raise sliding cover on left side of elevation indicator. Raise detent engaged in the toothed wheel. Turn toothed wheel until mechanical (outside) index reads 800 mils. Release detent and close cover. Check gun at several other elevations with gunner's quadrant. Readjust if necessary.

c. To orient the director in elevation, see instructions contained in the manual, Director, M4, part I, issued with the director.

d. Bore sighting on a celestial body may be used as a method of orientation and also to check parallelism of lines of sight of various instruments and axes of bores of the guns. The operation is performed as follows:

(1) Level guns and all instruments.

(2) Select a celestial body such as the sun, moon, a planet, or well-defined star, as a datum point at infinite range. If the sun is selected, a filter must be interposed in the line of sight.

(3) If the azimuth of the celestial body is known, then the director can be set with that azimuth on the dials, otherwise the azimuth dials of the director should be set to read approximate azimuth as determined by compass or other means.

(4) A breach bore sight is placed in the breach and vertical and horizontal cross hairs are centered across the muzzle of each gun.

(5) The guns and instruments are pointed simultaneously at the celestial body. All track the celestial body.

(6) At the command TAKE, all motion of the guns and instruments is stopped.

(7) The lines of sight of all instruments and the axes of the bores are now parallel. If the azimuth and elevation indicators on the guns do not agree with the A_o and ϵ_o dials respectively on the director, change gun indicators to agree with director dials by the procedure indicated in *b* above and in paragraph 227*c*(3). If the height finder azimuth indicator does not agree, proceed as outlined in paragraph 227*d*.

■ 229. **Fuze Range.**—*a*. A battery is properly oriented in fuze range when the fuze setter actually sets the fuze on a projectile to the fuze range indicated on the fuze indicator at the gun.

b. To orient the fuze setter, proceed as follows:

(1) Set fuze setter at some convenient setting, such as 15.

(2) Insert a round of ammunition in fuze setter and set fuze.

(3) Take the round out of fuze setter and read setting on fuze. If this agrees with fuze indicator reading (15), no further adjustment is necessary. If it does not agree, take off window of fuze indicator. Loosen screws which tighten clamping ring in place on the scale and slip scale around until mechanical (outer) pointer is opposite the reading that is on the fuze. Tighten screws in the clamping ring and replace window. Check at several other settings and readjust if necessary.

■ 230. **Height Finder.**—*a*. Orientation of the height finder is necessary only because of the target designating system. Data for orienting the height finder in azimuth is computed in the same manner as that for orienting guns. (See par. 227.)

b. To orient the height finder in azimuth, proceed as follows:

(1) Level instrument.

(2) Traverse height finder until center symbol of reticle is accurately centered on datum point.

(3) Hold instrument stationary. The orienting clutch (fig. 65) is then turned (unscrew dust cap) until mechanical

(outer) dial indicates the azimuth of datum point from height finder. Check alinement on datum point and reading and readjust if necessary. Replace dust cap on orienting clutch.

c. To orient the height finder in elevation, proceed as follows: Depress tube of instrument, using elevation drive, until level on tube is centered. At this point the mechanical (outer) dial of the elevation indicator should read zero. If it does not read zero, proceed as indicated in the manual, Height Finder, M1.

Section III

SYNCHRONIZATION

■ 231. General.—The process of synchronizing the gun battery is divided into five parts; synchronization of the azimuth indicators, elevation indicators, fuze range indicators, altitude indicator at the director, and target designating system at the height finder. Synchronization is an entirely separate process from orientation and may be performed either before or after orientation. It should seldom be necessary to synchronize after the initial adjustment has been made. Lack of synchronization usually indicates some fault in the data transmission system. Primarily as a precaution against faults, the synchronization should be checked each time the data transmission system is used. A further discussion of synchronization will be found in section VII, chapter 3, and in the manual, Notes on Matériel, Data Transmission Systems, M3 and M4.

■ 232. Azimuth Indicators.—*a.* The azimuth indicators at the guns are said to be synchronized with the firing azimuth dials at the director when the dials indicate identical readings at all azimuths.

b. To synchronize, proceed as follows:

(1) Energize data transmission system.

(2) Set director so that firing azimuth dials read any even azimuth, such as 600 mils.

(3) Match pointers at guns and read azimuth of guns.

(4) If reading on any gun differs from the transmitted azimuth, raise sliding cover on left side of azimuth indicator. Turn large screw at bottom of cavity until electrical (inner) fine index reads the transmitted azimuth. Close cover.

(5) After the operations described in (3) and (4) above have been performed, traverse director and change firing azimuth by at least 1,000 mils. Check to see that azimuth indicators are still in synchronization. If they are, the fine dial of azimuth data transmission is synchronized. If they are not, there is some fault in the system. If azimuth indicators are badly out of synchronization on the first check, it indicates a probable fault in the system. (See sec. VII, ch. 3.)

(6) If coarse indicator dials are not in synchronization, adjustment is made in the same manner as for fine dials. The adjusting screw is found by removing the plate which is screwed on right side of indicator.

■ 233. **Elevation Indicators.**—*a.* The elevation indicators at the guns are synchronized with the quadrant elevation dials at the director when the dials indicate identical readings at all elevations.

b. To synchronize, proceed exactly as outlined in paragraph 232 for the azimuth dials, except that the check is made between the elevation indicators and the quadrant elevation dials on the director.

■ 234. **Fuze Range Indicators.**—*a.* The fuze range indicators at the guns are synchronized with the fuze range dial at the director when the dials indicate identical readings at all fuze ranges.

b. To synchronize, proceed as follows:

(1) Energize data transmission system.

(2) Set director so that fuze dial reads any even fuze range, such as 14.

(3) Match pointers on fuze setters.

(4) Check fuze reading on each fuze setter with that transmitted by the director. If the readings do not agree, take off cover plate of lamp well on right side (facing it) of fuze range indicator, and the electrical synchronizing screw is found in the cavity. Turn it with a screw driver until the electrical (inner) dial reads the transmitted fuze range. Replace the cover plate.

(5) Check fuze range indicators at several other fuze ranges, both greater and less than the original. If they check, the fuze range indicators are synchronized. If they

do not check, there is a fault. If the indicators are badly out of synchronism on the first check, there is probably a fault. In either case, consult section VII, chapter 3.

■ 235. **Altitude Indicator and Target Designating System.**—*a.* The altitude indicator at the director is synchronized with the altitude transmitter at the height finder when the dials indicate identical readings at all settings.

b. The target designating system is synchronized with the director when the dials at the height finder and the present azimuth and present angular height dials at the director indicate identical readings at all azimuths and elevations.

c. To synchronize proceed as outlined in the manual, Notes on Matériel, Data Transmission Systems, M3 and M4.

Section IV

APPLICATION OF CALIBRATION CORRECTIONS

■ 236. **General.**—In paragraph 113 it was stated that the purpose of calibration fire is to determine the corrections which must be applied to the individual guns in order that the battery may shoot a predetermined pattern. This section explains the mechanics of applying the calibration corrections to the guns.

■ 237. **Azimuth.**—To apply calibration corrections in azimuth proceed as follows:

a. Set gun at some even azimuth, such as 800 mils.

b. Raise sliding cover on left side of azimuth indicator.

c. Using toothed wheel, move mechanical (outer) fine pointer to the value of the correction in the opposite sense to that of the correction. For example, if indicator is set at 800 mils and a plus 5-mil correction is to be applied, make pointer read 795 mils; if a minus 5-mil correction is to be applied make pointer read 805 mils. Close cover.

d. Record amount of correction, and remember that if gun is checked in orientation, it should be in error by the amount of calibration correction; for example, if a calibration correction of plus 5 mils has been applied and the gun is pointed at a datum point whose azimuth is 1,500 mils, the azimuth indicator should read 1,495 mils.

■ 238. ELEVATION.—To apply calibration corrections in elevation, proceed as follows:

a. Set gun at any convenient elevation, such as 900 mils, by means of a gunner's quadrant.

b. If calibration correction is, say plus 5 mils, raise sliding cover on left side of elevation indicator and turn toothed wheel until mechanical (outer) dial reads 895 mils. If a minus 5-mil correction is to be made, the indicator dial should be made to read 905 mils. Check at other elevations and adjust if necessary. Lower cover. Record amount of calibration correction. Remember that when orientation of the gun in elevation is checked at subsequent times, the guns should be in error by the amount of calibration correction. For example, if the gun is laid at 400 mils by means of a gunner's quadrant and a minus 5-mil correction has been applied, the mechanical (outer) pointer of the elevation indicator should read 405 mils.

■ 239. FUZE RANGE.—To apply calibration corrections in fuze range, proceed as follows:

a. Energize data transmission system.

b. Set director so that fuze dial reads any fuze range, such as 12.

c. By means of the electrical synchronizing screw (which is in lamp well on right side of fuze indicator as you face the dial), make electrical (inner) dial read fuze range plus or minus the correction. For example, if it is desired to apply a correction of plus 2 corrector divisions, make the dial read 12.2.

d. Record amount and sense of calibration correction, remembering that when synchronization is checked, the fuze setter should be out of synchronization by amount of correction applied. For example, if the fuze dial on the director reads 10 and a correction of plus 2 corrector divisions has been applied, the fuze indicator dial on the fuze setter at the gun should read 10.2.

CHAPTER 5

TARGET PRACTICE; ORGANIZATION AND DUTIES OF THE RECORD AND THE RANGE SECTIONS

SECTION I

TARGET PRACTICE

■ 240. **GENERAL.**—The purpose of all firing problems is the training of the command for battle. Target practices serve the additional purpose of providing a comparative test of such training. Requirements which must be met by an organization conducting target practice and records which must be kept are prescribed in TM 4–235 (now printed as TM 2160–35) and in training memoranda published from time to time by the War Department.

■ 241. **RECORDS.**—The problem of obtaining accurate records of antiaircraft target practices is greatly complicated by the time factor. This has led to the development of special devices and methods which are capable of determining and recording the position of a target moving at high speed and the deviations of bursts which occur with rapid frequency. These methods are as follows:

a. Camera records are made by photographing the target during the firing, with an oriented motion-picture camera (recording theodolite) located at each end of a measured base line. All bursts occurring within the field of view of the camera and the azimuth, angular height, time, and number of the instrument are also photographed on the film.

b. Past experience has indicated the necessity of supplementing the camera records with visual records to take care of possible failure of camera records. Oriented observing instruments are set up at the ends of a measured base line one end of which should be at the guns. The instruments track the target continuously during the course. A time interval system (usually at 5 seconds' interval) is employed to synchronize the readings. Readers at each of the instruments read the azimuth and angular height "on the bell." Three instruments are required to read the deviations, two at the end of the base line near the guns for lateral and vertical deviations, and one at the other end of the base line to read range deviations. The deviations of the bursts are recorded in sequence and according to the record time. Record time starts with the designation of a certain bell as time zero. Each bell thereafter is numbered in sequence until tracking ceases.

c. The functioning of the record section requires close coordination if satisfactory results are to be obtained. This coordination can be obtained only by constant practice as a unit. TM 4–235 (now published as TM 2160–35) prescribes that a record section be organized in each antiaircraft regiment. The officer in charge of this section is responsible for the training and functioning of the section and that accurate, synchronized records are obtained. The coordinated training of the record section cannot be overemphasized. Accurate information on the state of training of an organization depends, in a large measure, upon the thoroughness, completeness, and accuracy of the record section's reports.

SECTION II

RECORD SECTION

■ 242. GENERAL.—The record section is an important part of an antiaircraft regiment. A measure of an organization's preparedness is the manner in which it conducts a target practice as well as the results of that practice. An accurate analysis of the results of a practice cannot be made without accurate records from a thoroughly trained record section. This training should be concurrent with that of the firing batteries. An excellent firing battery should be guaranteed that the records of its practices will be of the same high standard.

■ 243. ORGANIZATION.—The organization of the record section is dependent upon local conditions. A type record section follows:

a. Officer in charge.

b. Assistant to the officer in charge.—(In charge of records.)

c. Communication detail.

1 noncommissioned officer in charge.
1 time interval operator.
Telephone operators.
Linemen.

d. Noncommissioned officer in charge of each station (O_1 and O_2).

e. Camera detail.—Noncommissioned officer in charge.

O_1 station:	O_2 station:
1 observer.	1 observer.
1 operator.	1 operator.
1 assistant operator.	1 assistant operator.
1 recorder.	1 recorder.
1 telephone operator.	1 telephone operator.

f. Visual detail.—Noncommissioned officer in charge.

O_1 station:	O_2 station:
2 observers.	1 observer.
2 spotters (1 lateral 1 vertical).	1 spotter.
1 azimuth reader.	1 azimuth reader.
1 angular height reader.	1 angular height reader.
4 recorders.	3 recorders.

g. Plotting detail.

1 noncommissioned officer in charge.
1 noncommissioned officer film reader.
1 plotter.
1 data editor.
1 slide rule operator.
1 recorder.

■ 244. Duties.—The duties of the members of the record section are indicated by their titles. Other members may be attached during target practice season for such duties as umpires, timekeepers, recorders, communication personnel, and assistants. In some cases it may be necessary to double up on duties of individuals.

Purpose------------------------------ Course number---------------
Date--------------- Time------------ Direction----------- Rounds fired--------

Visual records			General computations			Camera records		
	Inserted	Checked		Inserted	Checked		Inserted	Checked
O_1 Az (AA8)--------			Time record (AA10)-----------			O_1 (AA18)-----		
O_1 ϵ (AA8)---------			Target position (AA4a) R computed—visual.			O_2 (AA18)-----		
O_2 Az (AA8)--------			Target position (AA4a) H and D—visual.			Data edited---		
O_2 ϵ (AA8)---------			Target position (AA4a) R computed—camera.					
O_1 Lat (AA9)-------			Target position (AA4a) H and D—camera.					
O_1 Ver (AA9)-------			Comp. impacts (AA11)--------					
O_2 Lat (AA9)-------								
Data edited---------								

Battery commander						Disposition
Detection phase only		Firing phase				
Graphical (AA6A)-----		Summary (AA2b)-------		Graph anal (AA6b)-----		
Summary (AA2A)-----		HF Alt (AA8)----------		M and P report---------		
		HF result (AA4b)-------		Nar. report-------------		
		TAB anal (AA5)--------				
						Date:

■ 245. **CHECK OF RECORDS.**—A systematic check of all the records of an organization should be made to insure that none are lost or misplaced. The preceding type form, if pasted on the outside of a large envelope, will assist in making this check.

SECTION III

RANGE SECTION

■ 246. **ORGANIZATION AND DUTIES.**—*a.* The following table extracted from pertinent Tables of Organization gives the organization of the range section for both mobile and semimobile gun batteries.

ORGANIZATION RANGE SECTION, GUN, ANTIAIRCRAFT

Unit	Gun battery (mobile)		Gun battery (semimobile)	
	T/O 4–17		T/O 4–117	
	P	W	P	W
1st or 2d lieutenant	1	1	1	1
Staff sergeant, including	--------	1	1	1
Electrician	--------	(1)	(1)	(1)
Sergeant, including	2	3	2	3
Chief of section	(1)	(1)	(1)	(1)
Observer, height finder	(1)	(2)	(1)	(2)
Corporal, including	2	2	2	2
Instrument	(2)	(2)	(2)	(2)
Private, 1st class Private } including	14	16	12	14
Chauffeur	(3)	(4)	(1)	(2)
Instrument	(11)	(12)	(11)	(12)
Total enlisted	18	22	17	20

b. (1) The formation for the range section of a mobile gun battery, war strength, is shown in figure 88.

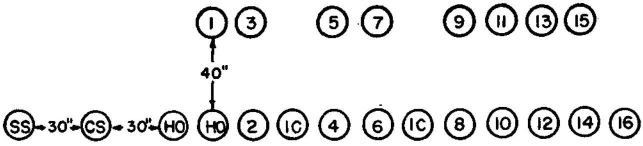


FIGURE 88.—Formation of range section, mobile gun battery.

DRILL TABLE

RANGE SECTION 3-INCH ANTIAIRCRAFT GUN BATTERY

Details	PREPARE FOR ACTION	DETAILS, POSTS	TARGET	CEASE TRACKING	MARCH ORDER
Chief of range section	Repeats the command. Supervises work of entire range section. Indicates positions for various instruments. Gives command to turn on power. When section is in order, he reports to range officer, "Sir, range section in order."	Repeats the command. Supervises work of section.	Repeats the command. Assists in getting director on target if necessary. Reports to range officer, "Sir, range section on target" as soon as both director and height finder locate target and commence tracking. In addition, may be required to assist in fire adjustment.	Repeats the command	Repeats the command. Supervises replacing of equipment as directed.
Height finder observer	Supervises setting up of height finder at indicated position. Levels instrument. Using data furnished him, orients height finder. After power has been turned on, assists instrument corporals in checking synchronization of all electrical data transmission between height finder and director. Makes all adjustments necessary for operation of instrument. (See par. 167.) Reports to chief of range section, "Height finder in order."	Takes post facing height finder at observer's eyepiece.	If necessary, assists trackers in getting on target. When trackers report "On target," looks through eyepiece and establishes and maintains stereoscopic contact with target. Indicates to height or range setter at height finder when to send data to director. If so directed by range officer, performs stereoscopic spotting in addition to range or altitude determination.	Repeats the comand. Ceases tracking. Remains at post.	Repeats the command. Supervises replacing of the height finder as directed.
Elevation tracker, height finder.	Assisted by azimuth tracker, height finder, sets up tripod and cradle for height finder at indicated position. Assists in removing height finder tube from carrying case and placing it on cradle. Procures his telescope from packing chest and mounts it on height finder.	Takes post in rear of height finder facing elevation tracker's telescope.	If director is on target, matches pointers of elevation receiver of target designating system. If not, searches in designated area for target. Once target is located, tracks it accurately and smoothly in elevation.	Ceases tracking. Remains at post.	Removes telescope and replaces it in packing chest. Assists in replacing height finder tube in carrying case. Assisted by azimuth tracker, dismantles cradle and tripod and replaces them in packing cases.
Azimuth tracker, height finder.	Assists elevation tracker, height finder, in setting up tripod and cradle for height finder. Assists in removing height finder tube from carrying case and placing it on cradle. Procures his telescope from packing chest and mounts it on height finder.	Takes post in rear of height finder facing azimuth tracker's telescope.	If director is on target, matches pointers of azimuth receiver of target designating system. If not, searches in designated area for target. Once target is located, tracks it accurately and smoothly in azimuth.	Ceases tracking. Remains at post.	Removes telescope and replaces it in packing chest. Assists in replacing height finder tube in carrying case. Assists elevation tracker to dismantle cradle and tripod and replace them in packing cases.
Height or range setter, height finder.	Assists in removing height finder tube from carrying case and placing it on cradle. Connects plug for wiring circuit from cradle to height finder tube. Assists in placing director at indicated position. Assists in removing power plant from truck if so directed. Lays cable from height finder to main junction box and connects cable to height finder and main junction box.	Takes post in front of height finder facing range or altitude transmitter.	If necessary, assists in locating target and getting height finder on target. Sets altitude or range transmitter to values indicated on altitude or range scale when directed by observer.	Ceases to send altitudes or ranges to director. Remains at post.	Removes cable from height finder. Disconnects plug for wiring circuit from cradle to height finder tube. Assists in replacing height finder tube in carrying case. Assists in replacing director and power plant as directed. Disconnects cable from height finder at main junction box and replaces cable on reel.
Instrument corporal (in charge of director).	Supervises setting up of director at indicated position. Levels director. Using data furnished him, orients director. After power has been turned on, assisted by height finder observer and gun commanders, checks synchronization of entire electrical data transmission system. Reports to chief of range section, "Director in order."	Repeats the command. Supervises work of manning detail of director.	Repeats the command. Turns on power at director. Gives such instructions as necessary to assist in getting director on target. Reports to chief of range section, "On target" as soon as trackers commence to track target. In addition, may be required to assist in fire adjustment and spotting.	Repeats the command. Turns off power at director about 10 seconds after tracking has stopped.	Repeats the command. Supervises replacing of director as directed.
Instrument corporal (assistant).	Supervises laying of cable and connecting of receptacles. Supervises setting up of power plant at indicated position, and operation of power plant.	Takes post in vicinity of director as directed by instrument corporal in charge.	If necessary, assists in locating and getting director on target. In addition, may be required to assist in fire adjustment and spotting.	No duties	Supervises removal of receptacles and picking up of cables. Supervises replacing of cable reels and power plant as directed.
Elevation tracker, director	Assists in placing director and power plant at indicated positions. Assists instrument corporal in orienting and synchronizing director.	Takes post on left side of director facing elevation tracking telescope.	Looks through telescope and elevates or depresses as directed. When he sees target, calls out "On target." Thereafter tracks target bisecting it with horizontal cross hair. Uses "slow motion" whenever possible in order to track target smoothly.	Ceases tracking. Remains at post.	Assists in replacing director and power plant as directed.
Azimuth tracker, director	Assists in placing director at indicated position. Assists in removing height finder tube from carrying case and placing it on cradle. Assists in placing power plant in position if necessary.	Takes post on right side of director facing azimuth tracking telescope.	Looks through telescope and traverses as directed. When he sees target, calls out "On target." Thereafter tracts target bisecting it with the vertical cross hair. Uses "slow motion" whenever possible in order to track target smoothly.	Ceases tracking. Remains at post.	Assists in replacing director as directed.
Range setter, director	Assists in placing director at indicated position. Assists in removing height finder tube from carrying case and placing it on cradle. Assists in placing power plant in position if necessary.	Takes post in front of director facing angular height dials.	As soon as director is on target, matches angular height dials (both coarse and fine) using range setting handwheel. Thereafter, by regulating range rate knob and handwheel, keeps angular height dials matched continuously. Uses prediction button (red button) as required.	Sets range rate knob to zero. Ceases to match angular height dials. Remains at post.	Assists in replacing director, height finder tube, and power plant as directed.
Altitude setter, director	Assists in placing director at indicated position. Assists in removing height finder tube from carrying case and placing it on cradle. Assists in placing the power plant in position if necessary.	Takes post in front of director facing altitude dial.	As soon as altitudes are transmitted from height finder, matches pointers of altitude dial using altitude setting handwheel. Uses prediction button (red button) as required.	Ceases to match altitude dial. Remains at post.	Assists in replacing director, height finder tube, and power plant as directed.
Power plant operator	Assists in placing power plant at indicated position. With help of assistant power plant operator, lays cable from power plant to main junction box. Connects receptacles to power plant and main junction box. When directed by chief of range section, starts power plant.	Takes post at power plant	Operates power plant as directed	No duties	Stops power plant. Removes receptacles of cable and with the aid of his assistant, reels up cable. Assists in replacing power plant.
Assistant power plant operator.	Assists in placing director at indicated position. Assists in removing height finder tube from carrying case and placing it on cradle. Assists in placing power plant at indicated position.	Takes post at power plant	Assists power plant operator in his duties	No duties	Assists in replacing director, height finder, and power plant as directed.
Instrument privates (2)	Assist in placing director at indicated position. Assist in removing height finder tube from carrying case and placing it on cradle. Assist in placing power plant in position if necessary. Procure and place main junction box at position indicated. Lay cable from director to main junction box. Connect receptacles to director and main junction box.	Take post in vicinity of director.	NOTE.—Replacements for various trackers or setters at the director or height finder as needed. May assist in spotting for fire adjustment.	No duties	Remove receptacle from director. Assist in replacing director, height finder tube, and power plant as directed.

(2) Members of the range section are designated as follows:

SS staff sergeant, electrician
CS Chief of range section
HO Height finder observer
HO Height finder observer
IC Instrument corporal
IC Instrument corporal
No. 1 Elevation tracker, height finder
No. 2 Azimuth tracker, height finder
No. 3 Height or range setter, height finder
No. 4 Elevation tracker, director
No. 5 Azimuth tracker, director
No. 6 Range setter, director
No. 7 Altitude setter, director
No. 8 Power plant operator
No. 9 Assistant power plant operator
No. 10 Instrument
No. 11 Instrument
No. 12 Instrument
No. 13 Chauffeur
No. 14 Chauffeur
No. 15 Chauffeur
No. 16 Chauffeur

(3) The following members of the range section are eliminated in the war strength semimobile unit:

Chauffeur No. 15
Chauffeur No. 16

(4) The following members of the range section are eliminated in the peace strength mobile unit:

Staff sergeant, electrician
1 observer, height finder
Chauffeur No. 16
Instrument private No. 12

(5) The following members of the range section are eliminated in the peace strength, semimobile unit.

1 observer, height finder
Chauffeur No. 14
Chauffeur No. 15
Chauffeur No. 16
Instrument private No. 12

(6) The duties of the members of the range section will be found in the drill table (*c* below). Extra members authorized in Tables of Organization for a mobile unit, and for war strengths of both the mobile and semimobile units, are chauffeurs and reserve members of the range section.

c. The drill of the range section is shown in the accompanying table.

CHAPTER 6

REFERENCE DATA

SECTION I

SYMBOLS

■ 247. **GLOSSARY OF SYMBOLS.**—*a.* All the symbols normally used in the discussion and computation of the elements of antiaircraft firing data are listed below in alphabetical order.

b. Both English and Greek letters are used as symbols and as prefixes to symbols. The former are also used as subscripts to symbols. Numbers are used as subscripts only.

c. The prefix d is used with a symbol to indicate a correction to the element of data. The prefix Δ (delta) is used to indicate a change in the element of data.

d. The subscripts o and p are used with T to indicate, respectively, the position at the instant of firing (present position) and the predicted (future) position. These subscripts are used similarly with A, α, D, ϵ, F, H, R, and t to indicate the particular element corresponding to these two positions of the target. The other subscripts used have, in general, a special meaning, depending upon the symbol with which they are used.

Symbol	Name	Definition
A	A	Azimuth.
A_f	A sub f	Firing azimuth.
A_o	A sub o	Azimuth of target at instant of firing (present position).
A_p	A sub p	Azimuth of target at its predicted (future) position.
A_w	A sub w	Wind azimuth.
α	Alpha	Angle of approach.

