FM 4-111

WAR DEPARTMENT

COAST ARTILLERY FIELD MANUAL

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ANTIAIRCRAFT ARTILLERY

POSITION FINDING AND CONTROL
ANTIAIRCRAFT SEARCHLIGHTS

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FIELD MANUAL

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POSITION FINDING AND CONTROL
ANTIAIRCRAFT SEARCHLIGHTS

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Chief of Coast Artillery

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BY ORDER OF THE SECRETARY OF WAR:

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Chief of Staff.

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The Adjutant General.

TABLE OF CONTENTS

COAST ARTILLERY FIELD MANUAL

ANTIAIRCRAFT ARTILLERY

POSITION FINDING AND CONTROL, ANTIAIRCRAFT SEARCHLIGHTS

CHAPTER 1

GENERAL

■ 1. SCOPE.—This manual treats of the position finding, control, and illumination phenomena pertaining to antiaircraft searchlights. A knowledge of the basic principles described in FM 4–110 and FM 4–112 will be helpful in understanding the problem of locating and illuminating aerial targets. Pertinent definitions and symbols should be studied, and a thorough understanding of the picture in space of the various elements of data should be acquired. The training of antiaircraft artillery searchlight units is covered in FM 4–115.

■ 2. ILLUMINATION PROBLEM.—From the description of fire control instruments contained in FM 4–110 it is evident that the success of the methods employed depends upon the actual tracking of the target by the various instruments. During the hours of daylight, under normal atmospheric conditions, the target can usually be seen and tracked. This, however, is impossible during the hours of darkness unless the target is illuminated in some manner. The illumination must be maintained during all the firing, if continuous pointed fire is to be used. Of all the methods of illumination, searchlights have been found to give the most satisfactory results.

■ 3. LOCATION PROBLEM.—A searchlight beam swinging aimlessly in the sky would illuminate the target only by chance. Therefore, before the searchlight can be trained on the target, the target must be located. The problem is to determine the azimuth and angular height of the position of the target. At the present time the only practical field method of locating the target is by sound. Various methods of utilizing sound have been tried, the best results being obtained by a horn collector with its acoustic tract leading directly to the listener's ear.

■ 4. CONTROL PROBLEM.—The ability of the searchlight to pick up a target and illuminate it continuously depends upon a number of factors all of which tend to decrease the visibility. Research indicates that the visibility of the target increases as the operator moves away from the searchlight. Approximately 90 percent of the advantage which can be gained is obtained at a distance of about 50 feet. Manual control of the searchlight is impractical at this distance, hence electrical control is employed. The control problem is that of pointing the searchlight in the direction indicated by the sound locator, the operator being located 50 feet or more from the light source.

■ 5. SEARCHING.—Even with the latest equipment and well-trained listeners, the target seldom will be located exactly at the azimuth and angular height indicated by the sound locator. Because of the effect of atmospheric conditions on the speed and direction of sound waves, it will be necessary to search around the azimuth and angular height as computed by the sound locator. However, the total effect of the above-mentioned variables seldom exceeds 5° in azimuth or angular height. This is well within the limits of searching. So far no practical field method has been found for determining the value of the atmospheric effects on the sound waves. For this reason it is impractical to apply corrections for these atmospheric effects prior to tracking the airplane by sound.

CHAPTER 2

SOUND LOCATION

■ 6. **Theory of Sound Location.**—*a.* (1) All persons possessing normal hearing with both ears have a faculty known as the "binaural sense" which enables one to locate the approximate direction of a sound source. When the sound source is directly in front of a person, the sound waves travel the same distance in reaching both ears. (See fig. 1 in which R_L equals R_R.) If, however, the head is turned to one side, the sound waves will travel farther to reach one ear than the other. (See fig. 1 in which R_L does not equal R_R.) Sound travels through the air at a speed of about 1,100 feet per second. Therefore, when the head is turned to one side, the ear closest to the sound source receives the sound vibration slightly before the other ear. The binaural sense enables the listener to distinguish this brief phase difference between the reception of the sound by each ear. The listener turns his head until the phase difference becomes imperceptible. At this point the head will be pointed toward the sound source.