Symbol	Name	Definition
α_o	Alpha sub o	Angle of approach of target at instant of firing (present position).
α_p	Alpha sub p	Angle of approach of target at its predicted (future) position.
β	Beta	Wind-fire angle.
CB	CB	Center of burst.
D	D	Slant range.
D_o	D sub o	Slant range of target at instant of firing (present position).
D_p	D sub p	Slant range of target at its predicted (future) position.
ΔA	Delta A	Change in azimuth.
$\Delta\epsilon$	Delta epsilon	Change in angular height.
ΔH	Delta H	Change in altitude.
ΔR	Delta R	Change in horizontal range.
ΔX	Delta X	Travel of the target in E-W direction during the time of flight.
ΔY	Delta Y	Travel of the target in N-S direction during the time of flight.
dH or $\%H$	dH or %H	Altitude correction.
$d\phi$	d phi	Quadrant elevation correction.
dt	dt	Time of flight correction.
dV	dV	Muzzle velocity correction.
δ	Delta	Lateral deflection angle.
δ_1	Delta sub 1	Principal lateral deflection angle.
δ_2	Delta sub 2	Lateral pointing correction.
δ_{2a}	Delta sub 2a	Lateral ajustment correction.
δ_{2d}	Delta sub 2d	Lateral pointing correction due to drift.
δ_{2w}	Delta sub 2w	Lateral pointing correction due to cross wind.
ϵ	Epsilon	Angular height.
ϵ_o	Epsilon sub o	Angular height of target at instant of firing (present position).
ϵ_p	Epsilon sub p	Angular height of target at its predicted (future) position.
F	F	Fuze range.
H	H	Altitude.
H_o	H sub o	Altitude of target at instant of firing (present position).
H_p	H sub p	Altitude of target at its predicted (future) position.
LD	LD	Lateral deflection setting.
$\not{m}$	Mils	Mils.
MV	MV	Muzzle velocity.
O_1	O-one	Observing station at battery.
O_2	O-two	Flank observing station.
PE	PE	Probable error.
π	Pi	3.1416.
ϕ	Phi	Quadrant elevation.

Symbol	Name	Definition
ϕ_s	Phi sub s	Superelevation under firing-table conditions.
ϕ_{sa}	Phi sub sa	Superelevation under conditions actually existing.
R	R	Horizontal range.
R_o	R sub o	Horizontal range to target at instant of firing (present position).
R_p	R sub p	Horizontal range to target at its predicted (future) position.
S_a	S sub a	Air speed of target.
S_g	S sub g	Ground speed of target.
Σ	Sigma	Angular velocity.
Σ_a	Sigma sub a	Angular velocity in azimuth.
Σ_e	Sigma sub e	Angular velocity in angular height.
σ	Sigma	Vertical deflection angle.
σ_1	Sigma sub 1	Principal vertical deflection angle.
σ_2	Sigma sub 2	Vertical pointing correction.
σ_{2a}	Sigma sub 2a	Vertical adjustment correction.
σ_{2d}	Sigma sub 2d	Vertical pointing correction due to density.
σ_{2V}	Sigma sub 2V	Vertical pointing correction due to muzzle velocity.
σ_{2w}	Sigma sub 2w	Vertical pointing correction due to range wind.
T	T	Position of target.
T_o	T sub o	Position of target at instant of firing (present position).
T_p	T sub p	Predicted (future) position of target.
t	t	Time of flight.
t_o	t sub o	Time of flight to present position of target.
t_p	t sub p	Time of flight to future position of target.
TSP	TSP	Trial shot point.
VD	VD	Vertical deflection setting.
W	W	Velocity of the ballistic wind.
X_o	X sub o	E-W component of horizontal range to target at instant of firing (present position).
X_p	X sub p	E-W component of horizontal range to target at its predicted (future) position.
Y_o	Y sub o	N-S component of horizontal range to target at instant of firing (present position).
Y_p	Y sub p	N-S component of horizontal range to target at its predicted (future) position.

SECTION II

ILLUSTRATIVE PROBLEMS

■ 248. O_1 AND O_2 DATA USING LEWIS CHART.—*a. Tabulation of steps.*—Tabulation is given below of successive steps to be followed:

(1) Fill in known data on the prepared form (*C* below):

Azimuth of base line (O_1–O_2) -----	As measured.
Length of base line (b) ----------	
Azimuth, O_1 to *TSP* (A_1) ---------	As selected.
TSP No.-------------------------	
Firing Tables No----------------	
Muzzle velocity-----------------	
Horizontal range, O_1 to *TSP* (R_1)	From firing table.
Altitude of *TSP* (H) ------------	
Angular height, O_1 to *TSP* (ϵ_1) ----	
ϕ ------------------------------	
F-------------------------------	

(2) Draw the position sketch and letter the proper points O_1, O_2, and *TSP*.

(3) Complete the upper half of the table by entering the known data and performing the indicated subtraction, resulting in the determination of ∠B (the O_1 angle).

(4) Select the proper section of the Lewis chart. ∠B (the O_1 angle) must be included in the abscissae numbers across the top. If R_1 is less than the base line, the "S" section is used.

(5) Place the log range scale on the vertical line whose abscissa equals ∠B with the graduation corresponding to the length of the base line on the zero ordinate line of the chart. Opposite the division on the log range scale equal to R_1 read ∠A (the O_2 angle). (See fig. 89.) ∠A and ∠B readings are always in the same relative positions; both readings are either the upper figures or the lower figures on the chart. Mark the point just determined on the chart T′.

(6) Fill in the value of ∠A in the table and perform the indicated addition resulting in the determination of the azimuth of *TSP* from O_2 (A_2).

(7) To determine the horizontal range O_2 to *TSP* (R_2), use the upper figures on the Lewis chart if ∠A and ∠B in (5) above were the lower figures (and vice versa). Determine the point on the chart whose abscissa is ∠A and the ordinate is ∠B. Mark this point T″. Place the log range scale on the vertical line through T″ with the graduation corresponding to the length of the base line on the zero ordinate line. Read the horizontal range O_2 to *TSP* (R_2) on the log range scale opposite the point T″.

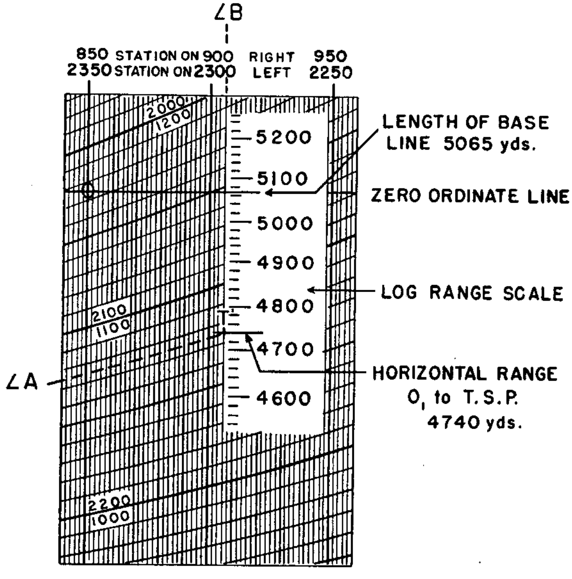


FIGURE 89.—Determining ∠A.

(8) To determine the angular height O_2 to *TSP* (ϵ_2), use the 1,600-mil scale on the left of the Lewis chart if *H* is less than R_2 and the scale on the right if *H* is greater than R_2. Place the log range scale on the 1,600-mil scale with the graduation corresponding to R_2 on the 800-mil mark. Opposite *H* on the log range scale read ϵ_2 on the 1,600-mil scale. (See fig. 90 and *c* below.)

b. Illustrative problem.—Assume the following basic data:

TSP No. 1, using 3″ AA shrapnel, Mk. I (normal *MV*, 2,600 f/s).
Azimuth *TSP* from O_1, 1,300 mils.
Azimuth of base line, 321 mils.
Length of base line, 6,444 yards.
O_1 and O_2 at the same elevation.

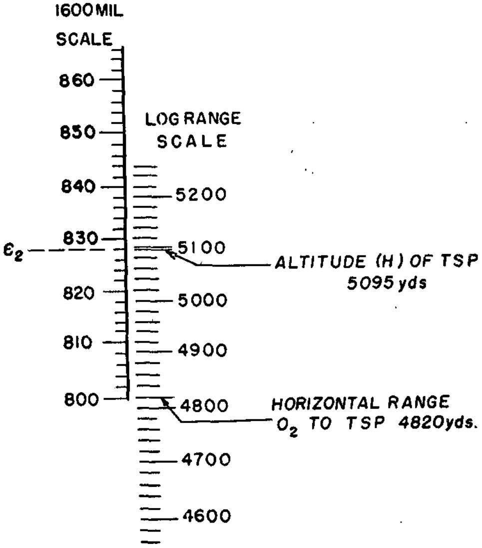


FIGURE 90.—Determining ϵ_2.

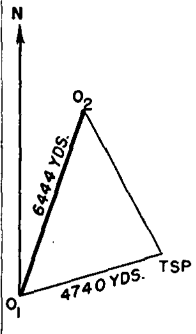
c. Form.—A form for the computation of the required O_1 and O_2 data using the Lewis chart is shown below:

FORM FOR USE WITH LEWIS CHART

(1)	Azimuth of base line (O_1-O_2)	321 mils	Determined by survey, or from a map.
	Length of base line (b)	6,444 yards	
	Azimuth, O_1 to *TSP* (A_1)	1,300 mils #	As selected.
	TSP No. 1 Firing Tables No. 3-AA-J-2a		
	MV 2,600 f/s.		
(2)	Horizontal range, O_1 to *TSP* (R_1)	4,740 yards	Selected from firing tables
	Altitude of *TSP* (H)	3,223 yards	ϕ = 700 mils
	Angular height, O_1 to *TSP* (ϵ_1)	608 mils #	F = 13
(3)	# Notify O_1 station		
(4)	Azimuth, O_2 to *TSP* (A_2)	2,700 mils ##	To be solved using the Lewis chart.
	Horizontal range, O_2 to *TSP* (R_2)	5,390 yards	
	Angular height, O_2 to *TSP* (ϵ_2)	549 mils ##	
(5)	## Notify O_2 station		

(6)

	O_1 is on the right	O_1 is on the left
Azimuth *TSP* from O_1 (A_1)	1,300	
Minus azimuth of base line	−321	╳
Minus back azimuth of base line	╳	
T′ plotted at abscissa ∠B	979	
Read ordinate ∠A at T′	2,379	
Plus azimuth of base line	+321	╳
Plus back azimuth of base line	╳	
Azimuth *TSP* from O_2 (A_2)	2,700	



NOTE.—Always draw a position sketch. Do not confuse A_1 and A_2 with ∠B and ∠A.

(1) In the form, sections (1), (2), (3), and (5) can be filled in immediately. Section (6) consists of a table and a position sketch. A sketch should always be drawn as it will help to identify the particular angles and sides of the triangles to be solved. It should be noted in the table in section (6)

that ∠B and ∠A are the coordinates of the point T′ on the Lewis chart. Also the entire computation in the table is in one column or the other, but never in both.

(2) The data to complete section (4) of the form is computed on the Lewis chart as follows:

(*a*) *First step.*—To determine ∠A (fig. 91) and from it the azimuth of *TSP* from O_2.

1. From the position sketch on the form it will be seen that O_1 is on the right of the base line (facing the field of fire). Fill in the upper half of the table section (6) of the form and perform the indicated subtraction. ∠B is now computed as 979 mils. (See par. 203.)

2. Section 2–S of the Lewis chart is required. (See chart facing page 218.) Place the log range scale on the vertical line of the Lewis chart whose abscissa is ∠B (979 m̸) with the length of the base line (6,444 yards) on the zero ordinate line. (See fig. 92.) Opposite the horizontal range to the *TSP* from O_1 (4,740 yards) mark the Lewis chart and call the point T′. Read the curve through T′. The value is the ∠A, in this problem 2,379 mils. Fill in the remainder of the table in section (6) of the form and perform the indicated addition. The azimuth of the *TSP* from O_2 has been computed (2.700m̸). Fill in the proper line of section (4) of the form.

(*b*) *Second step.*—To determine the horizontal range (R_2) to *TSP* from O_2. (See fig. 91.)

1. The known data are now the base line (6,444 yards) and the angles at each end of the base line. The included angle is now at the left of the base line (facing the field of fire). The lower figures on both the vertical lines and the curves of the Lewis chart are used.

2. Place the log range scale on the vertical line whose abscissa equals ∠A (2,379 mils) with the length of the base line (6,444 yards) on the zero ordinate line. (See fig. 92.) Read the value on the log range scale where the curve equal to 979 mils intersects it. Mark this point T″. This value is

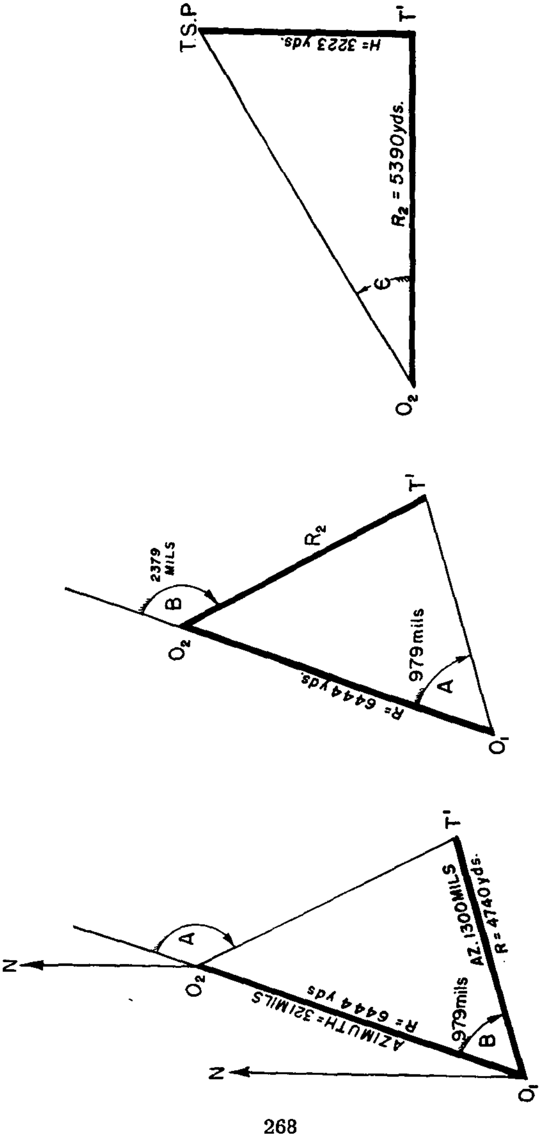


FIGURE 91.—Three steps in determining O_2 data.

R_2 (5,390 yards). Fill in R_2 on the proper line of section (4) of the form.

(*c*) *Third step*.—To determine the angular height (ϵ_2) of *TSP* from O_2. (See fig. 91.)

1. The known data, R_2 (5,390 yards) and H (3,223 yards), are two legs of a right triangle. Therefore use the 1,600-mil scale on the border of the Lewis chart. Since R_2 is greater than H, use the left-hand scale.

2. Place the log range scale on the 1,600-mil scale with R_2 (5,390 yards) opposite the 800-mil mark. (See fig. 92.) Opposite H (3,223 yards) on the log range scale read the angular height of *TSP* from O_2, on the 1,600-mil scale. This value is 549 mils. Fill in ϵ_2 on the proper line of section (4) of the form.

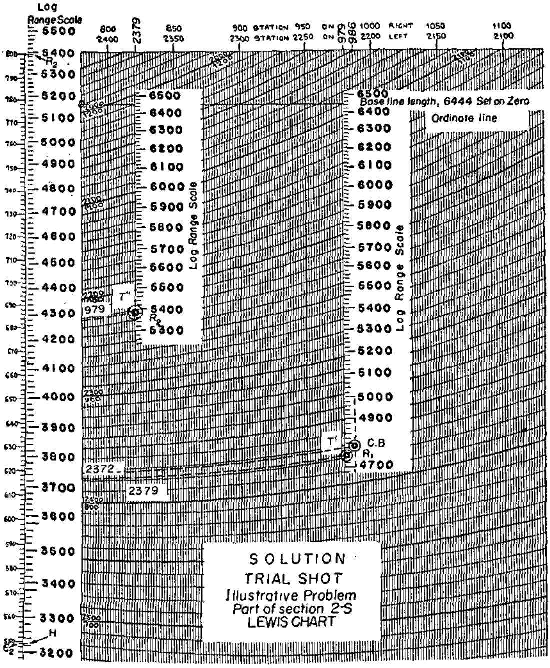


FIGURE 92.—O_1 and O_2 data from the Lewis chart.

■ 249. **O_1 and O_2 Data Using Crichlow Slide Rule** (par. 207).—*a. Tabulation of steps.*—Tabulation is given below of successive steps to be followed:

(1) Fill in known data on prepared form (*c* below):

Azimuth of base line (O_1–O_2) ------	As measured.
Length of base line (*b*) ------------	
Approximate azimuth, O_1 to *TSP*---	As selected.
TSP No.-------------------------	
Firing Tables No.----------------	
Muzzle velocity------------------	
Horizontal range, O_1 to *TSP* (R_1) --	From firing table.
Altitude of *TSP* (*H*) -------------	
Angular height, O_1 to *TSP* (ϵ_1) ----	
ϕ-------------------------------	
F-------------------------------	

(2) Draw a position sketch to scale similar to figure 93.

(3) Using the sketch constructed in (2) above, select the value of the azimuth of *TSP* from O_2 (A_2) so that A_1 will approximate the value desired.

(4) Using the prepared form, substract the azimuth of the base line from the O_2 azimuth of the *TSP* to obtain the O_2 angle, when O_2 is on the left. If O_2 is on the right, subtract the back azimuth of the base line from the O_2 azimuth of the *TSP* to obtain the O_2 angle.

(5) To determine the O_1 angle, set the arm "S" of the slide rule at the length of the base line on scale E. Without moving the arm "S", set the arm "L" at the value of R_1 on scale E. Without changing the angular displacement between the arms "S" and "L", set the arm "S" to the value of the O_2 angle on scale D. Under the arm "L" read target angle *T* on scale D. (A reference to the position sketch will indicate which of the two values to read. One is greater than and the other less than 1,600 mils.) The target angle *T* is equal to the difference between the exterior angle on the left and the interior angle on the right. The O_1 angle is obtained by performing the addition or substraction indicated on the form.

(6) Add the azimuth of the base line to the O_1 angle to obtain the azimuth of *TSP* from O_1, if O_1 is on the right. If O_1 is on the left add the back azimuth of the base line to the O_1 angle.

(7) To determine the horizontal range O_2 to *TSP* (R_2), set the arm "S" of the slide rule at the value of the O_1 angle on scale D. Without moving the arm "S", set the arm "L" at the value of the target angle (*T*) on scale D. Without changing the angular displacement of the arms "S" and "L", set the arm "S" to the length of the base line on scale E. Under the arm "L" read R_2 on scale E.

(8) To determine the angular height O_2 to *TSP* (ϵ_2), set the arm "S" of the slide rule on the smaller of the values of *H* or R_2 on scale E. Without moving the arm "S", set the arm "L" on the larger of the values of *H* or R_2 on scale E. Without changing the angular displacement of the arms "S" and "L", set the arm "S" on the "index". Read the value of ϵ_2 under the arm "L" on scale C. (ϵ_2 will be greater than 800 mils if *H* is greater than R_2.) (See illustrative problem below.)

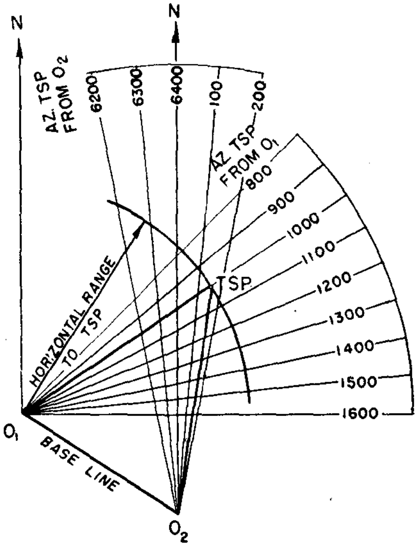


FIGURE 93.—Position sketch.

b. Illustrative problem.—Assume the following basic data:

TSP No. 1, using 3″ AA shrapnel Mk. I (normal MV, 2,600 f/s).
Approximate azimuth of *TSP* from O_1, 1,400 mils.
Azimuth of base line, 321 mils.
Length of base line, 6,444 yards.
O_1 and O_2 are at the same elevation.

c. Form.—A form for the computation of the required O_1 and O_2 data using the Crichlow slide rule is shown on opposite page. In working problems by this method it is essential that a position sketch be drawn similar to figure 94. First, the position sketch assists in selecting the azimuth of *TSP* from O_2 so that the azimuth of *TSP* from O_1 will be close to the approximate azimuth selected. Second, as can be seen from figure 94, the problem has two solutions for given values of O_2 and R_1. This is because the sine of the exterior angle at *T* is equal to the sine of the interior angle at *T*. One angle will be greater than 1,600 mils, the other less than 1,600 mils. The target angle *T*, which is the angle desired, is the interior angle. A reference to the position sketch will show which value to select.

(1) Fill in the data in sections (1), (2), and (3) of the form. Using the position sketch select the azimuth of *TSP* from O_2, and enter this value (2,720 m̸) on the proper line of section (2) of the form.

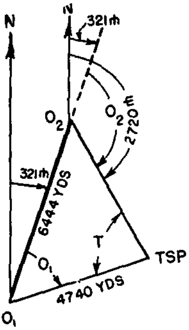
(2) Fill in the known data in section (4) and perform the indicated subtraction. The angle at O_2 is 2,399 mils.

(3) On the Crichlow slide rule, set the arm "S" to the length of the base line (6,444 yards) on scale E. Without moving arm "S", set arm "L" to R_1 (4,740 yards) on scale E. Without changing angular displacement of arms "S" and "L", set arm "S" to the O_2 angle (2,399 m̸) on scale D. Under arm "L" read target angle *T* (1,315 m̸) on scale D. (See *c* above.) Enter this value on the proper line of section (4) of the form. Complete the indicated subtraction in section (4). The O_1 angle is therefore 1,084 mils. Complete the indicated operation of the table in section (4). The azimuth of *TSP* from O_1 (1,405 m̸) has now been determined.

FORM FOR USE WITH CRICHLOW SLIDE RULE

(1)	Azimuth of base line (O_1-O_2)	321 mils	Determined by survey or from a map.
	Length of base line (b)	6, 444 yards	
(2)	Approximate azimuth O_1 to *TSP*	1, 400 mils	As selected.
	## Azimuth O_2 to *TSP* (A_2) (from position sketch).	2, 720 mils	
	TSP No. 1 Firing Tables No. 3 AA-J-2a		
	MV 2,600 f/s		
(3)	Horizontal range O_1 to *TSP* (R_1)	4, 740 yards	Selected from firing tables.
	Altitude of *TSP* (H)	3, 223 yards	
	#Angular height O_1 to *TSP* (ϵ_1)	608 mils	
	ϕ = 700 mils	F = 13	

		O_2 is on the right	O_2 is on the left
(4)	Azimuth of *TSP* from O_2		2, 720
	Add 6,400 if necessary		
	Subtract azimuth of base line	╳	321
	Subtract back azimuth of base line		╳
	O_2 angle		2, 399
	Target angle (T)	(+)	╳
	Target angle (T)	╳	(−)1, 315
	O_1 angle		1, 084
	Add azimuth of base line	╳	321
	Add back azimuth of base line		╳
	Azimuth of *TSP* from O_1		1, 405



NOTE.—Always draw a position sketch.

(5)	Horizontal range O_2 to *TSP* (R_2)	5, 860 yards	To be solved using the Crichlow slide rule.
	##Angular height O_2 to *TSP* (ϵ_2)	512 mils	

(6) #Notify O_1 station

(7) ##Notify O_2 station

(4) Next solve for R_2 using the rules for the solution of oblique triangles printed on the face of the slide rule. R_2 equals 5,860 yards. Fill in R_2 on the proper line of section (5) of the form.

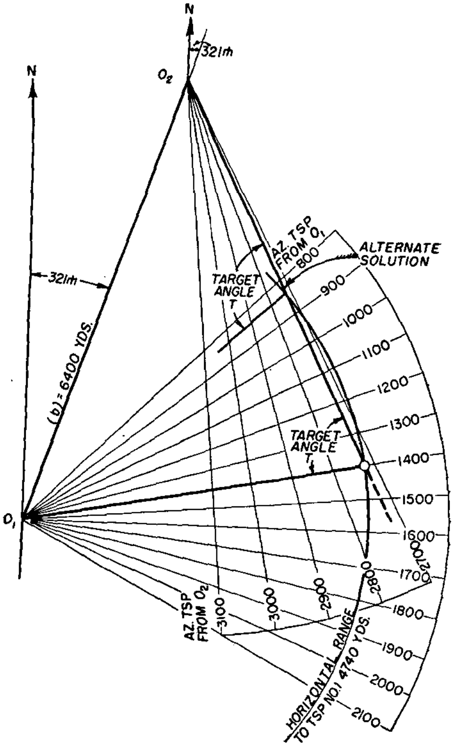


FIGURE 94.—Position sketch for Crichlow slide rule method.

(5) Solve for ϵ_2 using the rules for the solution of right triangles given on the face of the slide rule. ϵ_2 equals 512 mils. Fill in ϵ_2 on the proper line of section (5) of the form.

■ 250. **BALLISTIC CORRECTIONS**—*a*. Assume the following:

TSP No. 1 is being used. (Shrapnel.)

The assumed developed *MV* is -58 f/s below normal. (See problem, par. 254.)

The assumed fuze correction is —1 corrector division. (See problem, par. 254.)

Ballistic density (from meteorological message) is 98 (—2%) in the zone where the *TSP* is located.

Powder temperature is 60° F.

b. Determine—

(1) Ballistic corrections to be applied prior to the trial fire.

(2) Total corrections to be applied for fire for effect at a target which appears at an altitude of 4,000 yards and fuze 16.

c. Determination of initial ballistic corrections.

(1) Muzzle velocity deviation.

The developed muzzle velocity variation = —58 f/s
Density effect (for —2%) = +25 f/s
(From table VIII, par. 256)
Powder temp. effect (for 60° F. from table IX, par. 256) = —16 f/s

Total muzzle velocity deviation = —49 f/s
Tables V and III for—50 f/c are therefore selected.
For *TSP* No. 1, $H = 3{,}223$ yards
$F = 13.0$ (approximately)
Then, $dH_o = +45$ yards (interpolating), and $d\phi = +2$ ᵯ

(2) Fuze correction.

The fuze correction will be $\frac{2}{10}$ of that given in table II, paragraph 256 since density is —2% and the table is computed for —10%.

$dF = -\frac{2}{10} \times 10 = -2 = -2$ corrector divisions $= -.2$ fuze.

The trial shots are then fired with the following corrections on the proper spot dials of the director:

$dH_o = +45$ yards.
$d\phi = +2$ ᵯ
$dF = -3$ divisions (this includes the constant fuze error of —1 division assumed in *a* above).
$dA = +3$ ᵯ (the M4 director, has a flat correction of 10 mils for drift, while for *TSP* No. 1 the drift is only 7 ᵯ).

■ 251. **TRIAL FIRE CORRECTIONS USING TRIAL SHOT CHART** (pars. 103 and 107).—*a*. Assume that a trial shot problem has been fired at the *TSP* determined in paragraph 248. Ballistic corrections were computed and applied prior to the firing. (See problem, par. 250.) The average deviations of the *CB* were:

DEVIATIONS OF TRIAL SHOTS (Observed)

Shot No.	O_1 station				O_2 station	
	Above	Below	Left	Right	Left	Right
1						
2						
3						
4						
5						
6						
Total						
Alegbraic total						
Average	A-5		R-6		L-6	

b. Using conversion chart (fig. 41), or the Crichlow slide rule, the lateral deviations of the *CB* are converted into corresponding deviations measured in the horizontal plane as follows:

	O_1 station				O_2 station	
	Above	Below	Left	Right	Left	Right
Observed deviations of *CB*	5			6	6	
Deviations of *CB* converted to horizontal plane				7	7	
Correction, (*dA*)			7		(for O_1 only)	

c. Using the Lewis chart or Crichlow slide rule, compute the horizontal range to the *CB* from O_1. (See par. 105*a*.)

Horizontal range to *CB*=4,795 yards.

d. Plot the *CB* on the trial shot chart, as shown in figure 95, using the horizontal range to *CB* (4,795 yards) and the vertical deviation of the *CB* (+5 mils).

e. To determine the altitude correction, draw a line through the *CB* parallel to the ϕ line and project the point where it intersects the line of position horizontally to the left-hand margin and read the $\%H$ correction=—1.5% (98.5 on scale).

f. The $d\phi$ correction equals the vertical deviation of the *CB* with the sign changed.

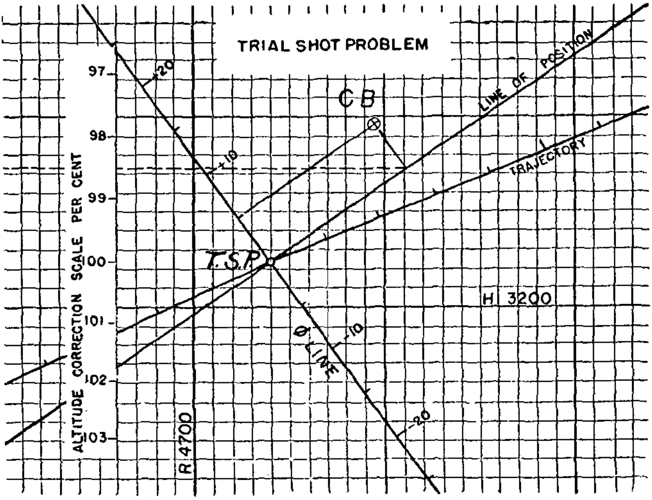


FIGURE 95.—Determinations of trial shot corrections from the trial shot chart.

g. Trial shot corrections:

$dA = -7$m̸; $d\phi = -5$m̸; $dH = -1.5\%$

■ 252. TOTAL CORRECTIONS, FIRE FOR EFFECT.—*a.* To determine the total corrections to be applied for fire for effect at a target at an expected altitude of 6,000 yards and fuze 16.

(1) Assume that the trial shots are fired and that the corrections obtained therefrom are:

$d\phi$	$\%H$	dA
—5m̸	—1.5%	—7m̸ (see previous problem, par. 251).

(2) The total corrections for fire for effect will be the algebraic sum of the trial fire corrections and the ballistic corrections for the actual altitude and fuze range of the target. The ballistic conditions are the same as in the problem, paragraph 250.

Approximate altitude of target 6,000 yards
Approximate fuze range of target 16.0

	Constant fuze error	Ballistic corrections	Trial fire corrections	Total corrections
dF	−1 (1)	−2 (2)		−3 corrector divisions.
$d\phi$		+2 m̸ (3)	−5 m̸	−3 m̸.
dH		+ 80 yards (4)	−1.5 percent of 6,000 yards −90 yards.	−10 yards.
dA			−7 m̸	−7 m̸.

NOTES: 1. See problem, paragraph 254.
2. Table II, paragraph 256.
−10% (at H–6,000 and F–16) $dF=-9$ corrector divisions.
∴ −2% (at H–6,000 and F–16) $dF=-1.8$ corrector divisions.
3. Table V, paragraph 256. H–6,000, F–16.
4. Table III, paragraph 256. MV −50 f/s, H–6,000.

b. If no opportunity had been afforded to fire trial shots, fire would have been opened on this target with only the ballistic corrections for the altitude and fuze range of the target. (See ballistic corrections above.)

$dF=-3$ corrector divisions. (Includes constant fuze error.)
$d\phi=+2$ mils.
$dH_o=+80$ yards.

■ 253. CALIBRATION CORRECTIONS USING TRIAL SHOT CHART (pars. 122, 125, and 129).—*a*. Assume the following data:

Given a battery of four guns emplaced as in figure 96. It has been decided to calibrate the guns using the following data:

Azimuth of base line=500 mils.
Length of base line=5,350 yards.
Azimuth of calibration point from O_1=1,560 mils.
TSP No. 1, using 3″ AA shrapnel Mk. 1 (normal *MV*, 2,600 f/s is selected as the calibration point.
O_1 and O_2 are at the same elevation.

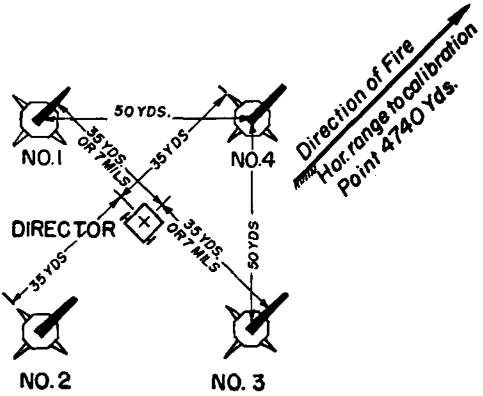


FIGURE 96.—Emplacement of battery and lateral parallax corrections.

b. Using the following form, compute the O_1 and O_2 data for calibration point selected by the Lewis chart method.

(1) Azimuth of base line (O_1–O_2) 500 mils
Length of base line (b) 5,350 yards
} Determined by survey or from a map.
Azimuth, O_1 to CP (A_1) 1,560 mils #
TSP No. 1 Firing Tables No. 3-AA-J-2a
MV 2,600 f/s
} As selected.

(2) Horizontal range, O_1 to CP (R_1) 4,740 yards
Altitude of *TSP* (H) 3,223 yards
Angular height, O_1 to CP (ϵ_1) 608 mils #
} Selected from firing tables ϕ=700 mils. F=13

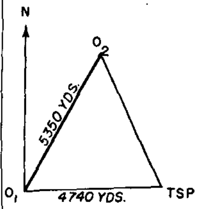
(3) # Notify O_1 station

(4) Azimuth, O_2 to CP (A_2) 2,737 mils ##
Horizontal range, O_2 to CP (R_2) 5,045 yards
Angular height, O_2 to CP (ϵ_2) 579 mils ##
} To be solved using Lewis chart.

(5) ## Notify O_2 station

(6)

	O_1 is on the right	O_1 is on the left
Azimuth *TSP* from O_1 (A_1)	1,560	
Minus azimuth of base line	−500	╳
Minus back azimuth of base line	╳	
T′ plotted at abscissa ∠*B*	1,060	
Read ordinate ∠*A* at T′	2,237	
Plus azimuth of base line	500	╳
Plus back azimuth of base line	╳	
Azimuth *TSP* from O_2 (A_2)	2,737	



NOTE.—Always draw a position sketch.

(The above data may be computed using the Crichlow slide rule.)

c. The calibration shots were fired and the following table shows the observed deviations of each burst:

RECORD OF DEVIATIONS

(Calibration fire)

Gun No. 1

Shot No.	O_1				O_3	
	A	B	L	R	L	R
1	7	---	4	---	---	23
2	5	---	3	---	---	26
3	---	2	---	1	---	17
4	10	---	5	---	---	15
5	8	---	2	---	---	16
6	---	---	---	---	---	---
7	---	---	---	---	---	---
Total	30	2	14	1	---	97
Algebraic total	28	---	13	---	---	97
Average	6	---	3	---	---	19

Gun No. 2

Shot No.	O_1				O_2	
	A	B	L	R	L	R
1	10	---	6	---	---	23
2	8	---	8	---	---	28
3	2	---	4	---	---	20
4	7	---	6	---	---	17
5	6	---	7	---	---	25
6	---	---	---	---	---	---
7	---	---	---	---	---	---
Total	33	---	31	---	---	113
Algebraic total	33	---	31	---	---	113
Average	7	---	6	---	---	23

Gun No. 3

Shot No.	O_1				O_2	
	A	B	L	R	L	R
1	10	---	---	4	---	21
2	13	---	2	---	---	15
3	13	---	line		---	20
4	11	---	---	3	---	14
5	9	---	---	5	---	20
6	---	---	---	---	---	---
7	---	---	---	---	---	---
Total	56	---	2	12	---	90
Algebraic total	56	---	---	10	---	90
Average	11	---	---	2	---	18

Gun No. 4

Shot No.	O_1				O_2	
	A	B	L	R	L	R
1	line		line		---	10
2	3	---	2	---	---	12
3	line		line		---	18
4	4	---	4	---	---	15
5	1	---	---	1	---	9
6	---	---	---	---	---	---
7	---	---	---	---	---	---
Total	8	---	6	1	---	64
Algebraic total	8	---	5	---	---	64
Average	2	---	1	---	---	13

d. Plot points *C*1, *C*2, *C*3, and *C*4 on the trial shot chart (fig. 97) for each of the guns, using as a basis:

Gun	H	R
1	3, 223	4, 740
2	3, 223	4, 705
3	3, 223	4, 740
4	3, 223	4, 775

(See par. 127.)

e. Tabulate the lateral deviations and convert to the horizontal plane using conversion chart (fig. 41) or Crichlow slide rule.

LATERAL DEVIATIONS OF CALIBRATION SHOTS

(Observed *CB*)

Gun No.	O_1 station				O_2 station			
	(1) Observed		(2) Converted to horizontal plane		(3) Observed		(4) Converted to horizontal plane	
	Left	Right	Left	Right	Left	Right	Left	Right
1	3		4			19		23
2	6		7			23		27
3		2		2		18		21
4	1		1			13		15

f. Using either the Lewis chart or Crichlow slide rule, compute the horizontal range to the *CB* of each gun. Tabulate below with the vertical deviations. (See par. 105*d*.)

CB No.	(5) Horizontal Range to *CB*	(6) Vertical deviation of *CB*
*CB*1	4, 615	Above 6
*CB*2	4, 580	Above 7
*CB*3	4, 625	Above 11
*CB*4	4, 655	Above 2

g. The *CB* for each individual gun is plotted in the same manner as described in the trial shot problem. (Horizontal range and vertical deviation to the center of burst.) (See par. 105*d*.) *CB*1, *CB*2, *CB*3, and *CB*4 are shown plotted in figure 97.

h. Through *C*2 and *C*4, draw lines parallel to the trajectory. The trajectory line of the trial shot chart is used for guns Nos. 1 and 3. From each *CB*, draw a line parallel to the ϕ line until it intersects its trajectory line.

i. Measure the deviation in quadrant elevation from each *CB* to the respective trajectory line. From the point of intersection with the trajectory line measure the fuze error to the calibration point. Tabulate these errors with reversed signs and they become the initial corrections. (See fig. 97.)

CB No.	Corrections	
	(7) dF	(8) $d\phi$
1	+4	−2
2	+4	+1
3	+3	−8
4	+4	−2

j. Consideration must be given to lateral parallax, when the guns are emplaced in the square formation, in order to obtain proper lateral corrections. This parallax for the flank guns is 7 mils for the normal 50 yard square. Therefore minus 4 mils must be subtracted from the parallax correction of No. 1 gun. Likewise, minus 2 mils must be subtracted from the parallax correction of No. 3 gun, to obtain proper corrections. (See par. 129*b*.)

LATERAL CALIBRATION CORRECTIONS

No.	(9) Gun parallax	(10) Center of burst (observed)	(11) dA (9)−(10)
1	(−7)	−4	−3
2	0	−7	+7
3	(+7)	+2	+5
4	0	−1	+1

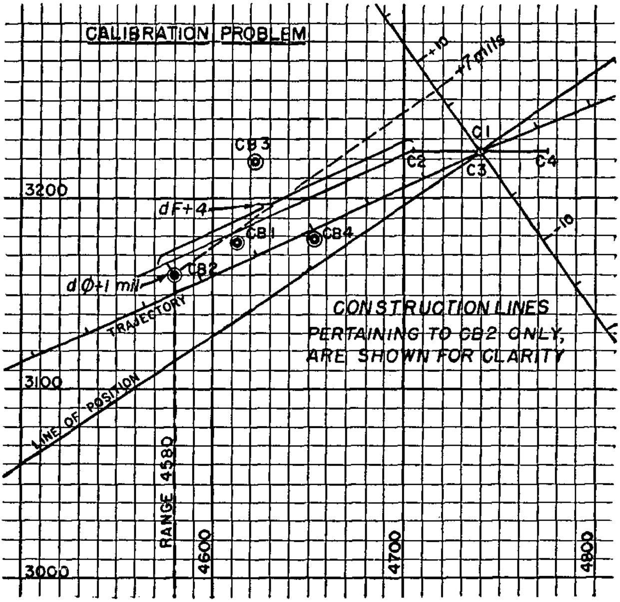


FIGURE 97.—Calibration corrections using trial shot chart.

k. Tabulate the $d\phi$, dF, and dA corrections.

Gun No.	From Column (8) $d\phi$	From Column (7) dF	From Column (11) dA
1	−2	+4	−3
2	+1	+4	+7
3	−8	+3	+5
4	−2	+4	+1

l. Select the base piece. In this problem, either No. 1, 2, or 4 could be selected, with the resultant fuze error being held to the minimum. No. 1 is selected as the base piece. Final calibration corrections are obtained by subtracting the corrections for the base piece from the corrections for the other guns. Tabulate the results as follows:

	Gun No.	$d\phi$	dF	dA
Base piece Gun No. 1	1	0	0	0
	2	+3	0	+10
	3	−6	−1	+8
	4	0	0	+4

Apply these corrections to the indicators on the guns and record them for future use with orientation and synchronization procedure. (See par. 236.)

■ 254. **DEVELOPED *MV* AND FUZE ERROR USING THE TRIAL SHOT CHART** (pars. 133 and 135).—*a*. Assume the following data: O_1 and O_2 stations are located as in the trial shot problem above (pars. 248 and 251).

The following trial shot problems have been selected and the necessary data extracted. *TSP* No. 1, using 3″ AA shrapnel, Mk. I (normal *MV* 2,600 f/s) was used in each case. All problems were fired at the same azimuth.

Problem No.	Density	Powder temperature	Deviations	
			Vertical	Horizontal range to CB
	Percent	°*F.*	*Mils*	*Yards*
1	100	80	0	4,710
2	102	70	−4	4,630
3	100	65	−3	4,680
4	98	64	−5	4,755
5	104	50	−2	4,530
6	corrected		−3	4,733
7	corrected		0	4,730
8	corrected		−5	4,685
9	corrected		−6	4,688
10	corrected		−5	4,710

b. It is desired to obtain a *CB* for the group of problems. Since some of the problems were fired without corrections for density and powder temperature, it is necessary to correct the location of the *CB* before plotting the *CB* on the trial shot chart. The computation of corrected horizontal range to *CB* and vertical deviation of *CB* follows:

Problem No.	*R*	Corrected range		Corrected range	$d\phi$	Corrected Vertical Deviation		
		Density correction	Temperature correction			Density correction	Temperature correction	Correction $d\phi$
1	4,710	0	−19	4,691	0	0	−1	−1
2	4,630	+83	0	4,713	+4	−1	0	+3
3	4,680	0	+9	4,689	−3	0	0	−3
4	4,755	−83	+10	4,682	−5	+1	0	−4
5	4,530	+166	+38	4,734	−2	−3	+1	−4
6	4,733	0	0	4,733	−3	0	0	−3
7	4,730	0	0	4,730	0	0	0	0
8	4,685	0	0	4,685	−5	0	0	−5
9	4,688	0	0	4,688	−6	0	0	−6
10	4,710	0	0	4,710	−5	0	0	−5
Total				47,027				−28
Average				4,703				−3

In determining the above density and temperature corrections, the density and temperature variations from standard are reduced to *MV* effects using tables VIII and IX, paragraph 256. Effect of total *MV* variation on *R* and ϕ are obtained from differential effects in Firing Tables 3 AA–J–2a (F–1 and F–3).

c. The values of the corrected range (4,703 yards) and the corrected vertical deviation (−3 mils) are used to plot the center of burst on the trial shot chart. (See fig. 98.) The *CB* is plotted at a horizontal range of 4,703 yards and 3 mils below the line of position. (The 3 mils being measured parallel to the quadrant elevation (ϕ) line.) Draw a line through the *CB* parallel to the trajectory until it intersects the muzzle velocity line. The length of this line applied to the scale on the trajectory indicates that a minus 0.1 fuze correction is needed to move the *CB* to the muzzle velocity line. The point of intersection on the muzzle velocity line corresponds to a developed muzzle velocity of 58 f/s below normal.

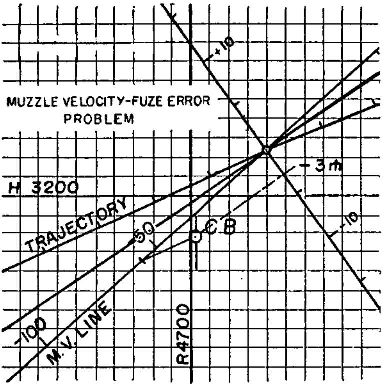


FIGURE 98.—Determination of developed *MV* and fuze error using the trial shot chart.

d. In case the retained records verified the fact that all of the trial shot problems had not been fired at the same azimuth, the procedure below may be used for obtaining the horizontal range to each center of burst.

(1) Assume the following data:

O_1 and O_2 stations are located as in problem in paragraph 248.

The following trial shot problems have been selected and the necessary data extracted. *TSP* No. 1 using 3″ AA shrapnel, Mk. I, (normal MV—2,600 f/s) was used in each case.

Problem No.	Azimuth of *TSP* from O_1	Density in %	Powder temperature	O_1 lateral deviations	O_1 vertical deviations	O_2 range deviations
1	1,450	Corr.	Corr.	L-6	A-1	R-13
2	1,450	Corr.	Corr.	L-4	B-2	R-15
3	1,450	Corr.	Corr.	line	B-1	R-20
4	1,300	Corr.	Corr.	R-2	B-3	R-16
3	1,300	Corr.	Corr.	L-2	A-2	R-22
6	1,300	Corr.	Corr.	R-4	B-1	R-25
7	1,300	Corr.	Corr.	L-6	B-4	R-14
8	1,100	Corr.	Corr.	L-4	A-1	R-19
9	1,100	Corr.	Corr.	L-2	B-2	R-15
10	1,100	Corr.	Corr.	L-2	B-1	R-35

(2) It is desired to obtain a *CB* for the group of ten problems. Since the problems were not fired at the same azimuth, it will be necessary to convert the range deviations to yards. Plot each *TSP* and *CB* on the Lewis chart (or solve by Crichlow slide rule) and measure the horizontal range to each *CB* from O_1. (See par. 105.) The results are tabulated below.

Problem No.	Horizontal range to *CB*	Vertical deviation of *CB*	
		Above	Below
1	4,635	1	--------
2	4,630	--------	2
3	4,595	--------	1
4	4,640	--------	3
5	4,600	2	--------
6	4,590	--------	1
7	4,650	--------	4
8	4,640	1	--------
9	4,660	--------	2
10	4,560	--------	1
Total	46,200	4	14
Average	4,620	--------	1

Using this average horizontal range(4,620 yards) and vertical deviation (below 1 mil), proceed as in *c* above.

SECTION III

BALLISTIC TABLES

■ 255. **METHOD OF COMPUTING.**—*a.* The effects of atmospheric density, variation in developed *MV*, and temperature of the powder can be corrected for by application of corrections to the $d\phi$, dF, and dH spot dials. The amount of the correction is a variable. Tables have been prepared which give the corrections for various fuze ranges and altitudes for two combinations of guns and ammunition. The use of these tables is explained in paragraph 100. The tables are given in this section.

b. For example, Table VII, vertical corrections in mils for 100 f/s variation from normal *MV*, is computed as follows:

(1) Extracting from table F–3, Firing Tables 3 AA–J–2a we get the effect on angular height due to 100 f/s variation in *MV*.

Time of flight	Quadrant elevation				
	500	600	700	800	
10	2.8	2.7	2.6	2.4	Values for odd times of flight are interpolated.
11	3.1	3.0	2.9	2.7	
12	3.4	3.3	3.2	3.2	
13	3.7	3.6	3.5	3.3	
14	4.0	3.9	3.8	3.6	

(2) Insert the above values on the trajectory chart 3 AA–J–2a. A portion of the chart is shown in figure 99.

(3) Extract from the trajectory chart the vertical corrections by interpolation for the various fuzes and altitudes, that is, the points circled on figure 99.

Fuze	Altitude in yards		
	2,500	3,000	3,500
11	2.8	2.8	-------
12	3.1	3.1	3.0
13	3.4	3.4	3.4
14	3.7	3.7	3.7

(4) The smallest correction made in $d\phi$ is 2 mils. The above table is changed to read to the nearest 2 mils.

Fuze	Altitude in yards		
	2,500	3,000	3,500
11	2	2	-----
12	4	4	4
13	4	4	4
14	4	4	4

c. Tables IV, V, and VI are constructed by taking proportional parts of the table in *b*(3) above and then changing all values to read to the nearest 2 mils.

d. Tables **XIV**, **XV**, **XVI**, and **XVII** are constructed in the same manner as shown in *b* and *c* above, using Firing Tables and trajectory chart 3 AA–O–1.

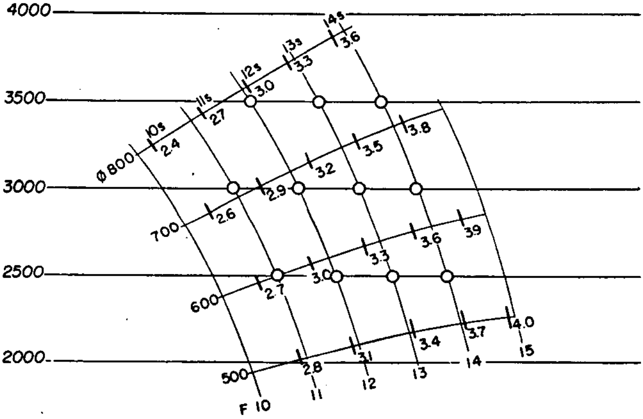


FIGURE 99.—Section of trajectory chart 3 AA–J–2a.

e. Table III, altitude corrections in yards for 100 f/s variation from normal *MV*, is computed as follows:

(1) Extracting from table F–2, Firing Tables 3 AA–J–2a, we get the effect on altitude due to 100 f/s variation in *MV*.

Time of flight	Quadrant elevation			
	500	600	700	800
10	68	81	93	105
11	71	84	97	109
12	73	87	100	113
13	75	90	104	117
14	77	92	107	121

(2) Insert the above values on the trajectory chart 3 AA–J–2a. A portion of the chart is shown in figure 100.

(3) Extract from the trajectory chart, by interpolation, the effect of variation in *MV* on altitude for various fuze ranges and altitudes, that is, the points circled on figure 100.

Fuze	Altitude in yards		
	2,500	3,000	3,500
11	83	97	-------
12	82	97	111
13	82	97	111
14	82	------	-------

(4) The vertical corrections for variation in *MV* have an effect on the altitude also, and are always in such a direction so as to reduce the amount of the altitude correction necessary. Extracting from table E–2, Firing Tables 3 AA–J–2a, we get the effect of 10 mils change in ϕ on the altitude.

Time of flight	Quadrant elevation			
	500	600	700	800
10	43	41	39	36
11	46	44	41	38
12	49	47	44	41
13	52	50	47	44
14	55	53	50	46

(5) Insert the above values on the trajectory chart 3 AA–J–2a. A portion of the chart is shown in figure 100.