(2) Normally the head is erect and the ears are in a horizontal plane resulting in binaural sense in azimuth. However, if the ears are placed in the vertical plane, the elevation of the sound source can be determined just as readily. The unaided ears can usually determine the direction of a sound source within 10°.

b. The accuracy of the binaural sense is proportional to the distance between the ears. This can be seen from figure 1. If the base line between the ears is made longer, the difference between ranges R_L and R_R will become greater, and the corresponding phase difference at which the sound strikes each ear will become greater. Since the accuracy of sound location is dependent upon the minimum phase difference that the ears can detect, extending the base line of the ears in effect reduces the minimum phase difference that the ears are able to recognize. The base line between the ears can readily be increased by the use of a pair of horns mounted some distance apart and connected to the ears by tubes.

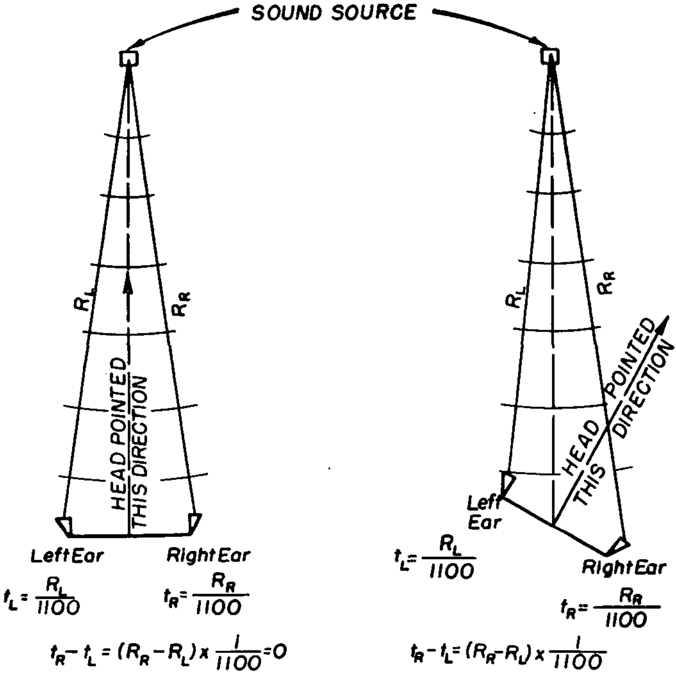


FIGURE 1.—Binaural sense.

c. The horns serve another purpose. Sound is essentially a vibration transmitted through some medium, generally air. The sensation of sound usually is experienced by a person when the vibrations are felt by the ear. The stronger the vibration, the greater will be the sensation experienced by the ear. The practice of cupping the hand over the ear in order to hear faint sounds is well known. Horns will do the same as the cupped hands except that they collect the vibrations from a greater area than the hands. The intensity of the sound is thus increased, and the listener is able to distinguish sounds which he would be unable to hear with the unaided ear.

d. To summarize, all persons with normal ears possess binaural sense. A listener possesses binaural sense in the vertical plane if his ears are located in the vertical plane. The accuracy of the binaural sense is increased and the intensity of the sound magnified by the use of horns separated by some distance.

■ 7. **SOUND LOCATOR DESIGN.**—Sound locators are designed to aid the listener's binaural sense. Basically they are all alike, consisting of two pairs of horns mounted so that the base lines of the pairs are perpendicular to each other, and one base line is horizontal. This arrangement allows one pair of horns to determine the location of the target in azimuth and the other in angular height. The base lines of the horns are made perpendicular by the design of the instrument. One base line is made horizontal by the use of leveling jacks or screws.

a. To locate target.—(1) Sound locators now have either 3 or 4 horns. The 4-horn type uses one pair for azimuth determination and the other pair for angular height. In the 3-horn type 1 horn is used by both listeners by dividing the acoustic tract at the exit of the horn. It will be seen that basically the 3-horn type functions the same as the 4-horn type.