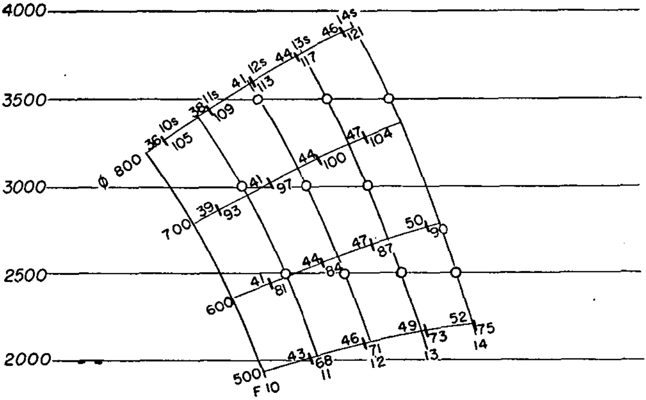


FIGURE 100.—Section of trajectory chart 3 AA–J–2a.

(6) Extract from the trajectory chart, by interpolation, the effect of 10 mils change in ϕ on altitude for various fuzes and altitudes, that is, the points circled on figure 100.

Fuze	Altitude in yards		
	2,500	3,000	3,500
11	42	40	--------
12	45	43	41
13	48	47	45
14	52	----	--------

(7) Combining the tables in (3) and (6) above:

Fuze		Altitude in yards			
		2,500	3,000	3,500	
11	Altitude effect	83	97		From (3) above (1)
	$d\phi$ effect in mils	−2	−2		From Table VII (2)
	Effect of 10 mph on H	42	40		From (6) above (3)
	A 2-mil proportional effect of $d\phi$ on H.	−8	−8		(2)×(3)×(.1) (4)
	Algebraic sum	75	89		(1)+(4) (5)
12	Altitude effect	82	97	111	
	$d\phi$ effect	−4	−4	−4	
	Effect of 10 mph on H	45	43	41	
	A 4-mil proportional effect of $d\phi$ on H.	−18	−17	−16	
	Algebraic sum	64	80	95	
13	Altitude effect	82	97	111	
	$d\phi$ effect	−4	−4	−4	
	Effect of 10 mph on H	48	47	45	
	A 4-mil proportional effect of $d\phi$ on H.	−19	−19	−18	
	Algebraic sum	63	78	93	
14	Altitude effect	82			
	$d\phi$ effect	−4			
	Effect of 10 mph on H	−52			
	A 4-mil proportional effect of $d\phi$ on H.	−21			
	Algebraic sum	61			

(8) Extracting from the table in (7) above:

Fuze	Altitude in yards		
	2, 500	3, 000	3, 500
11	75	89	--------------
12	64	80	95
13	63	78	93
14	61	------------	--------------

Examination of the entire table above will show that an average value for all fuze ranges at a particular altitude can be taken without introducing excessive errors. The portion of table III pertaining to 100 f/s variation in *MV* is made in this manner.

(9) The remainder of table III is completed by duplicating the process in (7) above using proportional parts for the altitude effect and table IV, V, or VI for the $d\phi$ effect.

f. Tables X, XI, XII, and XIII are constructed in the same manner as illustrated in *e* above using Firing Tables and trajectory chart 3 AA–O–1. However the final form of the table is different. In table III, an average value for all fuze ranges at a particular altitude was sufficiently accurate for the purpose. But tables X, XI, XII, and XIII, if constructed in this manner, would not have the accuracy desired. Hence, a proportional part of each altitude correction, for each variation of 25 f/s muzzle velocity at all fuze ranges, will cause erroneous results. This is caused primarily by the $d\phi$ variation at different fuze ranges. Therefore, a separate table is made for each 25 f/s *MV* variation and corrections are given for fuze ranges and altitudes.

g. Table VIII. *MV* correction for atmospheric density. The density effect has a proportional relationship to a variation in *MV*. *A* +10 percent change in density is equivalent to —125 f/s variation in *MV*. Other density effects are obtained by taking proportional parts. This table should not be confused with tables I and II which are the corrections for burning of the powder train fuzes due to atmospheric density. The table is applicable to all muzzle velocities.

h. Table IX. *MV* correction for temperature of the powder. The data for this table were obtained from part 1H, page 6, Firing Tables 3 AA–O–1. (See fig. 102.) This chart gives the change in *MV* direct for 2,700 f/s *MV*. The values for the different powder temperatures are changed to per cent as shown in the table by the solution of the formula:

$$\text{per cent change in } MV = \frac{\text{change in } MV \text{ in f/s}}{2{,}700}$$

The percentage is applicable to all muzzle velocities.

CAUTION: Do not use the charts given in some firing tables in which the percentage change in MV *due to powder temperature is plotted as a curved line.*

■ 256. TABLES.—*a.* Tables I to VII, inclusive, are for shrapnel Mk. I with fuze Mk. III (powder train), normal cam *MV*, 2,550 f/s, Firing Tables 3 AA–J–2a.

b. Tables VIII and IX are applicable to all 3" AA ammunition.

c. Tables X to XVII, inclusive, are for M42 HE shell with fuze, M43 (mechanical), normal cam *MV*, 2,700 f/s, Firing Tables 3 AA–O–1.

FT 3 AA–J–2a

TABLE I

FUZE CORRECTIONS NEEDED FOR 10 PERCENT INCREASE IN DENSITY

Corrections are plus corrector divisions

(Altitude in yards)

Fuze	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000
3	2	2													
4	3	3	3												
5	3	3	3	3											
6	4	4	4	4	4										
7	5	4	4	4	4	4									
8	5	5	5	5	5	4	4								
9	6	6	6	6	5	5	5	5							
10	7	6	6	6	6	6	6	5	5						
11	8	7	7	7	7	7	6	6	6						
12	9	8	8	8	8	8	7	6	6	6					
13	10	10	9	9	9	9	8	7	6	6	6				
14	12	11	10	10	10	9	9	8	7	7	6	6			
15	13	12	11	11	11	10	9	9	8	8	7	6	6		
16	13	12	12	12	11	11	10	10	9	9	8	7	6		
17	13	13	13	13	12	12	11	11	10	9	8	8	7	6	
18	14	14	13	13	12	12	12	11	10	10	9	8	7	6	6
19	14	14	14	13	13	12	12	12	11	11	10	9	8	7	6
20	15	15	14	14	14	13	13	12	12	11	11	10	8	7	6
21	16	16	15	14	14	13	13	13	12	12	11	10	9	8	6

TABLE II

FUZE CORRECTIONS NEEDED FOR 10 PERCENT DECREASE IN DENSITY

Corrections are minus corrector divisions

(*Altitude in yards*)

Fuze	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
3	-3	-3													
4	-3	-3	-3												
5	-4	-4	-4	-3											
6	-5	-5	-4	-4	-4										
7	-6	-5	-5	-5	-5	-5									
8	-7	-6	-6	-6	-6	-5	-5								
9	-7	-7	-7	-7	-6	-6	-6	-5							
10	-9	-8	-8	-8	-8	-7	-7	-7	-7						
11	-10	-9	-9	-9	-9	-8	-7	-7	-7						
12	-11	-10	-10	-10	-9	-9	-8	-8	-7	-7					
13	-13	-11	-11	-11	-11	-10	-9	-8	-8	-8	-7				
14	-14	-13	-13	-13	-12	-11	-10	-10	-9	-8	-8	-8			
15	-15	-14	-14	-14	-14	-13	-12	-11	-10	-9	-8	-8	-7		
16	-15	-15	-15	-15	-14	-14	-13	-12	-11	-10	-9	-9	-8		
17	-16	-16	-16	-16	-14	-14	-14	-13	-12	-11	-10	-9	-8	-8	
18	-17	-17	-16	-16	-15	-15	-15	-14	-13	-12	-11	-10	-9	-8	-7
19	-18	-18	-17	-16	-16	-15	-15	-15	-14	-13	-12	-11	-10	-8	-7
20	-18	-18	-17	-17	-17	-16	-15	-15	-14	-14	-13	-12	-10	-9	-7
21	-19	-19	-18	-17	-17	-16	-16	-16	-15	-14	-14	-13	-11	-9	-7

FT 3 AA–J–2a

TABLE III

ALTITUDE CORRECTION IN YARDS FOR VARIATIONS IN MUZZLE VELOCITY

From 2,550 f/s

(*Altitude*)

ALTITUDE

VARIATION IN MUZZLE VELOCITY	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
25 ft/sec.	10	10	10	20	20	20	30	30	30	40	40	40	50	50	50
50 ft/sec.	10	20	30	30	40	50	60	60	70	70	80	90	90	100	110
75 ft/sec.	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
100 ft/sec.	30	40	50	70	80	90	110	120	130	140	160	170	180	200	220

MUZZLE VELOCITIES BELOW NORMAL THE CORRECTION IS PLUS.
MUZZLE VELOCITIES ABOVE NORMAL THE CORRECTION IS MINUS.

CORRECTIONS: *Plus* for *MV* below normal
Minus for *MV* above normal

TABLE IV

VERTICAL CORRECTIONS IN MILS FOR 25 f/s VARIATION FROM NORMAL 2,550 f/s *MV*

(*Altitude in yards*)

Fuze	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
3	0	0													
4	0	0	0												
5	0	0	0	0											
6	0	0	0	0	0										
7	0	0	0	0	0	0									
8	0	0	0	0	0	0	0								
9	0	0	0	0	0	0	0	0							
10	0	0	0	0	0	0	0	0	0						
11	0	0	0	0	0	0	0	0	0						
12	0	0	0	0	0	0	0	0	0	0					
13	0	0	0	0	0	0	0	0	0	0	0				
14	0	0	0	0	0	0	0	0	0	0	0	0			
15	2	2	2	2	2	2	2	0	0	0	0	0	0		
16	2	2	2	2	2	2	2	2	2	0	0	0	0		
17	2	2	2	2	2	2	2	2	2	2	2	0	0	0	
18	2	2	2	2	2	2	2	2	2	2	2	2	0	0	0
19	2	2	2	2	2	2	2	2	2	2	2	2	2	2	0
20	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

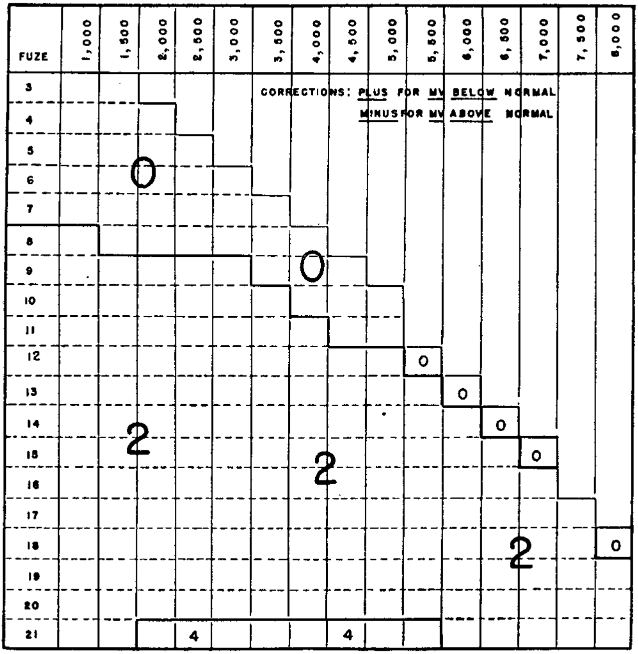
CORRECTIONS: PLUS For MV below normal
MINUS For MV above normal

FT 3 AA–J–2a

TABLE V

VERTICAL CORRECTIONS IN MILS FOR 50 f/s VARIATION FROM NORMAL 2,550 f/s *MV*

(*Altitude in yards*)



CORRECTIONS: PLUS FOR MV BELOW NORMAL
MINUS FOR MV ABOVE NORMAL

FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
3															
4															
5															
6			0												
7															
8															
9							0								
10															
11															
12										0					
13											0				
14			2									0			
15							2						0		
16															
17															
18													2		0
19															
20															
21				4				4							

FT 3 AA-J-2a

TABLE VI

VERTICAL CORRECTIONS IN MILS FOR 75 f/s VARIATION FROM NORMAL 2,550 f/s *MV*

(*Altitude in yards*)

CORRECTIONS: PLUS FOR MV BELOW NORMAL
MINUS FOR MV ABOVE NORMAL

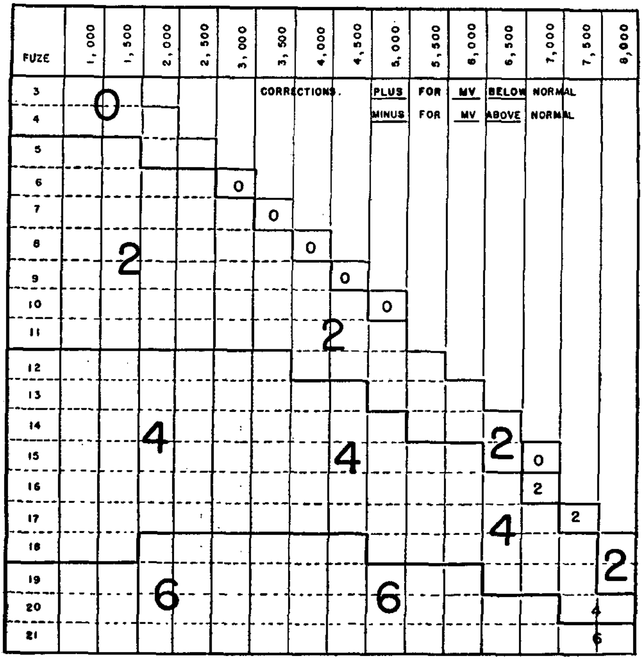
FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
3	0	0													
4	0	0	0												
5	0	0	0	0											
6	2	0	0	0	0										
7	2	2	2	2	0	0									
8	2	2	2	2	2	0	0								
9	2	2	2	2	2	2	0	0							
10	2	2	2	2	2	2	2	0	0						
11	2	2	2	2	2	2	2	2	0						
12	2	2	2	2	2	2	2	2	2	0					
13	2	2	2	2	2	2	2	2	2	2	0				
14	2	2	2	2	2	2	2	2	2	2	2	0			
15	4	4	4	4	4	4	4	2	2	2	2	2	0		
16	4	4	4	4	4	4	4	4	4	2	2	2	2		
17	4	4	4	4	4	4	4	4	4	4	4	2	2	2	
18	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2
19	4	4	4	4	4	4	4	4	4	4	4	4	4	4	2
20	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
21	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

FT 3 AA–J–2a

TABLE VII

VERTICAL CORRECTIONS IN MILS FOR 100 f/s VARIATION FROM NORMAL 2,500 f/s *MV*

(*Altitude in yards*)



FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
3	0					CORRECTIONS.			PLUS	FOR	MV	BELOW	NORMAL		
4									MINUS	FOR	MV	ABOVE	NORMAL		
5															
6					0										
7						0									
8		2					0								
9								0							
10									0						
11								2							
12															
13															
14			4									2			
15								4					0		
16													2		
17												4		2	
18															2
19			6						6						
20														4	
21														6	

FT 3 AA–J–2 or FT 3 AA–O–1

TABLE VIII

MUZZLE VELOCITY—DENSITY RELATIONSHIP

(Applies to high explosive or shrapnel)

An increase of 10 per cent in density has the same effect as a decrease of 125 f/s in muzzle velocity.

DENSITY %	MV CHANGE
100	0
99	+ 13
98	+ 25
97	+ 38
96	+ 50
95	+ 63
94	+ 75
93	+ 88
92	+ 100
91	+ 113
90	+ 125

DENSITY %	MV CHANGE
110	− 125
109	− 113
108	− 100
107	− 88
106	− 75
105	− 63
104	− 50
103	− 38
102	− 25
101	− 13
100	0

TABLE IX

POWDER TEMPERATURE—MUZZLE VELOCITY RELATIONSHIP

TEMP. DEGREES F	PERCENT CHANGE IN MV	MV — 2550 f/s FEET/SECOND CHANGE IN MV	MV — 2700 f/s FEET/SECOND CHANGE IN MV
100	+ 1.89	+ 48	+ 51
95	+ 1.55	+ 40	+ 42
90	+ 1.26	+ 32	+ 34
85	+ 0.96	+ 24	+ 26
80	+ 0.63	+ 16	+ 17
75	+ 0.33	+ 8	+ 9
70	0	0	0
65	− 0.33	− 8	− 9
60	− 0.63	− 16	− 17
55	− 0.96	− 24	− 26
50	− 1.26	− 32	− 34
45	− 1.55	− 40	− 42
40	− 1.89	− 48	− 51
35	− 2.18	− 56	− 59
30	− 2.52	− 64	− 68
25	− 2.85	− 73	− 77
20	− 3.14	− 80	− 85
15	− 3.44	− 88	− 93
10	− 3.78	− 96	−102
5	− 4.08	−104	−110
0	− 4.37	−111	−118

TABLE X

ALTITUDE CORRECTIONS IN YARDS FOR 25 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)

FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500
3									CORRECTIONS			PLUS	FOR	MV	BELOW		NORMAL	
4												MINUS	FOR	MV	ABOVE		NORMAL	
5																		
6																		
7																		
8																		
9	10	20	20	20														
10					30													
11						30												
12							40											
13								40										
14									50									
15										50								
16											50							
17												60						
18													60					
19																		
20														70				
21	0	10	10	10	20	20	20								70			
22								30										
23																80		
24									30									
25																		
26										40								
27											40	50						
28													50	60	60			
29	10	10	10	20	20	20	30	30	40							70	80	
30																		90
31																		

FT 3 AA–O–1

TABLE XI

ALTITUDE CORRECTIONS IN YARDS FOR 50 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)

FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500
3								CORRECTIONS:				PLUS	FOR	MV	BELOW	NORMAL		
4												MINUS	FOR	MV	ABOVE	NORMAL		
5																		
6	20	30	40	50														
7					60													
8						70												
9							70											
10								80	90									
11																		
12										100								
13											110							
14																		
15	20	20	30	40	50	60	60											
16								70										
17									80									
18										90	100							
19												110						
20													120					
21																		
22														130				
23															140			
24						40												
25																		
26	10	20	20	30	40		50											
27								60	70									
28										80	90					150		
29						50						100	110				160	
30			30				60							120	130			180
31																		

FT 3 AA-O-1

TABLE XII

ALTITUDE CORRECTION IN YARDS FOR 75 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)

CORRECTIONS

PLUS FOR MV BELOW NORMAL

MINUS FOR MV ABOVE NORMAL

FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500
3																		
4	30	40																
5			60	70														
6					80													
7						100												
8							110											
9								130										
10	20	40	50	60	80				140									
11						90				150								
12							100				160							
13								120										
14									130									
15										140								
16											150							
17												170						
18													180					
19																		
20	20	30	40	50	60	80	90	100	110					190				
21										130					210			
22											140							
23												150						
24													170					
25														190				
26																		
27																		
28	20	30	40	50	60	70	80	90	100	120	130	140	160	180	200	220	240	
29																		
30																		270
31																		

FT 3 AA–O–1

TABLE XIII

ALTITUDE CORRECTIONS IN YARDS FOR 100 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)

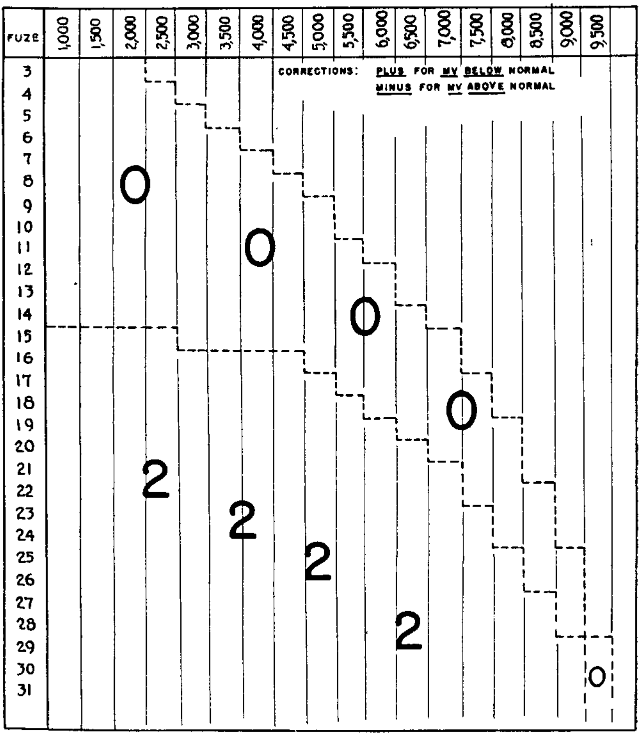
FUZE	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000	8,500	9,000	9,500
3	40	60	80															
4				90														
5	30	50	70	90	110													
6						130												
7							150											
8						120	140	170										
9								160	190									
10									180									
11										190								
12	30	50	60	80	90						210							
13						110	130											
14								140	160			230						
15										180			240					
16											190							
17														260				
18	30	40	50	70	80	100	110					210						
19								130					230		280			
20									150	160								
21											180			250				
22												200				300		
23													220		270			
24	20	30	50	60	70	90	100											
25								120	140					240			330	
26										160	170							
27												190						
28													210					
29																		360
30	10	20	40	50	60	80	90	110										
31																		

CORRECTIONS PLUS FOR MV BELOW NORMAL
MINUS FOR MV ABOVE NORMAL

TABLE XIV

VERTICAL CORRECTIONS IN MILS FOR 25 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)



FT 3 AA-O-1

TABLE XV

VERTICAL CORRECTIONS IN MILS FOR 50 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)

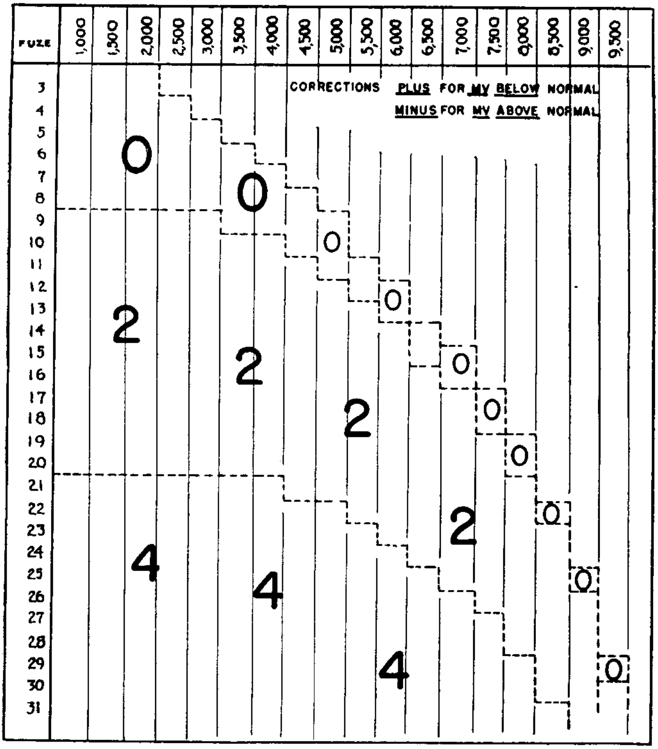
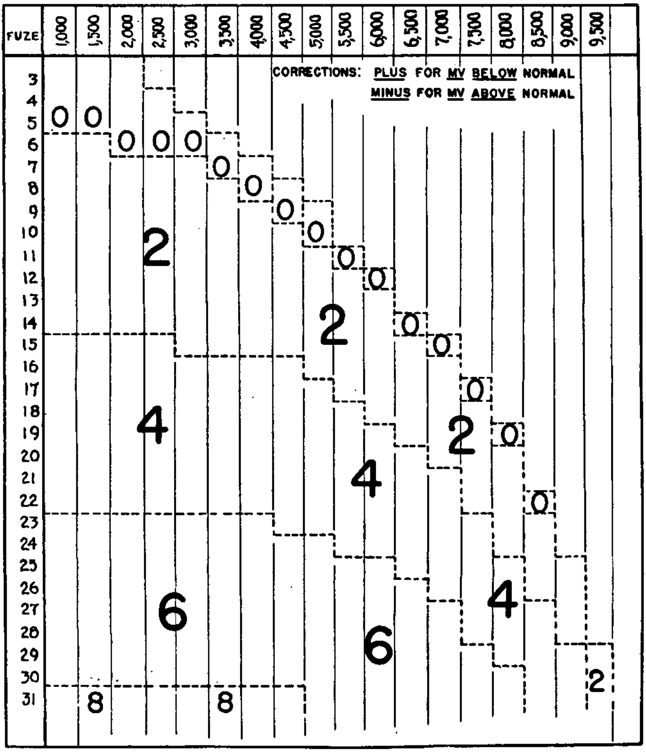


TABLE XVI

VERTICAL CORRECTIONS IN MILS FOR 75 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(Altitude in yards)

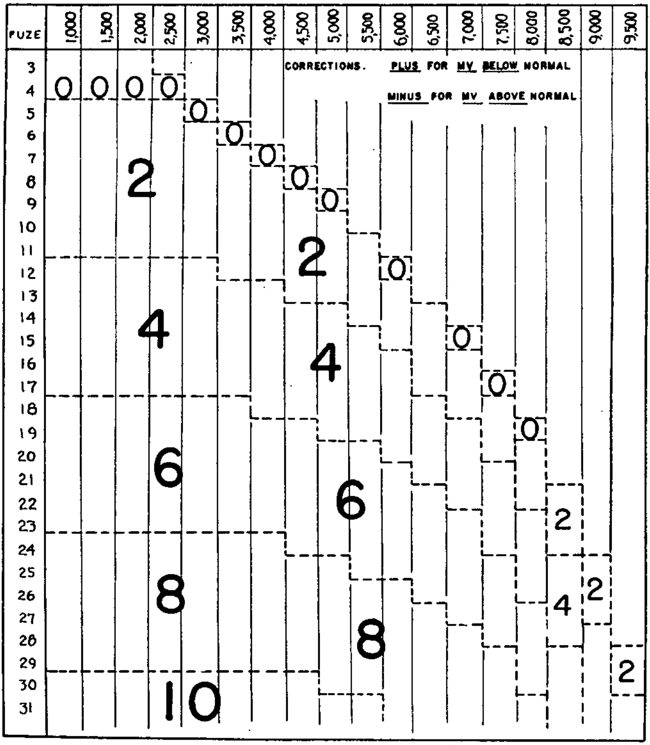


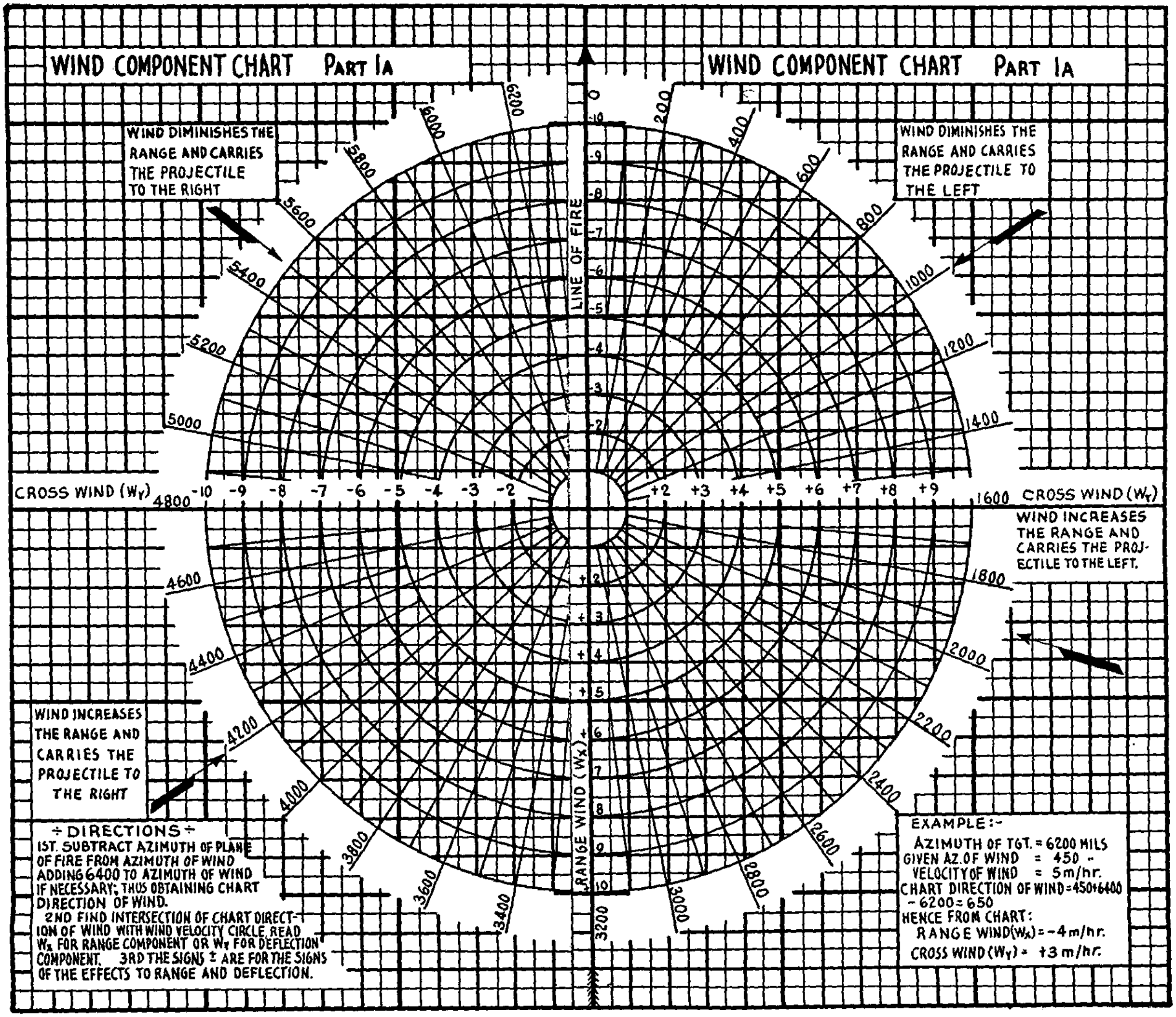
FT 3 AA–O–1

TABLE XVII

VERTICAL CORRECTIONS IN MILS FOR 100 f/s VARIATION FROM NORMAL 2,700 f/s *MV*

(*Altitude in yards*)





÷DIRECTIONS÷

1ST. SUBTRACT AZIMUTH OF PLANE OF FIRE FROM AZIMUTH OF WIND ADDING 6400 TO AZIMUTH OF WIND IF NECESSARY; THUS OBTAINING CHART DIRECTION OF WIND.

2ND FIND INTERSECTION OF CHART DIRECTION OF WIND WITH WIND VELOCITY CIRCLE, READ W_x FOR RANGE COMPONENT OR W_y FOR DEFLECTION COMPONENT. 3RD THE SIGNS ± ARE FOR THE SIGNS OF THE EFFECTS TO RANGE AND DEFLECTION.

EXAMPLE:-

AZIMUTH OF TGT. = 6200 MILS
GIVEN AZ. OF WIND = 450 "
VELOCITY OF WIND = 5 m/hr.
CHART DIRECTION OF WIND = 450 + 6400 - 6200 = 650
HENCE FROM CHART:
RANGE WIND (W_x) = -4 m/hr.
CROSS WIND (W_y) = +3 m/hr.

FIGURE 101.—Wind component chart (part 1a).

SECTION IV

FIRING TABLES (EXTRACTS)

■ 257. **EXTRACTS FROM FIRING TABLES.**—Portions of Firing Tables 3 AA–J–2a and 3 AA–O–1, have been extracted for the convenience of the student in working problems. For data not given in these tables see appropriate firing table.

a. Figure 101 is a wind component chart, applicable to all guns and ammunition.

b. Tables XVIII to XXII, inclusive, pertain to 3" AA shrapnel, Mk. I, with fuze, Mk. III (FT 3 AAA–J–2a).

c. Figure 102 is a chart for variation in *MV* due to temperature of powder, applicable to 2,700 f/s *MV* only.

d. Tables XXIII to XXVI, inclusive, pertain to 3" AA shell HE, M42 with fuze, M43 (FT 3 AA–O–1).

TABLE XVIII

TABLE A—TRAJECTORY DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917, M1917MI, M1917MII, AND M1925MI

AA Shrapnel, Mk. I
Part 2a

FT 3 AA–J–2a
Fuze, Scovil, Mk. III

(MV=2,600 f/s)

Quadrant elevation (ϕ) =500 mils

Time of flight t (Sec.)	Fuze setting F (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.)
1	1.2	706	372	494
2	2.4	1,316	683	488
3	3.5	1,850	946	481
4	4.6	2,325	1,169	474
5	5.7	2,755	1,360	467
6	6.8	3,149	1,526	460
7	7.8	3,515	1,670	452
8	8.8	3,860	1,795	443
9	9.8	4,191	1,904	434
10	10.9	4,511	1,998	425
11	11.9	4,822	2,079	415
12	12.9	5,124	2,148	405
13	13.9	5,419	2,205	394
14	14.9	5,708	2,250	382
15	15.9	5,992	2,284	371
16	16.9	6,270	2,306	359
17	17.8	6,544	2,317	347
18	18.7	6,813	2,318	334
19	19.6	7,078	2,308	321
20	20.5	7,339	2,287	308
21	21.4	7,595	2,256	294

Quadrant elevation (ϕ) =600 mils

Time of flight t (Sec.)	Fuze setting F (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.)
1	1.2	666	440	594
2	2.4	1,239	809	588
3	3.5	1,745	1,123	582
4	4.6	2,196	1,393	576
5	5.6	2,603	1,627	569
6	6.7	2,977	1,832	562
7	7.7	3,326	2,013	555
8	8.7	3,656	2,173	547
9	9.7	3,972	2,316	538
10	10.7	4,278	2,444	529
11	11.7	4,576	2,558	519
12	12.6	4,867	2,659	509
13	13.6	5,152	2,747	499
14	14.6	5,431	2,822	488
15	15.5	5,705	2,885	477
16	16.5	5,974	2,937	466
17	17.4	6,239	2,977	454
18	18.3	6,500	3,006	441
19	19.2	6,757	3,025	429
20	20.0	7,011	3,033	416
21	20.9	7,262	3,029	403
22	21.7	7,509	3,014	389

TABLE A—TRAJECTORY DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917, ETC.—Continued

Quadrant elevation (ϕ)=700 mils

Time of flight t (Sec.)	Fuze setting F (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.)
1	1.2	619	503	694
2	2.3	1,154	926	689
3	3.4	1,624	1,289	683
4	4.5	2,044	1,603	677
5	5.6	2,425	1,877	671
6	6.6	2,776	2,119	664
7	7.6	3,103	2,335	657
8	8.6	3,413	2,529	650
9	9.5	3,711	2,705	642
10	10.5	4,000	2,865	633
11	11.4	4,281	3,010	624
12	12.4	4,556	3,141	615
13	13.3	4,826	3,259	605
14	14.2	5,091	3,365	595
15	15.1	5,351	3,458	584
16	16.0	5,608	3,539	573
17	16.9	5,861	3,608	562
18	17.8	6,110	3,666	550
19	18.6	6,356	3,712	538
20	19.5	6,599	3,747	526
21	20.4	6,839	3,771	513
22	21.2	7,076	3,784	500

Quadrant elevation (ϕ)=800 mils

Time of flight t (Sec.)	Fuze setting F (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.
1	1.2	566	560	795
2	2.3	1,055	1,035	790
3	3.4	1,486	1,443	785
4	4.5	1,871	1,797	779
5	5.5	2,221	2,108	773
6	6.5	2,544	2,385	767
7	7.5	2,846	2,634	761
8	8.5	3,133	2,860	754
9	9.4	3,409	3,067	746
10	10.3	3,677	3,257	738
11	11.2	3,938	3,432	730
12	12.1	4,193	3,593	722
13	12.9	4,444	3,740	713
14	13.8	4,691	3,874	703
15	14.7	4,935	3,995	693
16	15.5	5,175	4,104	683
17	16.4	5,412	4,201	672
18	17.2	5,645	4,286	661
19	18.1	5,875	4,359	650
20	18.9	6,103	4,421	638
21	19.8	6,329	4,471	626
22	20.6	6,553	4,510	614
23	21.4	6,774	4,538	601

TABLE XIX

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917, M1917MI, M1917MII, AND M1925MI

AA Shrapnel, Mk. I
Part 2a

FT 3 AA–J–2a
Fuze, Scovil, Mk. III

(MV=2,600 f/s)

Fuze setting (F) 12

Quadrant elevation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.)	Superelevation ϕ_s (Mils.)	Time of flight t (Sec.)
100	5,031	76	15	85	10.24
200	5,062	567	114	86	10.44
300	5,045	1,070	213	87	10.66
400	4,977	1,578	313	87	10.88
500	4,855	2,088	414	86	11.11
600	4,679	2,594	515	85	11.35
700	4,449	3,091	618	82	11.61
800	4,169	3,578	722	78	11.92
900	3,834	4,047	827	73	12.23
1,000	3,438	4,482	933	67	12.52
1,100	2,977	4,872	1,041	59	12.78
1,200	2,453	5,202	1,151	49	12.97
1,300	1,884	5,467	1,262	38	13.12
1,400	1,277	5,667	1,374	26	13.24
1,500	642	5,785	1,487	13	13.33

Fuze setting (F) 13

100	5,316	29	7	93	11.13
200	5,354	547	104	96	11.35
300	5,342	1,078	203	97	11.59
400	5,276	1,615	303	97	11.84
500	5.153	2,154	403	97	12.10
600	4,973	2,692	505	95	12.37

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917, ETC.—Continued

Fuze setting (F) 13—Continued

Quadrant elvation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils.)	Superelevation ϕ_s (Mils.)	Time of flight t (Sec.)
700	4,740	3,223	608	92	12.68
800	4,460	3,750	712	88	13.07
900	4,131	4,264	816	84	13.51
1,000	3,720	4,750	923	77	13.94
1,100	3,244	5,188	1,032	68	14.31
1,200	2,684	5,552	1,142	58	14.56
1,300	2,060	5,842	1,255	45	14.73
1,400	1,396	6,056	1,369	31	14.87
1,500	701	6,189	1,485	15	14.96

Fuze setting (F) 14

100					
200	5,641	519	94	106	12.27
300	5,634	1,076	192	108	12.53
400	5,571	1,642	292	108	12.81
500	5,446	2,209	392	108	13.09
600	5,264	2,778	494	106	13.40
700	5,027	3,341	597	103	13.76
800	4,748	3,903	701	99	14.23
900	4,415	4,459	805	95	14.79
1,000	4,006	4,994	911	89	15.37
1,100	3,506	5,482	1,020	80	15.88
1,200	2,904	5,885	1,133	68	16.21
1,300	2,238	6,207	1,248	52	16.44
1,400	1,521	6,444	1,364	36	16.63
1,500	765	6,593	1,482	18	16.76

TABLE XX

TABLE C–2—DEFLECTION DUE TO DRIFT FOR 3-INCH ANTIAIRCRAFT GUN, M1917, M1917MI, M1917MII, AND M1925MI

AA Shrapnel, Mk. I
Part 2a

FT 3 AA–J–2a
Fuze, Scovil, Mk. III

($MV=2{,}600$ f/s)

[1] *Deflection due to drift—Mils*

Fuze setting (sec.)	Quadrant Elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1
2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2
3	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−2	−3	−3	−3	−3
4	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3
5	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−3	−4	−4	−4
6	−3	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4
7	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4
8	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−5	−5
9	−4	−4	−4	−4	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5
10	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−6	−6	−6	−6
11	−5	−5	−5	−5	−5	−6	−6	−6	−6	−6	−6	−6	−7	−7	−7
12	−5	−5	−6	−6	−6	−6	−6	−6	−7	−7	−7	−7	−7	−7	−7
13	−6	−6	−6	−6	−6	−6	−7	−7	−7	−8	−8	−8	−8	−8	−8
14	−6	−6	−6	−7	−7	−7	−7	−7	−8	−8	−9	−9	−9	−9	−9
15		−7	−7	−7	−7	−7	−8	−8	−9	−9	−9	−10	−10	−10	−10
16		−7	−7	−7	−8	−8	−8	−8	−9	−9	−9	−10	−11	−11	−11
17		−7	−7	−8	−8	−8	−9	−9	−9	−9	−10	−10	−11	−11	−11
18		−8	−8	−8	−8	−9	−9	−9	−10	−10	−10	−11	−11	−12	−12
19		−8	−8	−8	−8	−9	−9	−9	−10	−10	−10	−11	−12	−13	−13
20		−8	−8	−8	−9	−9	−9	−9	−10	−10	−10	−11	−13	−14	−16
21		−8	−8	−9	−9	−9	−9	−9	−10	−10	−11	−12	−14	−18	−24

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[1] The minus sign indicates that the drift is to the right.

TABLE XXI

TABLE D-1—PROBABLE ERROR DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917, M1917MI, M1917MII, AND M1925MI

AA Shrapnel, Mk. I
Part 2a

FT 3 AA-J-2a
Fuze, Scovil, Mk. III

($MV = 2{,}600$ f/s)

Probable error in time of flight in seconds

Time of flight (sec.)	Quadrant Elevation—Mils							
	100	300	500	700	900	1,100	1,300	1,500
2	0.03	0.04	0.04	0.05	0.05	0.05	0.06	0.06
4	0.04	0.05	0.05	0.06	0.07	0.07	0.07	0.08
6	0.05	0.06	0.06	0.07	0.08	0.09	0.09	0.10
8	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.13
10	0.06	0.07	0.08	0.10	0.12	0.13	0.14	0.15
12	0.07	0.08	0.10	0.12	0.14	0.16	0.17	0.18
14		0.09	0.11	0.14	0.17	0.18	0.20	0.22
16		0.10	0.13	0.16	0.20	0.21	0.23	0.25
18		0.12	0.15	0.19	0.23	0.25	0.27	0.29
20		0.14	0.18	0.22	0.26	0.29	0.31	0.33
22			0.22	0.26	0.30	0.33	0.36	0.38
24			0.25	0.30	0.34	0.38	0.41	0.43
26				0.35	0.39	0.43	0.46	0.48
28					0.44	0.48	0.51	0.53
30							0.56	0.59
32							0.62	0.65
34								0.71
36								0.77

TABLE XXII

DIFFERENTIAL EFFECTS FOR 3-INCH ANTIAIRCRAFT GUN, M1917, M1917MI, M1917MII, AND M1925MI

AA Shrapnel, Mk. I — FT 3 AA–J–2a
Part 2a — Fuze, Scovil, Mk. III

($MV = 2{,}600$ f/s)

TABLE E–1.—*Effect on horizontal range in yards due to a 10-mil increase in angle of elevation*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	−1	−1	−2	−3	−3	−4	−5	−5	−6	−6	−6	−7	−7	−7	−7
2	−1	−2	−4	−5	−6	−8	−9	−10	−11	−11	−12	−13	−13	−13	−14
3	−2	−3	−5	−7	−9	−10	−12	−13	−15	−16	−17	−18	−18	−19	−19
4	−2	−4	−7	−9	−11	−13	−15	−17	−19	−20	−21	−22	−23	−24	−24
5	−3	−5	−8	−10	−13	−15	−18	−20	−22	−24	−25	−27	−28	−28	−29
6	−3	−5	−9	−12	−15	−18	−20	−23	−25	−27	−29	−31	−32	−33	−33
7	−3	−6	−9	−13	−16	−19	−23	−26	−28	−31	−33	−34	−36	−37	−37
8	−4	−6	−10	−14	−18	−21	−25	−28	−31	−34	−36	−38	−39	−40	−41
9	−4	−6	−10	−15	−19	−23	−27	−30	−34	−37	−39	−41	−43	−44	−45
10	−4	−6	−11	−15	−20	−24	−29	−32	−36	−39	−42	−45	−46	−48	−49
11	----	−6	−11	−16	−21	−26	−30	−35	−39	−42	−45	−48	−50	−51	−53
12	----	−6	−11	−17	−22	−27	−32	−37	−41	−45	−48	−51	−54	−55	−56
13	----	−6	−12	−17	−23	−28	−34	−39	−43	−48	−51	−54	−57	−59	−60
14	----	−6	−12	−18	−24	−30	−35	−41	−46	−50	−54	−58	−60	−62	−64
15	----	−6	−12	−18	−25	−31	−37	−43	−48	−53	−57	−61	−64	−66	−67
16	----	−6	−12	−19	−25	−32	−38	−44	−50	−55	−60	−64	−67	−69	−71
17	----	−6	−12	−19	−26	−33	−40	−46	−52	−58	−63	−67	−70	−72	−74
18	----	−6	−12	−19	−27	−34	−41	−48	−54	−60	−66	−70	−73	−77	−77
19	----	----	−12	−19	−27	−35	−42	−50	−57	−63	−68	−73	−76	−79	−81
20	----	----	−12	−19	−28	−36	−44	−51	−59	−65	−71	−76	−80	−82	−84
21	----	----	----	----	−29	−37	−45	−53	−61	−67	−74	−79	−83	−86	−88
22	----	----	----	----	----	−38	−46	−54	−62	−70	−76	−81	−86	−89	−91
23	----	----	----	----	----	----	−47	−55	−64	−72	−79	−84	−89	−92	−94
24	----	----	----	----	----	----	----	−56	−66	−74	−81	−87	−92	−95	−98
25	----	----	----	----	----	----	----	----	----	−76	−84	−90	−95	−99	−101
26	----	----	----	----	----	----	----	----	----	----	−86	−93	−98	−102	−104
27	----	----	----	----	----	----	----	----	----	----	----	−95	−101	−105	−107
28	----	----	----	----	----	----	----	----	----	----	----	−98	−104	−108	−111
29	----	----	----	----	----	----	----	----	----	----	----	−101	−107	−111	−114
30	----	----	----	----	----	----	----	----	----	----	----	−104	−110	−114	−117
31	----	----	----	----	----	----	----	----	----	----	----	----	−113	−117	−120
32	----	----	----	----	----	----	----	----	----	----	----	----	−116	−120	−124
33	----	----	----	----	----	----	----	----	----	----	----	----	----	−123	−127
34	----	----	----	----	----	----	----	----	----	----	----	----	----	−126	−130

TABLE E–2.—*Effect on altitude in yards due to a 10-mil increase in angle of elevation*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	7	7	7	7	6	6	6	5	5	4	3	3	2	2	1
2	13	13	13	12	12	11	10	10	9	8	6	5	4	3	1
3	19	19	18	18	17	16	15	14	12	11	10	8	6	4	2
4	24	24	23	22	21	20	19	17	16	14	12	9	7	5	2
5	28	28	27	27	25	24	23	21	19	16	14	11	8	6	3
6	32	32	31	31	29	28	26	24	21	19	16	13	10	7	3
7	36	36	35	34	33	31	29	27	24	21	18	15	11	8	4
8	39	39	39	38	36	35	32	30	27	24	20	16	12	8	4
9	43	43	42	41	40	38	36	33	30	26	22	18	14	9	5
10	46	46	46	44	43	41	39	36	32	28	24	20	15	10	5
11	49	49	49	48	46	44	41	38	35	31	26	21	16	11	5
12	----	52	52	51	49	47	44	41	37	33	28	23	17	12	6
13	----	56	55	54	52	50	47	44	40	35	30	24	19	12	6
14	----	59	58	57	55	53	50	46	42	37	32	26	20	13	7
15	----	62	61	60	58	56	53	49	45	40	34	28	21	14	7
16	----	65	64	63	61	59	56	52	47	42	36	29	22	15	7
17	----	67	66	66	64	62	59	54	50	44	38	31	23	16	8
18	----	70	69	68	67	64	61	57	52	46	40	32	25	17	8
19	----	73	72	71	70	67	64	60	54	48	41	34	26	17	9
20	----	----	75	74	72	70	67	62	57	50	43	35	27	18	9
21	----	----	----	----	74	73	69	65	59	53	45	37	28	19	9
22	----	----	----	----	----	75	72	67	61	55	47	39	29	20	10
23	----	----	----	----	----	----	75	70	64	57	49	40	30	21	10
24	----	----	----	----	----	----	----	72	66	59	51	42	32	21	11
25	----	----	----	----	----	----	----	----	68	61	52	43	33	22	11
26	----	----	----	----	----	----	----	----	----	62	53	44	34	23	12
27	----	----	----	----	----	----	----	----	----	----	54	45	35	24	12
28	----	----	----	----	----	----	----	----	----	----	----	47	36	24	12
29	----	----	----	----	----	----	----	----	----	----	----	49	37	25	13
30	----	----	----	----	----	----	----	----	----	----	----	51	39	25	13
31	----	----	----	----	----	----	----	----	----	----	----	----	40	27	13
32	----	----	----	----	----	----	----	----	----	----	----	----	41	28	14
33	----	----	----	----	----	----	----	----	----	----	----	----	----	28	14
34	----	----	----	----	----	----	----	----	----	----	----	----	----	29	15

TABLE F–1.—*Effect on horizontal range in yards due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	28	28	27	26	25	24	22	20	18	16	14	11	9	6	2
2	50	50	49	48	46	44	41	37	33	29	25	21	16	10	4
3	67	68	67	66	64	61	57	51	45	40	34	28	21	16	6
4	81	82	82	80	78	75	70	63	56	50	42	34	26	17	8
5	92	93	93	91	89	86	80	73	66	58	49	40	30	20	10
6	101	102	102	100	98	95	89	82	74	65	55	45	34	22	11
7	107	109	109	108	105	102	96	89	80	70	60	49	37	24	11
8	111	114	115	114	111	107	101	94	85	75	64	52	39	25	12
9	114	118	119	118	115	111	105	98	89	79	67	54	40	26	12
10	117	121	122	121	119	115	109	101	92	82	70	56	42	27	13
11	120	123	124	124	122	118	112	104	95	85	72	58	43	28	13
12	----	125	127	127	125	121	115	107	98	87	74	60	45	29	14
13	----	127	129	130	128	124	118	110	100	89	76	61	46	30	14
14	----	128	131	132	130	126	120	112	103	91	77	62	46	31	15
15	----	130	133	134	133	129	123	115	105	93	79	64	48	32	16
16	----	132	135	136	135	131	125	117	107	95	81	66	50	33	16
17	----	134	137	138	137	134	128	120	109	97	83	67	51	34	17
18	----	136	139	140	139	136	130	122	111	98	84	69	53	36	17
19	----	138	141	142	141	138	132	124	113	100	86	70	54	37	18
20	----	----	143	144	143	140	134	126	115	102	88	72	55	37	18
21	----	----	----	----	145	142	136	128	117	104	90	74	57	38	18
22	----	----	----	----	----	143	138	131	120	106	91	75	58	39	19
23	----	----	----	----	----	----	140	133	122	109	93	76	58	39	19
24	----	----	----	----	----	----	----	134	124	111	95	78	59	40	20
25	----	----	----	----	----	----	----	----	126	113	97	79	60	41	21
26	----	----	----	----	----	----	----	----	-----	115	99	81	62	42	21
27	----	----	----	----	----	----	----	----	-----	-----	101	83	63	42	21
28	----	----	----	----	----	----	----	----	-----	-----	-----	84	64	43	22
29	----	----	----	----	----	----	----	----	-----	-----	-----	86	66	44	22
30	----	----	----	----	----	----	----	----	-----	-----	-----	87	67	45	23
31	----	----	----	----	----	----	----	----	-----	-----	-----	-----	68	46	23
32	----	----	----	----	----	----	----	----	-----	-----	-----	-----	69	47	24
33	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	48	24
34	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	49	25
35	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	25
36	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	25

Table F–2.—*Effect on altitude in yards due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	2	5	8	10	13	16	19	21	23	25	26	27	28	28	28
2	4	9	14	19	24	29	34	38	42	45	47	49	50	51	52
3	6	13	20	27	33	40	46	52	57	61	64	67	69	71	72
4	8	17	25	33	41	49	57	64	70	75	79	83	85	87	89
5	10	20	29	38	48	57	66	74	81	87	92	96	99	101	103
6	11	22	32	42	53	64	74	83	91	97	102	106	110	113	115
7	12	24	35	46	57	69	80	90	99	106	111	115	119	122	124
8	13	25	37	49	61	73	85	96	105	113	119	123	126	129	131
9	14	27	40	52	65	77	89	101	111	119	125	129	133	136	137
10	15	28	42	55	68	81	93	105	116	124	130	135	139	142	143
11	16	30	44	57	71	84	97	109	120	128	135	141	145	148	149
12	----	31	45	59	73	87	100	113	124	133	140	146	150	153	154
13	----	33	47	61	75	90	104	117	128	137	145	151	155	158	159
14	----	34	48	62	77	92	107	121	133	142	149	155	159	162	164
15	----	36	50	64	79	94	110	125	137	146	153	159	164	167	169
16	----	37	51	66	81	97	113	128	140	150	158	164	169	172	174
17	----	39	53	68	83	99	116	131	144	155	163	169	174	177	179
18	----	40	54	69	85	102	119	135	148	159	168	174	178	181	183
19	----	41	56	71	87	105	122	138	152	163	172	178	183	186	188
20	----	----	58	73	89	107	125	141	155	167	176	183	188	191	192
21	----	----	----	----	91	109	127	143	158	170	180	187	192	195	196
22	----	----	----	----	----	112	130	146	161	174	184	192	197	200	201
23	----	----	----	----	----	----	132	149	165	178	189	197	202	205	206
24	----	----	----	----	----	----	----	153	169	182	193	201	206	209	210
25	----	----	----	----	----	----	----	----	172	186	197	205	210	213	216
26	----	----	----	----	----	----	----	----	-----	190	201	209	214	217	219
27	----	----	----	----	----	----	----	----	-----	-----	206	214	219	222	224
28	----	----	----	----	----	----	----	----	-----	-----	-----	218	223	226	228
29	----	----	----	----	----	----	----	----	-----	-----	-----	223	228	231	233
30	----	----	----	----	----	----	----	----	-----	-----	-----	227	233	236	237
31	----	----	----	----	----	----	----	----	-----	-----	-----	-----	237	241	242
32	----	----	----	----	----	----	----	----	-----	-----	-----	-----	241	245	246
33	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	250	251
34	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	254	255
35	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	259
36	----	----	----	----	----	----	----	----	-----	-----	-----	-----	-----	-----	263

TABLE F–3.—*Effect on angular height in mils due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant Elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
2	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1
4	1.1	1.1	1.1	1.0	0.9	0.9	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
6	1.7	1.7	1.7	1.6	1.5	1.4	1.3	1.3	1.1	1.0	0.8	0.7	0.5	0.4	0.2
8	2.3	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.6	1.4	1.2	0.9	0.7	0.5	0.3
10	2.9	3.0	2.9	2.9	2.8	2.7	2.6	2.4	2.1	1.8	1.6	1.2	0.9	0.6	0.4
12	3.5	3.6	3.6	3.5	3.4	3.3	3.2	3.0	2.7	2.3	2.0	1.6	1.2	0.8	0.5
14		4.2	4.2	4.1	4.0	3.9	3.8	3.6	3.3	2.9	2.4	1.9	1.5	1.0	0.6
16		4.7	4.8	4.7	4.7	4.6	4.4	4.2	3.8	3.4	2.9	2.3	1.8	1.2	0.6
18		5.2	5.3	5.3	5.3	5.2	5.0	4.8	4.4	3.9	3.4	2.8	2.1	1.4	0.7
20			5.9	5.9	5.9	5.8	5.6	5.4	5.0	4.5	3.9	3.2	2.4	1.6	0.8
22				6.5	6.5	6.4	6.2	6.0	5.6	5.1	4.4	3.6	2.8	1.9	1.0
24					7.1	7.0	6.8	6.6	6.2	5.7	5.0	4.2	3.2	2.2	1.1
26							7.6	7.3	6.9	6.3	5.6	4.7	3.7	2.5	1.2
28									7.6	7.1	6.3	5.3	4.1	2.8	1.4
30												6.0	4.6	3.2	1.6
32													5.3	3.7	1.8
34															2.0

TABLE G–1.—*Effect on horizontal range in yards due to a 10 m. p. h. rear wind*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1
3	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3
4	7	7	7	7	6	6	6	6	6	5	5	5	4	4	4
5	10	10	10	10	9	9	8	8	8	7	7	7	6	6	6
6	14	14	13	13	12	12	11	11	10	10	9	9	9	9	8
7	18	18	17	16	16	15	14	14	13	13	12	11	11	11	10
8	23	22	21	20	20	19	18	17	16	16	15	14	14	14	13
9	27	26	25	24	24	23	21	20	19	19	18	17	17	16	15
10	32	31	30	29	28	27	25	24	23	22	21	20	20	19	18
11	36	35	34	33	32	31	29	28	26	25	24	23	22	21	20
12		40	39	38	36	35	33	32	30	28	27	26	25	24	23
13		44	43	42	40	39	37	35	33	31	30	29	27	26	26
14		49	48	46	45	43	41	39	37	35	34	32	30	29	29
15		53	52	50	49	47	45	43	40	38	37	35	33	32	32
16		58	57	55	53	51	49	47	44	42	40	38	37	36	35
17		62	61	59	57	55	53	51	48	45	43	41	40	39	37
18		68	66	64	62	60	57	55	52	49	46	44	42	41	40
19		72	71	69	66	64	61	58	55	52	49	47	45	44	43
20			76	74	71	68	65	62	59	56	53	50	48	47	46
21					76	73	70	66	63	59	56	54	52	50	48
22						78	74	70	67	63	60	57	55	53	51
23							78	74	70	66	63	60	58	56	54
24								78	74	70	67	63	60	58	57
25									78	74	70	66	63	61	60
26										78	74	70	67	64	63
27											77	73	70	67	66
28												76	73	71	69
29												79	76	74	72
30												83	79	77	75
31													82	79	78
32													85	82	81
33														85	84
34														89	87

TABLE G–2.—*Effect on altitude in yards due to a 10 m. p. h. rear wind*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0
4	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
5	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0
6	0	1	1	2	2	2	2	2	2	2	2	2	2	1	0
7	1	1	2	2	2	2	2	2	2	2	2	2	2	1	1
8	1	1	2	3	3	3	3	3	3	3	3	3	3	2	1
9	1	2	2	3	3	3	3	4	4	4	4	3	3	2	1
10	1	2	2	3	3	4	4	5	5	5	5	4	3	2	1
11	1	2	2	3	4	5	5	5	5	5	5	4	3	2	1
12		2	3	4	5	6	6	6	6	6	6	5	4	3	1
13		2	3	4	5	6	6	7	7	7	6	5	4	3	1
14		2	4	5	6	7	7	8	8	8	7	6	5	4	2
15		2	4	5	6	7	8	8	8	8	7	6	5	4	2
16		3	5	6	7	8	9	9	9	9	8	7	6	4	2
17		3	5	6	8	9	10	10	10	10	9	8	6	4	2
18		3	5	7	9	10	11	11	11	11	10	9	7	5	3
19		3	5	7	9	10	11	11	11	11	10	9	7	5	3
20			6	8	10	11	12	12	12	12	11	10	8	6	3
21					10	11	12	13	13	13	12	10	8	6	3
22						12	13	14	14	14	13	11	9	6	3
23							13	14	14	14	13	11	9	6	3
24								15	15	15	14	12	10	7	4
25									16	16	15	13	10	7	4
26										17	16	14	11	8	4
27											16	14	11	8	4
28												15	12	8	4
29												15	12	8	4
30												16	13	9	4
31													13	9	5
32													14	9	5
33														9	5
34														10	5

TABLE H-2.—*Effect on deflection in mils due to a 10 m. p. h. cross wind*

Time of flight (sec.)	Quadrant Elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.8	0.9	1.0	1.2	1.6	2.5	4.9
2	1.0	1.0	1.0	1.0	1.1	1.1	1.2	1.3	1.5	1.7	2.0	2.4	3.2	4.8	9.5
3	1.5	1.5	1.5	1.5	1.6	1.7	1.8	2.0	2.2	2.5	2.9	3.6	4.7	7.0	13.9
4	1.9	1.9	1.9	2.0	2.1	2.2	2.4	2.6	2.8	3.2	3.8	4.7	6.2	9.1	18.1
5	2.4	2.4	2.4	2.5	2.6	2.7	2.9	3.2	3.5	3.9	4.6	5.7	7.6	11.1	22.0
6	2.8	2.8	2.8	2.9	3.0	3.2	3.4	3.7	4.1	4.6	5.4	6.7	8.8	13.0	25.7
7	3.2	3.2	3.2	3.3	3.4	3.6	3.9	4.2	4.6	5.2	6.1	7.6	9.9	14.7	29.1
8	3.6	3.6	3.6	3.7	3.8	4.0	4.3	4.7	5.1	5.8	6.8	8.4	10.9	16.3	32.2
9	4.0	4.0	4.0	4.1	4.2	4.4	4.7	5.1	5.6	6.3	7.4	9.0	11.8	17.7	34.9
10	4.3	4.3	4.3	4.4	4.6	4.8	5.1	5.5	6.0	6.8	7.9	9.6	12.7	18.9	37.4
11	4.6	4.6	4.6	4.7	4.9	5.1	5.4	5.8	6.4	7.2	8.4	10.2	13.5	20.0	40
12		4.9	4.9	5.0	5.2	5.4	5.7	6.2	6.8	7.6	8.9	10.8	14.3	21.1	42
13		5.2	5.2	5.3	5.5	5.7	6.0	6.5	7.1	8.0	9.3	11.4	15.0	22.1	44
14		5.5	5.5	5.6	5.7	5.9	6.3	6.8	7.5	8.4	9.7	11.9	15.6	23.0	46
15		5.8	5.8	5.9	6.0	6.2	6.6	7.1	7.8	8.7	10.1	12.4	16.2	23.8	47
16		6.0	6.0	6.1	6.2	6.4	6.8	7.3	8.0	9.0	10.5	12.8	16.7	24.6	49
17		6.3	6.3	6.4	6.5	6.7	7.1	7.6	8.3	9.3	10.8	13.2	17.2	25.3	50
18		6.5	6.5	6.6	6.7	6.9	7.3	7.8	8.5	9.5	11.1	13.5	17.6	26.0	52
19		6.7	6.7	6.8	6.9	7.1	7.5	8.0	8.7	9.8	11.4	13.9	18.1	26.7	53
20			6.9	7.0	7.1	7.3	7.6	8.2	9.0	10.0	11.7	14.2	18.5	27.3	54
21					7.3	7.5	7.8	8.4	9.2	10.3	11.9	14.5	18.9	27.9	55
22						7.7	8.1	8.6	9.4	10.5	12.1	14.8	19.3	28.5	56
23							8.3	8.8	9.6	10.7	12.4	15.1	19.7	29.0	57
24								9.0	9.8	10.9	12.7	15.3	20.0	29.5	58
25									10.0	11.1	12.9	15.6	20.3	30.0	59
26										11.3	13.1	15.8	20.6	30.4	60
27											13.3	16.1	20.9	30.9	61
28												16.3	21.2	31.3	62
29												16.6	21.5	31.7	63
30												16.8	21.8	32.1	63
31													22.1	32.5	64
32													22.3	32.8	65
33														33.1	65
34														33.4	66

TABLE I–1.—*Effect on horizontal range in yards due to a 10-percent decrease in air density (59° F. and 29.5+in.)*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	6	6	5	5	5	4	4	4	3	3	2	2	2	1	1
2	20	19	18	18	17	16	15	14	12	11	9	7	6	4	2
3	38	37	36	35	33	30	28	26	23	21	17	14	10	7	4
4	60	58	56	54	51	48	45	41	37	32	27	22	16	11	6
5	80	78	76	73	70	66	61	56	50	43	37	30	23	16	8
6	100	98	96	93	88	83	77	70	63	55	47	38	29	20	10
7	119	116	114	110	105	99	92	84	75	66	56	45	34	23	12
8	134	132	129	125	120	113	105	96	86	76	64	52	39	26	13
9	148	146	143	138	132	125	116	106	96	84	71	58	44	29	15
10	161	158	155	150	144	136	127	116	105	92	78	63	48	32	16
11	174	170	166	161	154	146	137	126	113	99	84	68	52	35	17
12		181	177	171	164	156	146	135	121	106	90	74	56	37	18
13		191	187	181	174	166	155	143	129	113	96	79	60	40	20
14		201	197	191	184	175	164	152	137	120	102	84	64	43	21
15		211	207	201	194	185	174	160	144	127	109	89	67	45	22
16		221	217	211	204	195	183	168	152	134	115	94	71	47	23
17		231	227	221	214	204	192	177	160	141	121	99	75	50	25
18		240	236	230	223	213	201	186	168	148	126	103	78	53	26
19		250	246	240	233	222	209	194	176	155	132	108	82	56	28
20			256	250	243	232	218	202	183	162	138	113	86	58	29
21					252	241	227	211	191	169	145	118	90	61	31
22						251	237	220	199	176	151	123	94	64	32
23							247	229	207	184	157	128	98	67	34
24								238	216	191	163	133	102	69	35
25									224	198	169	138	106	72	36
26										205	175	143	110	74	37
27											181	148	114	77	39
28												153	117	79	40
29												158	121	82	41
30												164	125	84	42
31													129	87	44
32													133	90	45
33														93	46
34														95	47

Table I–2.—*Effect on altitude in yards due to a 10-percent decrease in air density (59° F. and 29.5+in.)*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	1	1	1	2	2	3	3	4	4	4	5	5	5	6	6
2	2	3	5	7	9	10	12	13	14	15	16	17	18	19	19
3	3	6	10	14	17	20	23	26	28	30	32	34	35	36	37
4	5	10	16	22	27	31	36	40	44	47	50	52	54	55	56
5	6	13	21	29	36	42	49	55	60	64	68	71	74	76	77
6	7	17	27	36	45	53	61	68	75	81	86	90	93	95	96
7	8	20	32	43	53	63	72	81	89	96	102	107	110	113	115
8	10	23	36	49	61	72	83	93	102	109	116	122	127	130	132
9	11	26	40	54	67	80	92	103	113	121	129	136	142	145	147
10	13	28	43	58	73	88	101	113	124	133	142	149	155	159	162
11	14	31	47	63	79	95	109	122	134	145	154	162	168	173	176
12		33	51	68	85	102	117	131	144	156	166	174	181	186	189
13		35	54	73	91	109	125	140	154	166	177	186	194	199	202
14		37	58	78	97	115	133	149	164	177	188	198	206	212	215
15		39	61	82	102	121	140	158	174	187	199	210	219	225	228
16		42	64	86	107	128	148	167	183	198	211	222	231	238	241
17		44	67	90	113	134	155	175	193	209	222	234	244	251	255
18		46	70	94	118	141	163	183	202	219	233	246	256	264	268
19		48	73	98	123	147	170	191	211	229	244	257	268	277	281
20			76	102	128	153	177	200	220	239	255	269	281	289	294
21					133	159	185	209	230	249	266	281	293	302	307
22						165	191	217	239	259	277	292	306	315	320
23							198	225	248	269	288	304	318	328	333
24								233	257	279	299	316	330	340	346
25									266	289	310	328	343	353	359
26										299	321	340	355	366	371
27											332	351	367	378	384
28												362	379	391	397
29												374	392	404	410
30												386	404	416	422
31													416	428	434
32													428	440	446
33														452	459
34														465	472

TABLE K–2.—*Effect on horizontal range in yards due to a decrease of 1 division in corrector setting*

Fuze setting (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	61	61	61	59	57	54	50	46	42	37	31	25	19	13	7
2	55	55	54	53	51	48	45	42	38	33	28	23	18	12	6
3	50	49	49	48	46	44	42	39	35	31	26	21	17	11	5
4	46	45	45	44	42	41	39	36	33	29	24	20	16	10	5
5	42	42	41	41	40	39	37	34	31	27	23	19	15	10	5
6	39	39	39	39	38	37	35	32	29	26	22	18	14	10	5
7	36	36	37	37	37	35	33	31	28	25	22	18	14	10	5
8	34	35	35	35	35	33	32	30	28	25	22	18	14	10	5
9	32	33	33	33	33	32	31	30	28	25	22	18	14	10	5
10	31	32	32	32	32	31	30	30	28	26	23	19	15	10	5
11	30	31	31	31	31	30	30	29	28	27	25	21	16	11	5
12	29	30	30	30	30	30	29	29	28	28	26	22	17	11	6
13	28	29	30	30	30	29	29	29	28	28	26	23	18	12	6
14		29	29	29	29	29	29	29	28	28	26	23	18	13	7
15		28	29	29	29	29	29	28	28	27	25	23	19	14	7
16		28	28	29	29	29	29	28	27	26	25	24	20	14	8
17		27	28	28	29	29	29	28	27	25	25	25	21	15	8
18		27	27	28	29	29	29	28	26	25	25	24	22	16	9
19		26	27	28	29	29	29	27	26	25	25	24	23	18	9
20		26	27	28	29	29	29	27	25	25	25	24	23	19	10
21		25	26	27	29	29	29	27	25	25	25	24	23	21	11

TABLE K–3.—*Effect on altitude in yards due to a decrease of 1 division in corrector setting*

Fuze setting (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	6	12	18	24	29	35	40	45	50	54	58	61	63	65	66
2	4	10	15	21	26	31	36	40	45	48	51	54	56	58	59
3	3	8	13	18	23	28	32	36	40	43	46	49	51	52	53
4	2	6	11	16	20	25	29	33	37	40	43	45	47	48	49
5	1	5	10	14	18	22	26	30	34	37	39	42	44	45	46
6	0	4	8	12	16	20	24	28	31	34	37	39	41	43	44
7	0	3	7	11	14	18	22	26	29	32	35	37	39	41	42
8	−1	2	6	9	13	16	20	24	27	31	34	36	38	40	41
9	−2	1	4	8	11	15	18	22	26	29	33	36	38	40	41
10	−3	0	3	6	10	13	17	21	25	29	33	36	38	39	41
11	−3	−1	2	5	8	12	15	19	24	28	33	36	38	39	40
12	−4	−2	1	4	7	10	14	18	22	27	32	35	38	39	40
13	−5	−2	0	3	6	9	12	16	20	26	30	34	37	39	40
14		−3	−1	2	5	8	11	14	18	23	28	32	35	38	40
15		−4	−2	1	4	7	10	13	16	20	24	29	33	36	39
16		−5	−3	0	3	6	8	11	14	17	21	26	31	34	36
17		−6	−3	−1	2	4	7	10	12	15	19	23	28	30	33
18		−7	−4	−2	1	3	6	8	10	13	16	20	24	26	28
19		−8	−5	−3	−1	2	4	7	9	11	13	16	19	21	21
20		−8	−6	−4	−2	0	3	5	7	9	11	12	13	15	14
21		−9	−7	−5	−3	−1	1	3	5	7	8	8	8	8	7

Directions: Enter chart with temperature of powder. Follow vertical line to the slanting line representing given muzzle velocity; from there follow the horizontal line either to the left or right edge of the chart, where the change in muzzle velocity may be read. The chart is based on the formula $\Delta V = 1.68$ (temperature 70°).

Example: Suppose temperature of powder=59° F. Muzzle velocity for powder of standard temperature (70° F.)=2,700 f/s. From the chart, the change in muzzle velocity is —18 f/s. The muzzle velocity to be expected is 2,682 f/s.

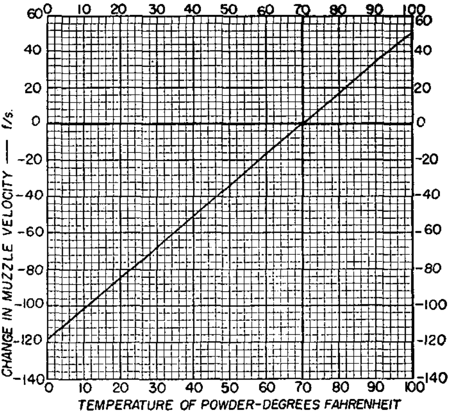

FIGURE 102.—*MV* variation due to temperature of powder (part 1H, FT 3–AA–O–1).

TABLE XXIII

TABLE A—TRAJECTORY DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, M1917A3, M1917MIA2, M1917MIA3, M1917MII, M1925MI; ALSO M1, M2, M3, AND M4

AA Shell, M42
Part 2

FT 3 AA-O-1
Fuze, M43

($MV=2{,}700$ f/s)

Quadrant elevation (ϕ) = *700 mils*

Time of flight[1] t (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)
1	648	525	694
2	1,228	985	689
3	1,751	1,390	683
4	2,228	1,749	678
5	2,665	2,068	672
6	3,070	2,353	666
7	3,447	2,608	660
8	3,799	2,837	654
9	4,132	3,043	647
10	4,452	3,229	639
11	4,762	3,399	631
12	5,065	3,555	623
13	5,361	3,697	615
14	5,650	3,825	606
15	5,933	3,940	597
16	6,210	4,041	587
17	6,480	4,129	578
18	6,745	4,204	568
19	7,005	4,266	557
20	7,261	4,317	546
21	7,512	4,357	535
22	7,760	4,386	523
23	8,004	4,404	512
24	8,245	4,411	500
25	8,482	4,407	488
26	8,716	4,392	476
27	8,946	4,367	463
28	9,173	4,331	449
29	9,397	4,285	436
30	9,618	4,230	422
31	9,835	4,164	408

Quadrant elevation (ϕ) = *800 mils*

Time of flight[1] t (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)
1	593	586	794
2	1,124	1,101	789
3	1,604	1,556	784
4	2,042	1,961	779
5	2,444	2,324	774
6	2,817	2,650	769
7	3,165	2,943	763
8	3,491	3,208	757
9	3,800	3,449	751
10	4,097	3,669	744
11	4,385	3,873	737
12	4,667	4,062	729
13	4,944	4,236	722
14	5,214	4,396	714
15	5,478	4,542	705
16	5,737	4,674	696
17	5,991	4,792	687
18	6,239	4,896	678
19	6,484	4,988	668
20	6,725	5,068	658
21	6,962	5,137	647
22	7,196	5,194	636
23	7,428	5,240	625
24	7,656	5,274	614
25	7,881	5,297	603
26	8,103	5,309	591
27	8,323	5,310	579
28	8,540	5,301	566
29	8,754	5,281	553
30	8,965	5,251	540
31	9,174	5,210	526

[1] Time of flight and fuze setting have the same value.

TABLE A—TRAJECTORY DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, ETC.—Continued

Quadrant elevation (ϕ) = *900 mils*

Time of flight[1] t (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)
1	533	641	894
2	1,010	1,206	890
3	1,441	1,707	886
4	1,835	2,154	881
5	2,198	2,557	877
6	2,535	2,920	872
7	2,850	3,248	866
8	3,146	3,547	861
9	3,427	3,820	855
10	3,696	4,072	849
11	3,958	4,307	843
12	4,215	4,526	836
13	4,468	4,730	829
14	4,715	4,920	822
15	4,957	5,095	814
16	5,194	5,256	806
17	5,427	5,403	798
18	5,655	5,535	789
19	5,880	5,655	780
20	6,102	5,763	771
21	6,321	5,859	761
22	6,537	5,943	751
23	6,751	6,015	741
24	6,962	6,076	731
25	7,171	6,125	720
26	7,377	6,163	709
27	7,582	6,190	698
28	7,784	6,207	686
29	7,984	6,213	673
30	8,181	6,208	661
31	8,376	6,191	648

Quadrant elevation (ϕ) = *1,000 mils*

Time of flight[1] t (Sec.)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)
1	468	690	995
2	886	1,299	991
3	1,264	1,841	987
4	1,610	2,326	983
5	1,929	2,764	979
6	2,226	3,160	975
7	2,504	3,520	970
8	2,765	3,849	965
9	3,014	4,152	960
10	3,253	4,432	955
11	3,485	4,695	950
12	3,713	4,942	944
13	3,938	5,174	937
14	4,158	5,391	931
15	4,374	5,593	924
16	4,586	5,780	917
17	4,794	5,953	910
18	4,998	6,112	902
19	5,199	6,258	894
20	5,398	6,391	886
21	5,594	6,512	877
22	5,788	6,621	868
23	5,980	6,718	859
24	6,170	6,804	850
25	6,358	6,878	840
26	6,544	6,940	830
27	6,729	6,991	820
28	6,912	7,032	809
29	7,093	7,062	797
30	7,273	7,081	786
31	7,451	7,088	774

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[1] Time of flight and fuze setting have the same value.

TABLE XXIV

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, M1917A3, M1917MIA2, M1917MIA3, M1917MII, M1925MI; ALSO M1, M2, M3, AND M4

AA Shell, M42
Part 2

FT 3 AA-O-1
Fuze, M43

(MV=2,700 f/s)

Fuze setting (F) 14

Time of flight=14

Quadrant elevation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)	Superelevation ϕ_s (Mils)
100				
200	6, 802	577	86	114
300	6, 710	1, 252	188	112
400	6, 550	1, 922	291	109
500	6, 320	2, 580	395	105
600	6, 020	3, 217	500	100
700	5, 650	3, 825	606	94
800	5, 214	4, 396	714	86
900	4, 715	4, 920	822	78
1, 000	4, 158	5, 391	931	69
1, 100	3, 549	5, 803	1, 041	59
1, 200	2, 895	6, 149	1, 152	48
1, 300	2, 206	6, 424	1, 263	37
1, 400	1, 490	6, 624	1, 375	25
1, 500	755	6, 746	1, 487	13

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, ETC.—Continued

Fuze setting (F) 15 *Time of flight=15*

Quadrant elevation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)	Super elevation ϕ_s (Mils)
100				
200	7, 115	529	75	125
300	7, 025	1, 235	177	123
400	6, 863	1, 937	280	120
500	6, 627	2, 628	385	115
600	6, 317	3, 299	490	110
700	5, 933	3, 940	597	103
800	5, 478	4, 542	705	95
900	4, 957	5, 095	814	86
1, 000	4, 374	5, 593	924	76
1, 100	3, 735	6, 028	1, 035	65
1, 200	3, 048	6, 395	1, 147	53
1, 300	2, 323	6, 687	1, 259	41
1, 400	1, 569	6, 898	1, 372	28
1, 500	735	7, 026	1, 485	15

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, ETC.—Continued

Fuze setting (F) 16 *Time of flight=16*

Quadrant elevation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)	Super elevation ϕ_s (Mils)
100				
200	7, 418	470	64	136
300	7, 330	1, 207	166	134
400	7, 167	1, 941	269	131
500	6, 926	2, 664	374	126
600	6, 607	3, 368	480	120
700	6, 210	4, 041	587	113
800	5, 737	4, 674	696	104
900	5, 194	5, 256	806	94
1, 000	4, 586	5, 780	917	83
1, 100	3, 918	6, 239	1, 029	71
1, 200	3, 198	6, 626	1, 142	58
1, 300	2, 438	6, 934	1, 256	44
1, 400	1, 647	7, 157	1, 370	30
1, 500	835	7, 292	1, 484	16

TABLE B—FUZE SETTER DATA FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, ETC.—Continued

Fuze setting (F) 17 *Time of flight=17*

Quadrant elevation ϕ (Mils)	Horizontal range R (Yds.)	Altitude H (Yds.)	Angular height ϵ (Mils)	Super elevation ϕ_s (Mils)
100				
200	7, 711	402	53	147
300	7, 626	1, 169	155	145
400	7, 462	1, 934	258	142
500	7, 217	2, 689	363	137
600	6, 890	3, 424	470	130
700	6, 480	4, 129	578	122
800	5, 991	4, 792	687	113
900	5, 427	5, 403	798	102
1, 000	4, 794	5, 953	910	90
1, 100	4, 097	6, 435	1, 023	77
1, 200	3, 345	6, 842	1, 137	63
1, 300	2, 550	7, 166	1, 252	48
1, 400	1, 723	7, 401	1, 367	33
1, 500	874	7, 543	1, 482	18

TABLE XXV

TABLE C–2—DEFLECTION DUE TO DRIFT FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, M1917A3, M1917MIA2, M1917MIA3, M1917MII, M1925MI; ALSO M1, M2, M3, AND M4

AA Shell, M42 FT 3 AA–O-1
Part 2 Fuze, M43

(*MV*=2,700 f/s)

[1] *Deflection due to drift—Mils*

Fuze setting (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	0	0	0	0	0	0	0	0	+1	2	4	6	10	15	22
2	0	0	0	0	0	0	0	0	0	1	3	6	10	15	22
3	0	0	0	0	0	0	0	0	0	1	3	6	10	15	22
4	0	0	0	0	0	0	0	0	0	+1	2	5	9	15	22
5	0	0	0	0	0	−1	−1	−1	−1	0	2	5	9	14	21
6	0	0	0	0	−1	−1	−1	−1	−1	0	2	5	9	14	21
7	0	−1	−1	−1	−1	−1	−1	−1	−1	0	1	4	8	14	21
8	−1	−1	−1	−1	−1	−1	−2	−2	−1	−1	1	4	8	13	20
9	−1	−1	−1	−1	−1	−2	−2	−2	−2	−1	+1	3	7	12	19
10	−1	−1	−1	−1	−2	−2	−2	−2	−2	−2	0	3	7	12	19
11	−1	−1	−1	−1	−2	−2	−2	−3	−3	−2	−1	2	6	11	18
12	−1	−1	−1	−2	−2	−2	−3	−3	−3	−2	−1	+1	5	10	17
13	−1	−1	−2	−2	−2	−3	−3	−3	−3	−3	−2	0	4	9	15
14		−2	−2	−2	−3	−3	−4	−4	−4	−3	−2	0	3	8	14
15		−2	−2	−3	−3	−4	−4	−4	−4	−4	−3	−1	2	7	13
16		−2	−2	−3	−3	−4	−4	−5	−5	−4	−3	−2	+1	5	11
17		−2	−3	−3	−4	−4	−5	−5	−5	−5	−4	−2	0	4	9
18		−3	−3	−4	−4	−5	−5	−6	−6	−6	−5	−3	−1	3	8
19		−3	−3	−4	−5	−5	−6	−6	−6	−6	−5	−4	−2	+1	6
20		−3	−4	−4	−5	−6	−6	−6	−7	−7	−6	−5	−3	0	4
21		−4	−4	−5	−5	−6	−7	−7	−7	−7	−7	−6	−4	−1	+2
22		−4	−4	−5	−6	−6	−7	−8	−8	−8	−8	−7	−5	−3	0
23			−5	−6	−6	−7	−8	−8	−8	−8	−8	−8	−7	−5	−3
24			−6	−6	−7	−8	−8	−9	−9	−9	−9	−9	−8	−7	−5
25			−6	−7	−7	−8	−9	−9	−10	−10	−10	−10	−9	−8	−7
26			−6	−7	−8	−9	−9	−10	−10	−10	−11	−11	−10	−10	−9
27			−7	−8	−8	−9	−10	−10	−11	−11	−12	−12	−12	−12	−11
28			−8	−8	−9	−10	−10	−11	−11	−12	−12	−13	−13	−13	−13
29			−8	−9	−10	−10	−11	−11	−12	−12	−13	−14	−14	−15	−15
30			−9	−10	−10	−11	−11	−12	−12	−12	−14	−15	−15	−16	−17
31				−10	−11	−11	−12	−12	−13	−14	−15	−16	−16	−17	−19

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[1] This includes also the effects of side-jump and initial yaw. A positive sign means that the total effect is to the left; a negative, that it is to the right.

TABLE XXVI

DIFFERENTIAL EFFECTS FOR 3-INCH ANTIAIRCRAFT GUN, M1917A2, M1917A3, M1917MIA2, M1917MIA3, M1917MII, M1925MI; ALSO M1, M2, M3, AND M4

AA Shell, M42
Part 2

FT 3 AA–O–1
Fuze, M43

$(MV = 2{,}700$ f/s)

TABLE E–1.—*Effect on horizontal range in yards due to a 10-mil increase in angle of elevation*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	−1	−2	−3	−3	−4	−5	−5	−6	−6	−7	−7	−8	−8	−8	−8
2	−1	−3	−5	−6	−7	−9	−10	−11	−12	−13	−14	−15	−15	−16	−16
3	−2	−4	−6	−8	−10	−12	−14	−16	−17	−19	−20	−21	−22	−23	−23
4	−2	−5	−8	−10	−13	−16	−18	−20	−22	−24	−26	−27	−28	−29	−29
5	−2	−6	−9	−12	−16	−19	−21	−24	−27	−29	−31	−32	−34	−35	−35
6	−2	−6	−10	−14	−18	−21	−24	−28	−31	−33	−35	−37	−39	−40	−41
7	−2	−6	−11	−15	−19	−23	−27	−31	−34	−37	−40	−42	−44	−45	−46
8	−2	−6	−11	−16	−21	−25	−30	−34	−37	−41	−44	−46	−48	−49	−50
9	−1	−6	−12	−17	−22	−27	−32	−36	−40	−44	−47	−50	−52	−54	−55
10	0	−6	−12	−18	−23	−29	−34	−39	−43	−47	−51	−54	−56	−58	−60
11	0	−6	−12	−18	−24	−30	−36	−41	−46	−51	−55	−58	−61	−63	−64
12	+1	−6	−12	−19	−25	−32	−38	−44	−49	−54	−58	−62	−65	−67	−68
13	+1	−6	−13	−19	−26	−33	−40	−46	−52	−57	−61	−65	−68	−71	−72
14		−5	−13	−20	−27	−34	−41	−48	−54	−60	−65	−69	−72	−75	−76
15		−5	−13	−20	−28	−36	−43	−50	−57	−63	−68	−72	−76	−79	−80
16		−5	−12	−20	−29	−37	−45	−52	−59	−65	−71	−76	−80	−83	−84
17		−4	−12	−21	−29	−38	−46	−54	−61	−68	−74	−79	−83	−86	−88
18		−4	−12	−21	−30	−39	−47	−56	−64	−71	−77	−82	−87	−90	−92
19		−3	−12	−21	−30	−40	−49	−58	−66	−73	−80	−86	−91	−94	−96
20		−2	−11	−21	−31	−41	−50	−59	−68	−76	−83	−89	−94	−98	−100
21		−2	−11	−21	−31	−41	−51	−61	−70	−78	−86	−92	−97	−101	−103
22		−1	−11	−21	−32	−42	−52	−62	−72	−81	−89	−95	−100	−104	−107
23			−10	−21	−32	−43	−53	−64	−74	−83	−91	−98	−104	−108	−111
24			−10	−21	−32	−43	−54	−65	−76	−86	−94	−101	−107	−111	−114
25			−9	−20	−32	−44	−55	−67	−78	−88	−97	−104	−110	−115	−118
26			−8	−20	−32	−44	−56	−68	−80	−90	−99	−107	−113	−118	−121
27			−8	−20	−32	−45	−57	−69	−81	−92	−102	−110	−117	−122	−125
28			−7	−19	−32	−45	−58	−71	−83	−94	−104	−113	−120	−125	−129
29			−6	−19	−32	−46	−59	−72	−84	−96	−107	−116	−123	−128	−132
30			−5	−18	−32	−46	−59	−73	−86	−98	−109	−118	−126	−132	−136
31				−17	−32	−46	−60	−74	−88	−101	−112	−121	−129	−135	−139

TABLE E–2.—*Effect on altitude in yards due to a 10-mil increase in angle of elevation*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	8	8	8	8	7	7	7	6	5	5	4	3	3	2	1
2	16	15	15	15	14	13	13	12	10	9	8	6	5	3	2
3	23	22	22	21	20	19	18	17	15	13	11	9	7	5	2
4	29	28	28	27	26	25	23	21	19	17	14	12	9	6	3
5	34	34	33	32	31	30	28	25	23	20	17	14	10	7	4
6	39	39	38	37	36	34	32	29	26	23	20	16	12	8	4
7	44	44	43	42	41	39	36	33	30	26	22	18	14	10	5
8	48	48	47	46	45	43	40	37	33	29	25	20	16	11	5
9	52	52	51	50	49	47	44	40	36	32	27	22	17	12	6
10	56	56	55	54	52	50	47	43	39	35	30	24	19	13	6
11	59	59	59	58	56	54	51	47	42	37	32	26	20	14	7
12	63	63	62	61	59	57	54	50	45	40	34	28	22	15	7
13	66	66	66	65	63	60	57	53	48	43	37	30	23	16	8
14		69	69	68	66	63	60	56	51	45	39	32	25	17	8
15		73	73	72	70	67	63	59	54	48	41	34	26	18	9
16		76	76	75	73	70	66	62	57	51	44	36	28	19	9
17		79	79	78	76	73	70	66	60	53	46	38	29	20	10
18		82	82	81	79	76	73	69	63	56	48	40	31	21	11
19		84	85	85	83	80	76	71	65	58	50	42	33	22	11
20		87	88	88	86	83	79	74	68	61	53	44	34	23	12
21		89	90	90	89	86	82	77	71	64	55	45	35	24	12
22		92	93	93	92	89	85	80	74	66	57	47	36	25	13
23			95	96	95	92	88	83	76	68	59	49	38	26	13
24			98	98	97	95	91	86	79	70	61	51	39	26	13
25			100	101	100	98	94	88	81	73	63	52	40	27	14
26			102	103	103	101	97	91	84	75	65	54	41	28	14
27			105	106	105	103	99	94	87	78	68	56	43	29	15
28			107	108	108	106	102	96	89	80	70	58	44	30	15
29			109	110	110	108	104	99	92	83	72	60	46	31	16
30			111	112	112	110	107	102	94	85	74	61	47	32	16
31				115	115	113	109	104	97	87	76	63	48	33	17

TABLE F–1.—*Effect on horizontal range in yards due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	31	31	30	29	27	25	24	22	20	17	14	11	9	6	3
2	58	57	56	54	51	48	45	41	37	32	27	22	17	12	9
3	81	80	78	76	73	69	64	58	52	46	39	32	24	17	6
4	102	101	98	95	92	87	80	73	66	58	50	41	31	21	11
5	120	119	116	112	108	102	95	87	78	69	59	48	37	25	13
6	135	134	131	127	122	116	108	99	89	78	67	55	42	29	15
7	147	147	145	141	135	129	120	110	99	87	75	62	47	32	16
8	157	158	157	153	147	140	131	120	108	96	83	68	51	34	17
9	166	168	167	163	157	149	140	129	117	104	89	73	55	37	19
10	173	175	174	171	165	157	147	136	124	110	94	77	59	40	20
11	178	180	180	177	171	163	153	142	129	114	98	81	62	42	21
12	181	184	184	181	176	168	158	146	133	118	102	84	65	44	22
13	184	187	187	185	180	172	162	150	137	122	105	87	67	46	23
14		191	191	189	184	177	167	155	141	125	108	89	69	47	24
15		194	195	193	188	181	171	159	145	129	111	92	71	49	25
16		197	199	197	192	185	175	162	148	132	114	95	74	51	26
17		200	202	201	196	188	178	166	152	135	117	98	76	52	27
18		203	205	204	199	192	182	170	155	138	120	100	78	54	28
19		206	208	207	202	195	185	173	158	141	122	102	80	56	29
20		208	211	210	206	199	189	176	161	144	125	105	82	57	30
21		210	214	213	209	202	192	179	164	147	128	107	84	58	30
22		213	217	216	212	205	196	183	167	150	131	110	86	59	30
23			221	220	216	209	199	186	170	153	134	112	88	61	31
24			224	223	219	212	202	190	174	156	137	115	90	62	32
25			227	226	222	215	206	193	177	159	139	117	92	64	33
26			229	229	225	218	209	196	180	162	142	120	94	65	34
27			231	232	228	221	212	199	183	165	145	122	96	67	35
28			234	235	231	224	215	202	186	168	147	124	98	68	35
29			238	238	234	227	218	205	189	171	150	126	99	69	36
30			244	241	236	230	221	208	192	173	152	128	101	70	36
31				244	239	233	224	211	195	176	154	130	103	72	37

TABLE F–2.—*Effect on altitude in yards due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	3	6	8	11	14	17	19	21	23	26	28	29	30	30	31
2	6	11	16	21	26	32	37	41	45	49	52	55	57	58	59
3	8	16	23	30	38	46	53	59	65	70	74	78	81	83	84
4	10	20	29	39	49	58	67	75	82	88	93	98	102	105	106
5	12	24	35	47	58	69	79	88	97	104	111	116	120	124	126
6	14	27	40	53	66	78	89	100	110	119	127	133	138	142	144
7	15	30	44	59	73	86	99	111	122	133	142	149	155	159	161
8	16	32	48	64	79	94	108	121	134	145	155	164	170	174	177
9	17	34	51	68	85	101	116	131	144	156	167	176	183	188	191
10	18	36	54	72	90	107	123	139	153	166	177	186	194	200	203
11	19	38	57	75	94	112	129	145	160	174	186	196	204	210	214
12	20	40	59	78	97	116	134	151	167	181	194	205	214	220	224
13	21	42	62	81	101	120	138	156	173	188	201	213	222	229	233
14		43	64	84	104	124	143	162	179	195	209	221	230	237	242
15		45	66	87	108	128	148	167	185	201	216	228	238	246	251
16		47	69	90	111	132	152	172	191	208	223	236	246	254	259
17		49	71	93	114	136	157	177	196	214	230	243	254	262	267
18		51	73	95	118	140	161	182	202	220	236	250	261	270	276
19		53	75	98	121	143	165	187	207	226	243	257	269	278	284
20		55	77	100	124	147	169	191	212	232	249	264	276	286	293
21		56	79	103	127	150	173	196	217	237	255	271	284	294	301
22		56	81	106	130	154	177	200	222	243	262	278	291	302	309
23			83	108	133	157	180	204	227	249	268	284	298	309	317
24			84	110	135	160	184	208	232	254	274	291	305	317	325
25			86	112	138	163	188	213	237	260	280	298	313	325	333
26			87	114	140	166	192	218	242	265	286	305	320	332	341
27			89	116	143	169	196	222	247	271	292	311	327	340	349
28			91	118	145	172	199	226	252	276	298	317	334	347	356
29			92	120	148	175	203	230	256	281	304	324	341	354	364
30			93	122	150	178	206	234	261	287	310	330	348	362	372
31				124	153	181	210	238	266	292	316	337	355	370	381

TABLE F–3.—*Effect on angular height in mils due to a 100-f/s increase in muzzle velocity*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
2	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.0
4	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.5	0.4	0.2	0.1
6	1.5	1.4	1.4	1.4	1.4	1.3	1.2	1.2	1.2	1.1	1.0	0.8	0.6	0.4	0.2
8	2.0	2.0	1.9	1.9	1.9	1.8	1.7	1.7	1.6	1.4	1.2	1.0	0.7	0.5	0.3
10	2.6	2.6	2.5	2.5	2.4	2.4	2.3	2.2	2.0	1.7	1.5	1.2	0.9	0.6	0.3
12	3.2	3.2	3.2	3.1	3.0	3.0	2.9	2.7	2.5	2.2	1.9	1.5	1.1	0.7	0.4
14	3.8	3.8	3.9	3.8	3.7	3.6	3.5	3.3	3.1	2.8	2.4	1.9	1.4	0.9	0.4
16	----	4.5	4.6	4.5	4.4	4.3	4.2	4.0	3.7	3.3	2.8	2.2	1.6	1.0	0.5
18	----	5.2	5.3	5.2	5.2	5.1	4.9	4.6	4.3	3.9	3.3	2.6	1.9	1.2	0.6
20	----	5.8	5.9	5.9	5.9	5.8	5.6	5.3	5.0	4.5	3.8	3.0	2.2	1.4	0.7
22	----	6.5	6.5	6.6	6.6	6.5	6.3	6.0	5.6	5.1	4.4	3.5	2.5	1.6	0.8
24	----	----	7.0	7.2	7.2	7.1	7.0	6.7	6.3	5.7	5.0	4.0	2.9	1.9	1.0
26	----	----	7.6	7.8	7.8	7.8	7.7	7.4	7.0	6.4	5.6	4.5	3.4	2.3	1.1
28	----	----	8.1	8.4	8.5	8.5	8.4	8.2	7.8	7.2	6.3	5.1	3.9	2.6	1.3
30	----	----	8.7	9.0	9.1	9.1	9.1	8.9	8.5	7.9	7.0	5.8	4.4	3.0	1.5
32	----	----	----	9.6	9.7	9.8	9.8	9.6	9.3	8.7	7.8	6.5	5.0	3.4	1.7

TABLE G–1.—*Effect on horizontal range in yards due to a 10 m. p. h. rear wind*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2
4	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4
5	7	7	7	7	7	6	6	6	6	6	6	6	6	6	6
6	10	10	10	9	9	9	9	9	8	8	8	8	8	8	8
7	13	13	13	12	12	12	11	11	11	10	10	10	10	10	10
8	16	16	16	15	15	15	14	14	14	13	13	13	13	12	12
9	20	19	19	18	18	18	17	17	17	16	16	15	15	14	14
10	24	23	23	22	22	21	21	20	20	19	19	18	18	17	17
11	28	27	27	26	26	25	25	24	23	22	21	20	20	19	19
12	32	31	31	30	30	29	28	27	26	25	24	23	23	22	21
13	36	35	35	34	34	33	32	31	30	29	28	27	26	25	24
14	----	40	40	39	38	37	36	34	33	32	31	30	29	28	27
15	----	44	44	43	42	41	40	38	37	36	34	32	31	30	29
16	----	49	49	48	47	45	44	42	41	39	37	35	34	33	32
17	----	53	53	52	51	49	48	46	44	42	40	38	37	36	35
18	----	58	57	56	55	53	51	49	47	45	44	42	40	39	37
19	----	63	62	61	59	57	55	53	51	49	47	45	44	42	40
20	----	68	67	65	63	61	59	57	54	52	50	48	47	45	43
21	----	73	72	70	68	66	64	61	58	56	54	52	50	48	46
22	----	77	76	74	72	70	68	65	62	59	57	55	53	51	49
23	----	----	80	78	76	74	72	69	66	63	60	58	56	54	52
24	----	----	85	83	81	79	76	73	70	67	64	61	59	57	55
25	----	----	90	88	86	84	81	77	74	70	67	64	62	60	58
26	----	----	94	92	90	88	85	81	78	74	71	68	66	64	62
27	----	----	98	96	94	92	89	85	82	78	74	71	69	67	65
28	----	----	103	101	99	96	93	89	85	81	78	75	72	70	68
29	----	----	107	105	103	100	97	93	89	85	81	78	75	73	71
30	----	----	112	110	108	105	102	98	93	89	85	81	78	76	74
31	----	----	----	115	112	109	106	102	97	92	88	85	82	79	77

TABLE G-2.—*Effect on altitude in yards due to a 10 m. p. h. rear wind*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0
7	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
8	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
9	0	1	1	1	1	2	2	2	2	1	1	1	1	1	1
10	0	1	1	1	2	2	2	2	2	2	2	1	1	1	1
11	0	1	1	2	2	2	3	3	3	2	2	2	2	1	1
12	0	1	1	2	2	3	3	3	3	3	3	2	2	2	2
13	0	1	1	2	3	3	3	4	4	4	4	3	3	2	2
14	----	1	2	3	3	4	4	4	4	4	4	3	3	2	2
15	----	1	2	3	4	4	4	5	5	5	4	4	3	2	2
16	----	1	2	3	4	5	5	6	6	6	5	5	4	3	2
17	----	1	2	3	4	5	5	6	6	6	6	5	4	3	2
18	----	1	2	3	4	5	6	7	7	7	6	6	5	3	2
19	----	1	3	4	5	6	7	8	8	7	7	6	5	4	2
20	----	1	3	4	5	7	8	8	8	8	8	7	6	4	2
21	----	1	3	4	6	7	8	9	9	9	8	7	6	4	2
22	----	2	3	5	6	8	9	9	9	9	9	8	6	4	2
23	----	----	3	5	7	8	9	10	10	10	9	8	7	5	2
24	----	----	3	5	7	9	10	11	11	10	10	9	7	5	2
25	----	----	3	5	7	9	10	11	11	11	10	9	7	5	3
26	----	----	4	6	8	10	11	12	12	12	11	10	8	5	3
27	----	----	4	6	8	10	11	12	13	13	12	10	8	5	3
28	----	----	4	6	8	10	12	13	13	13	12	11	9	6	3
29	----	----	4	6	8	10	12	13	14	14	13	11	9	6	3
30	----	----	4	6	9	11	13	14	14	14	13	11	9	6	3
31	----	----	----	7	9	11	13	14	15	15	14	12	10	7	4

TABLE I-1.—*Effect on horizontal range in yards due to a 10-percent decrease in air density (59° F. and 29.5+in.)*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	5	4	4	4	4	4	4	4	3	3	2	2	1	1	1
2	17	17	16	16	15	14	13	12	11	10	8	7	5	4	2
3	35	35	34	33	31	29	27	25	23	20	17	14	11	7	3
4	58	57	55	53	50	47	44	41	37	32	27	22	17	11	5
5	84	82	79	76	72	68	63	58	52	45	38	31	24	16	8
6	110	108	105	101	96	90	83	76	68	59	50	41	31	21	11
7	137	134	131	126	120	113	104	95	85	74	63	51	39	26	13
8	164	161	157	151	144	135	125	114	102	89	76	62	47	31	15
9	189	186	181	174	166	156	145	132	118	104	89	72	54	36	18
10	211	207	202	195	186	175	163	149	133	117	100	81	61	41	21
11	230	225	219	212	203	192	179	164	147	129	110	89	67	45	23
12	246	241	235	227	217	206	193	177	159	140	119	96	72	48	24
13	261	256	249	241	231	219	205	189	171	150	127	103	78	52	26
14	----	271	264	255	244	232	218	201	182	160	136	110	83	56	28
15	----	285	278	269	258	245	230	213	193	170	144	117	89	60	30
16	----	299	292	283	272	259	243	225	204	180	153	124	94	63	32
17	----	313	306	297	286	272	256	237	215	190	162	132	100	67	34
18	----	327	320	311	299	285	269	249	226	200	171	139	105	71	36
19	----	342	335	325	313	299	282	261	237	210	179	146	111	75	38
20	----	357	350	340	327	312	295	274	249	220	188	153	116	78	39
21	----	371	364	354	341	326	308	286	260	230	197	160	121	81	41
22	----	386	379	369	356	340	321	299	272	241	206	168	127	85	43
23	----	----	394	383	370	354	335	311	283	251	215	175	133	89	45
24	----	----	409	398	384	368	348	324	295	262	224	182	138	93	47
25	----	----	423	413	399	382	362	337	307	273	233	189	143	96	48
26	----	----	438	427	413	396	375	350	319	283	242	197	149	100	50
27	----	----	453	442	428	410	388	362	331	294	251	204	154	103	52
28	----	----	468	457	442	424	402	375	343	305	260	211	160	107	54
29	----	----	483	471	456	438	416	389	355	315	269	219	166	111	56
30	----	----	498	485	470	452	430	402	367	325	278	226	171	114	57
31	----	----	----	499	483	465	443	415	379	336	287	233	176	118	59

TABLE I–2.—*Effect on altitude in yards due to a 10-percent decrease in air density (59° F. and 29.5+in.)*

Time of flight (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1, 000	1, 100	1, 200	1, 300	1, 400	1, 500
1	1	1	1	2	2	3	3	3	4	4	4	4	4	4	4
2	2	3	5	7	8	10	11	12	13	14	15	15	15	16	16
3	3	6	10	14	17	20	22	25	27	29	30	31	32	33	33
4	4	10	16	22	27	32	36	40	44	47	48	50	52	53	54
5	5	14	22	30	38	45	51	57	62	66	69	72	74	76	77
6	7	18	29	39	49	58	66	74	81	86	91	95	98	100	102
7	9	22	35	48	60	71	82	92	101	108	114	119	123	126	128
8	11	26	41	56	71	85	98	110	121	130	137	143	148	152	154
9	12	30	47	64	82	99	114	127	139	150	159	166	172	176	178
10	13	33	53	72	92	111	128	143	156	168	179	187	193	198	201
11	14	36	58	80	101	121	140	157	172	185	197	206	213	218	222
12	15	39	63	87	110	131	151	170	187	201	213	223	231	237	241
13	16	42	68	93	118	141	163	183	201	216	229	240	249	256	260
14	----	46	73	99	125	150	174	195	214	231	245	257	267	274	279
15	----	49	77	105	132	159	184	207	228	246	261	274	284	292	298
16	----	52	82	111	139	167	194	219	242	261	277	291	302	310	316
17	----	55	86	117	147	176	204	231	255	276	293	307	319	328	334
18	----	57	90	122	154	185	215	243	268	290	309	324	336	345	352
19	----	59	94	128	161	194	225	254	281	305	325	341	353	362	369
20	----	61	97	133	168	202	235	266	294	319	340	357	370	380	387
21	----	62	100	138	175	211	245	278	308	334	356	374	387	397	405
22	----	64	103	142	181	219	255	289	321	349	372	390	404	415	423
23	----	----	106	147	187	227	265	301	334	363	387	406	421	433	441
24	----	----	109	151	193	235	275	313	347	377	402	422	438	450	459
25	----	----	111	155	199	242	284	324	360	391	417	438	455	468	477
26	----	----	113	159	205	250	294	335	372	405	433	455	472	485	495
27	----	----	116	163	210	257	303	346	385	419	448	471	489	503	512
28	----	----	118	167	216	265	312	357	398	433	463	487	506	520	529
29	----	----	120	171	222	272	321	368	410	447	478	503	523	537	546
30	----	----	121	174	227	279	330	378	422	461	494	520	540	555	564
31	----	----	----	177	232	286	339	389	435	475	509	536	557	572	582

Table K–2.—*Effect on horizontal range in yards due to increase of 0.1 of a unit of fuze range*

Fuze setting (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	82	81	79	76	72	67	62	57	52	46	39	32	24	16	8
2	73	72	70	68	65	61	57	52	47	41	35	29	22	15	8
3	65	64	63	61	59	56	52	48	43	37	32	26	20	13	7
4	59	58	57	55	53	51	48	44	39	34	29	24	18	12	6
5	53	53	52	51	49	47	44	40	36	32	27	22	17	11	6
6	48	48	48	47	45	43	40	37	34	30	25	21	16	11	5
7	44	44	44	43	42	40	37	35	32	28	24	19	15	10	5
8	41	41	41	40	39	37	35	33	30	26	22	18	14	10	5
9	38	39	39	38	37	35	33	31	28	25	21	18	14	9	5
10	36	37	37	36	35	34	32	30	27	24	21	17	13	9	4
11	35	35	35	35	34	33	31	29	26	23	20	17	13	9	4
12	34	34	34	34	33	32	30	28	26	23	20	16	12	8	4
13	33	33	33	33	32	31	30	28	25	22	19	16	12	8	4
14		32	32	32	32	31	29	27	25	22	19	16	12	8	4
15		31	31	31	31	30	28	26	24	22	19	15	12	8	4
16		30	30	30	30	29	28	26	24	21	18	15	12	8	4
17		29	30	30	29	28	27	25	23	21	18	15	11	8	4
18		28	29	29	29	28	27	25	23	21	18	15	11	8	4
19		28	28	28	28	27	26	25	23	20	18	15	11	8	4
20		27	27	28	28	27	26	24	22	20	17	14	11	8	4
21		26	27	27	27	26	25	24	22	20	17	14	11	7	4
22		25	26	26	26	26	25	24	22	20	17	14	11	7	4
23			25	26	26	25	24	23	21	19	17	14	11	7	4
24			25	25	25	25	24	23	21	19	17	14	11	7	4
25			24	25	25	25	24	23	21	19	17	14	11	7	4
26			24	24	24	24	23	22	21	19	16	14	11	7	4
27			23	24	24	24	23	22	20	18	16	13	10	7	4
28			23	23	23	23	23	32	20	18	16	13	10	7	4
29			22	23	23	23	22	21	20	18	16	13	10	7	4
30			21	22	23	23	22	21	20	18	16	13	10	7	4
31				22	22	22	22	21	20	18	15	13	10	7	3

TABLE K–3.—*Effect on altitude in yards due to increase of 0.1 of a unit of fuze range*

Fuze setting (sec.)	Quadrant elevation—Mils														
	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
1	7	15	23	30	38	45	51	57	63	68	72	75	78	80	81
2	5	12	19	26	33	39	45	51	56	60	64	67	69	71	72
3	3	10	16	23	29	34	40	45	49	53	57	60	62	64	65
4	2	8	14	20	25	30	35	40	44	48	51	54	56	58	59
5	1	6	12	17	22	27	31	36	40	43	46	49	51	53	54
6	0	5	10	14	19	24	28	32	36	39	42	45	47	48	49
7	−1	3	8	12	17	21	25	29	33	36	39	41	43	44	45
8	−2	2	6	10	15	19	23	26	30	33	36	38	40	41	42
9	−3	1	5	9	13	17	20	24	27	30	33	35	37	38	39
10	−4	0	4	7	11	15	18	22	25	28	31	33	35	36	37
11	−5	−1	2	6	10	13	17	20	23	26	29	31	33	34	35
12	−6	−2	1	5	8	12	15	19	22	25	27	29	31	32	33
13	−7	−3	0	4	7	11	14	17	20	23	26	28	29	30	31
14		−4	−1	3	6	9	13	16	19	22	24	26	28	29	30
15		−5	−2	1	5	8	11	14	17	20	22	24	26	27	28
16		−6	−3	0	3	7	10	13	16	19	21	23	25	26	27
17		−7	−4	−1	2	5	9	12	14	17	20	22	23	24	25
18		−8	−5	−2	1	4	7	10	13	16	18	20	22	23	24
19		−9	−6	−3	0	3	6	9	12	15	17	19	20	21	22
20		−10	−7	−4	−1	2	5	8	11	13	16	18	19	20	21
21		−10	−8	−5	−2	1	4	7	10	12	14	16	18	19	20
22		−11	−9	−6	−3	0	3	6	8	11	13	15	17	18	19
23			−10	−7	−4	−1	2	4	7	10	12	14	16	17	17
24			−10	−8	−5	−2	0	3	6	9	11	13	14	15	16
25			−11	−9	−6	−3	−1	2	5	7	10	12	13	14	15
26			−12	−10	−7	−4	−2	1	4	6	8	10	12	13	14
27			−13	−11	−8	−5	−3	0	3	5	7	9	11	12	13
28			−14	−11	−9	−6	−4	−1	2	4	6	8	10	11	12
29			−14	−12	−10	−7	−5	−2	0	3	5	7	9	10	11
30			−15	−13	−11	−8	−6	−3	−1	2	4	6	8	9	10
31				−14	−12	−9	−7	−4	−2	1	3	5	7	8	9

SECTION V

DERIVATION OF FORMULAS

■ 258. **DEFLECTION FORMULAS FOR ANTIAIRCRAFT GUNS (ANGULAR TRAVEL METHOD).**—*a.* (1) The elements of the problem to be solved are shown in figure 103. The target is traveling along the line T_oT_p at a known altitude (H) (above the horizontal plane of the gun) at a constant speed over the ground, S_g. The angular height of the target at T_o is ϵ_o and the angular height of the target at T_p is ϵ_p. The time of flight of a projectile to the point T_p is t_p seconds. The length of the line T_oT_p is S_gt_p. The horizontal projection of this line makes the angle a_o with the horizontal projection of the line of position to T_o. The horizontal angle between the plane Ga_oT_o and the plane Ga_pT_p is the principal lateral deflection angle, δ_1. The angular difference between the angular height ϵ_o and the angular height ϵ_p is the principal vertical deflection angle σ_1.

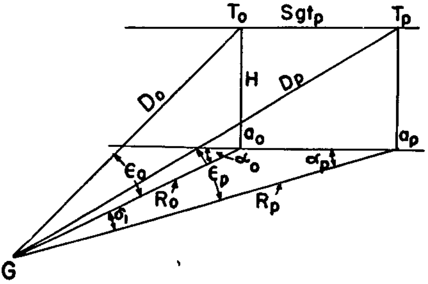

FIGURE 103.—Oblique projection.

(2) At each instant during the travel of the target along the line T_oT_p, its azimuth and its angular height as seen from the gun are continually changing. The rate of change in azimuth is called the lateral angular velocity and is represented by the symbol, Σ_a. The rate of change of angular height is called the vertical angular velocity and is represented by the symbol, Σ_e. These symbols will be used in the following discussion, to represent the respective angular velocities of the target at its T_o position.

(3) Figure 104 shows the problem to be solved in its horizontal and vertical projections, with the vertical projection of the plane through Ga_o (present position) rotated into the vertical projection of the plane through Ga_p (future position) in order that vertical angles may be compared by inspection.

(4) The magnitude of the principal lateral deflection angle can be determined mathematically under the basic assumptions of target flight. Referring to the horizontal projection,

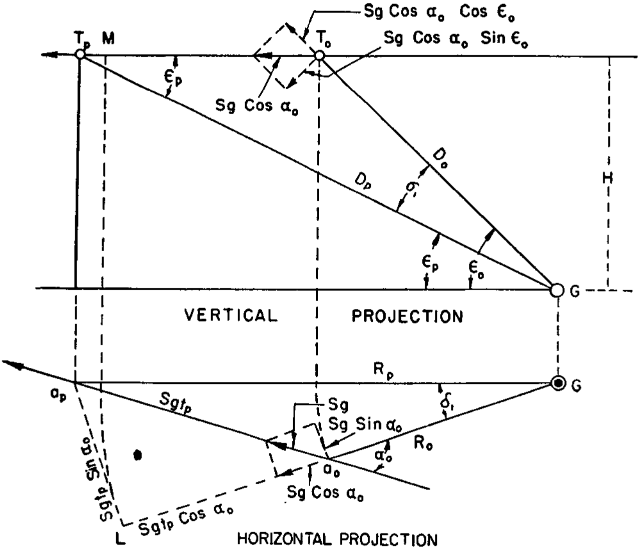

FIGURE 104.—Vertical and horizontal projections.

S_gt_p is the length of the line T_oT_p, since the target is moving at a speed S_g during t_p seconds. The line subtends the angle which is the principal lateral deflection, δ_1. The value of this angle may be represented by the equation:

$$\text{Sin } \delta_1 = \frac{S_g t_p \sin \alpha_o}{R_p} \tag{1}$$

This equation, however, is not in a convenient form for practical use. It is necessary first that the quantity S_gt_p, representing distance, be expressed in terms of angular velocity.

The lateral angular velocity at T_o is represented by the symbol Σ_a. The formula for the rate of angular travel in radians per second, for the conditions considered, is

$$\Sigma_a = \frac{S_g \sin \alpha_o}{R_o}$$

Solving this equation for S_g and substituting in equation (1), that equation becomes

$$\text{Sin } \delta_1 = \Sigma_a t_p \frac{R_o}{R_p} \tag{2}$$

The quantity R_o/R_p is in terms of horizontal range. Since these values are not, in practice, easily determined, it becomes desirable to convert the term into an expression involving angular height, which is readily determinable. From figure 104 it may be seen that

$$R_o = H \cot \epsilon_o$$

and,

$$R_p = H \cot \epsilon_p$$

Substituting these values in (2), the equation becomes

$$\text{Sin } \delta_1 = \Sigma_a t_p \frac{H \cot \epsilon_o}{H \cot \epsilon_p}$$

or

$$\text{Sin } \delta_1 = \Sigma_a t_p \frac{\sin \epsilon_p \cos \epsilon_o}{\sin \epsilon_o \cos \epsilon_p} \tag{3}$$

which is the equation for the principal lateral deflection angle. The part of the formula $\left(\frac{\sin \epsilon_p \cos \epsilon_o}{\sin \epsilon_o \cos \epsilon_p}\right)$ corrects the approximate deflection for the angular travel error.

(5) It is to be noted that the value of σ_1 depends upon the rate of change of angular height, and that the vertical angular velocity must be considered in determining σ_1, as will be seen from the appearance of ϵ_o and ϵ_p in (3) above. Similarly, it will be found that the value of the principal vertical deflection angle is dependent upon lateral deflection.

b. The principal vertical deflection angle, σ_1 is the vertical angle, as measured at the gun position, through which the target will move during the time intervening between the firing of the gun and the arrival of the target and the projectile at the future position. The magnitude of this vertical angle, like that of the principal lateral deflection angle, can be determined mathematically.

(1) The principal vertical deflection angle σ_1 is the amount that the angular height of the target changes during the time of flight, that is $\sigma_1 = \epsilon_o - \epsilon_p$. In figure 104, it is the angle $T_o\,G\,T_p$. Its value may be determined as follows:

In the triangle $T_o\,G\,T_p$

$$\frac{\sin\sigma_1}{\sin T_oT_pG} = \frac{T_oT_p}{D_o}$$

but the angle $T_o\,T_p\,G$ is equal to ϵ_p, therefore

$$\sin\sigma_1 = \frac{T_oT_p}{D_o}\sin\epsilon_p \qquad (1)$$

From the figure ,

$$T_oT_p = T_oM + MT_p$$

and equation (1) may be written

$$\sin\sigma_1 = \frac{T_oM}{D_o}\sin\epsilon_p + \frac{MT_p}{D_o}\sin\epsilon_p \qquad (2)$$

Also, from the figure,

$$T_oM = S_gt_p\cos a_o$$

Substituting this expression of T_oM in equation (2)

$$\sin\sigma_1 = \frac{S_gt_p}{D_o}\cos a_o\sin\epsilon_p + \frac{MT_p}{D_o}\sin\epsilon_p \qquad (3)$$

(2) Since the angular velocity of the target is more easily measured than the linear velocity it is preferable that the term S_g in equation (3) be replaced by its equivalent expressed in terms of Σ_e. The instantaneous vertical angular velocity (expressed in radians per second) may be determined by dividing the component of the target's linear velocity, perpendicular to the line of present position and contained in the same vertical plane, by the distance to the target. The horizontal component of the target's linear speed lying in the same vertical plane as the line of present position is $S_g\cos a_o$ (horizontal projection, fig. 104). Considering this component now as a resultant and further resolving it into its two components, one perpendicular and the other parallel to the line of position (vertical projection), the component desired is equal to $S_g\cos a_o\sin\epsilon_o$. The other component $S_g\cos a_o\cos\epsilon_p$, acts along the line of position and

therefore has no effect upon either lateral or vertical deflection. Therefore the angular velocity may be expressed as follows:

$$\Sigma_e = \frac{S_g \cos \alpha_o \sin \epsilon_o}{D_o} \text{ (4) where } \Sigma_e \text{ is in rads/sec}$$

Solving equation (4) for the value of S_g, we find

$$S_g = \frac{\Sigma_e D_o}{\cos \alpha_o \sin \epsilon_o} \tag{5}$$

Substituting equation (5) in equation (3) and simplifying

$$\sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} + \frac{MT_p}{D_o} \sin \epsilon_p \tag{6}$$

(3) From figure 104 it may be seen that

$$MT_p = R_p - GL$$

In the triangle a_pGL, $GL = R_p \cos \delta_1$

Therefore $MT_p = R_p - R_p \cos \delta_1$

$$= R_p \ (1 - \cos \delta_1)$$

From trigonometry, $1 - \cos\delta = \sin \delta \tan \frac{1}{2}\sigma$

$$= R_p \sin \delta_1 \tan \frac{\delta_1}{2} \tag{7}$$

Substituting equation (7) in the last part of equation (6),

$$\frac{MT_p}{D_o} \sin \epsilon_p = \frac{R_p}{D_o} \sin \delta_1 \tan \frac{\delta_1}{2} \sin \epsilon_p \tag{8}$$

$$R_p = H \cot \epsilon_p$$
$$D_o = H/\sin \epsilon_o$$

Therefore

$$\frac{R_p}{D_o} = \frac{H \cot \epsilon_p}{H} \sin \epsilon_o = \cot \epsilon_p \sin \epsilon_o \tag{9}$$

Substituting equation (9) in equation (8)

$$\frac{MT_p}{D_o} \sin \epsilon_p = \sin \delta_1 \tan \frac{\delta_1}{2} \sin \epsilon_p \cot \epsilon_p \sin \epsilon_o$$

The term $\sin \epsilon_p \cot \epsilon_p$ may be written $\cos \epsilon_p$.
Equation (6) may now be written,

$$\sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} + \sin \delta_1 \tan \frac{\delta_1}{2} \cos \epsilon_p \sin \epsilon_o \tag{10}$$

It should be noted that in the figure the horizontal range is increasing and the angular height is decreasing. Hence, σ_1

will be negative in this case. If the formula were derived for an approaching target, the same formula would be obtained except that the last expression of the right-hand member would have a negative sign. This expression,

$$\sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} - \sin \delta_1 \tan \frac{\delta_1}{2} \sin \epsilon_o \cos \epsilon_p \qquad (11)$$

is the general form of the equation for the principal vertical deflection angle. Reconciling these two equations involves a discussion of the second term of the equation which is called the complementary term.

c. (1) The complementary term varies with the principal lateral deflection angle and corrects the principal vertical deflection equation for that part of the angular travel error due to the change in horizontal range (MT_p in fig. 104) not considered in the first part of equations (10) and (11). It should be noted that when the principal lateral deflection is zero (a target coming directly toward or going directly away from the battery), no error will be made, MT_p will be zero, and T_oT_p will equal a_oL regardless of the target's ground speed.

(2) The horizontal projection of this situation is shown in figure 105 with the present position at T_o and the future position at T_p or T'_p, depending upon whether the target is coming in or going out.

If the target's course changes from the line GT_o and if the component of its linear velocity measured in a direction along the line GT_o remains unchanged, its future position will lie somewhere along the lines AB or $A'B'$, regardless of how much it may have been turned away from the course GT_o. Furthermore, the horizontal range to the new future position is certain to be greater than GT_p or GT'_p, as the case may be, and with the assumption of constant altitude, the future angular height is certain to be less than it would be if the target had not turned off the line GT_o. Thus, regardless of its sign, the complementary term must act to decrease future angular height. In equation (10), the target is going out, vertical deflection is negative, and the positive sign indicates that the complementary term increases the value of the principal vertical deflection angle, thus serving to still further decrease the future angular height. In equation (11), the target is coming in, vertical deflection is positive, and the negative sign of the complementary term shows that it acts to decrease vertical deflection and thus decrease the future angular height.

NOTE.—It was assumed above that the linear velocity of the target along the line GT_0 remains constant as the target changes direction. If this velocity does change, the value of the first term of the expression for principal vertical deflection will change correspondingly, and the above proof will be modified only in that it will refer to two new lines *AB* and *A′B′*.

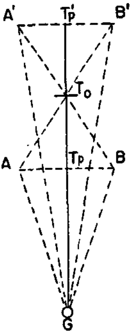

FIGURE 105.

d. The approximate vertical deflection angle is equal to the product of the instantaneous angular velocity and the time of flight.

$$\sigma_x = \Sigma_e t_p$$

It should be noted by comparing this equation with equations (10) and (11) that the complementary term corrects for only a part of the vertical angular travel error. The effect of the complementary term is usually small (5 mils or less). The major part of the vertical angular travel error is corrected by the terms sin in the left-hand sides and

$$\frac{\sin \epsilon_p}{\sin \epsilon_o}$$

in the first terms of the right-hand sides of equations (10) and (11). It will be seen that the equations for δ_1 and for σ_1 are simultaneous equations, neither of which may be solved without the other. Practically, these simultaneous equations are solved mechanically by the method of successive approximations.

■ 259. **DIRECTOR FORMULAS (LINEAR SPEED METHOD)**.—*a. Director, M4.*—(1) The target's present position is determined in the horizontal plane by a mechanism which solves the following equation:

$$R_o = H_o \cot \epsilon_o$$

The input elements are H_o and ϵ_o, and the output is R_o.

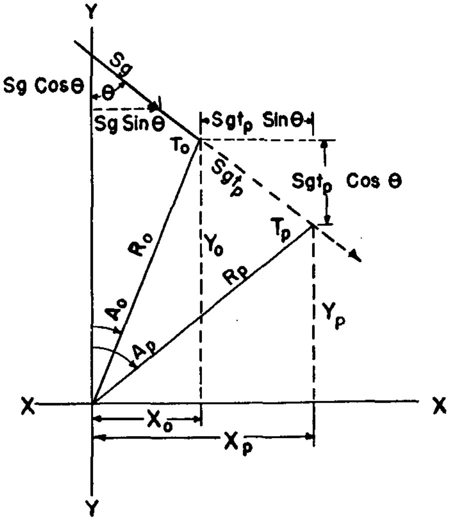

FIGURE 106.

(2) The target's future position is predicted in the horizontal plane by mechanisms which solve the following set of simultaneous equations:

$$X_p = X_o + S_g t_p \sin \theta$$
$$Y_p = Y_o + S_g t_p \cos \theta$$

The target's future azimuth is determined from the preceding pair of equations by converting the rectangular coordinates into polar coordinates.

b. In the director, M4, the effect of wind is corrected for by assuming that each component of the wind, N–S and E–W, has an effect on each component of the target's ground speed. For example, the effect of a 10-mile-an-hour north wind on the point of burst is nearly the same as the change in prediction caused by an addition of 2.4 yards per second to the north rate.

■ 260. ADDITIONAL FORMULAS.—The following mathematical expressions are given for academic interest. They apply to data computors which are no longer standard, but may pertain in part to directors of the future.

a. Director, M1A1.—(1) The director mechanism correctly solves the following equation for lateral deflection:

$$\delta_1 = \sin^{-1}\left(\Sigma_a t_p \frac{\sin \epsilon_p \cos \epsilon_o}{\sin \epsilon_o \cos \epsilon_p}\right)$$

(2) The director mechanism provides a solution for the vertical deflection which closely approximates the true value:

$$\text{(True value) } \sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} - \sin \delta_1 \tan \frac{\delta_1}{2} \cos \epsilon_p \sin \epsilon_o$$

$$\text{(Director solution) } \sin \sigma_1 = \Sigma_e t_p \frac{\sin \epsilon_p}{\sin \epsilon_o} - \sin \delta_1 \tan \frac{\delta_1}{2} \cos \epsilon_p \sin \epsilon_p$$

In addition, for case III firing, the assumption is made that

$$\sigma_1 = \sin \sigma_1$$

(3) The mechanism which corrects for drift provides a solution for the following empirical equation which closely approximates true firing table values:

$$\delta_{2d} \text{ (in mils)} = 1.75 + 0.4\ t$$

(4) The mechanism which corrects for the effect of ballistic wind provides a solution for the following empirical formulas which closely approximate true firing table values:

$$\delta_{2w} \text{ (in mils)} = 0.280\ W \sin \beta\ (H - 0.6)$$

$$\sigma_{2w} \text{ (in mils)} = 0.092\ W \cos \beta\ (H - 0.6)$$

where W is expressed in miles per hour and H in thousands of yards.

b. AA data computor, M1917.—(1) The computor provides a solution of the following equations:

For lateral deflection—

$$\delta_1 = \Sigma_{1a}\, t_1\, M$$

where

$$M = \frac{\cos^2 \epsilon_1}{\sin^2(\epsilon_1 + 1.25\sigma_1)} \times \frac{[1 + \sin(\epsilon_1 + 1.25\sigma_1)] \tan(\epsilon_1 + 1.25\sigma_1) \tan(\epsilon_1 + 0.25\sigma_1)}{(1 + \sin \epsilon_1)}$$

In deriving the equation for M, the assumption is made that

$$t_d/t_1=0.25 \text{ (See note below)}$$

For vertical deflection—

$$\sigma_1=\Sigma_{1e}t_1+X$$

where $X=\frac{\sin\epsilon_1\cos\epsilon_1}{1+\sin\epsilon_1}\left[\frac{1}{144}\sin\epsilon_1-\frac{1}{36}+\delta_1^2\right.$

$$\left.(0.25\sin^3\epsilon_1-\sin^2\epsilon_1-\sin\epsilon_1+0.25)\right]$$

In deriving the equation for X, the assumption is made that

$$t_d/t_p=0.25$$

(See note below)

(2) The computor mechanism is designed to solve the following equation in computing fuze range. The fuze range cylinder is rotated in altitude and the pointer is positioned in angular height according to the equation

$$\epsilon_p=\epsilon_1+\sigma_1(1+t_d/t_1)$$

(See note below)

where $t_d=8$ seconds.

NOTE.—t_d is dead time. t_1 is time of flight to observed position of target.

SECTION VI

REFERENCES

■ 261. STANDARD TABLES.—*a*. See FM 4–155 for the following tables:

(1) Trigonometric functions, formulas, and fundamental relations.

(2) Conversion tables for degrees and minutes to mils or vice versa.

(3) Natural functions of angles in degrees or mils.

b. See TM 5–236 for the following tables:

(1) Logarithmic functions of angles in degrees or mils.

(2) Logarithms of numbers.

■ 262. GLOSSARY OF TERMS.—See FM 4–155.

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