(2) The spacing of the horns varies in the different designs. Theoretically, the accuracy of the instrument increases with the length of the base line. The older models have a base line length of 112 inches. Recent exhaustive tests have shown that there is not much gained in accuracy if the length of the base line exceeds 60 inches. The new models have the shorter base line, thereby decreasing the weight and size of the instrument.

(3) The older models of sound locators use the exponential horn, so called because the cross section area of the horn at any point bears a definite relation to the length of the horn at that point. Such a design collects the sound within the frequencies of airplane noise and transmits it to the acoustic tract without distortion.

(4) Recent extensive tests in the laboratory and in the field have indicated that horn size and horn shape have little influence on the range of the sound locator. Hence, the latest models do not have the exponential horn but a horn which has certain other characteristics. (See *b* (3) below.)

b. To reduce ambient noises.—(1) The existence of ambient noises (that is, the general surrounding noise) serves to decrease the range at which the sound locator can operate. A sound locator will be used as much as possible at its maximum obtainable range. The more distant the target, the fainter will be the sound. On the other hand, the intensity of the ambient noises will remain fairly constant regardless of the range. It is evident then that in order to increase the range of the sound locator the ambient noises must be reduced as much as possible. An analogy will emphasize this point. The less noise there is in a room, the more easily a quiet conversation can be heard.

(2) Ambient noises are classified as—

(*a*) Reverberation of horn structure.

(*b*) Effect of wind blowing on horns and supporting structure.

(*c*) Gear and other noises transmitted through the structure itself to the acoustic tract.

(*d*) All air-borne noises except those in the direction of the target.

(3) Ambient noises are reduced greatly by the design of the latest type of sound locator. This type features sound insulating and vibration dampening materials, streamlining of the horns and supporting structure, and making the horn definitely directional within a 30° cone in the direction of the axis of the horn.

■ 8. **Sound Locator M2** (fig. 2).—This sound locator employs three horns. For further description see FM 4–115, TM 4–210, or the operator's manual issued with the sound locator. For information on setting up, orientation, operation, and care see FM 4–115. For information on training instruments and methods see chapter 7 of this manual and FM 4–115.

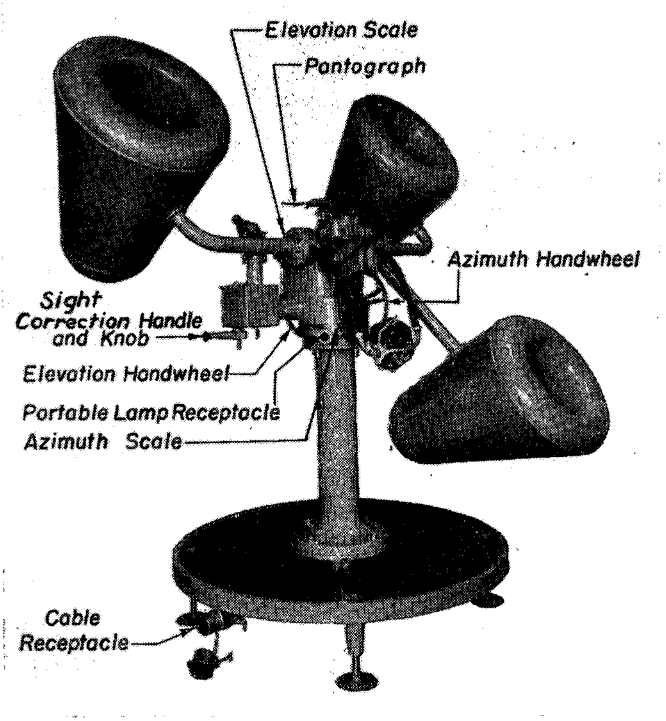


Figure 2.—Sound locator M2.

■ 9. **Sound Locator M1 Series** (fig. 3).—This instrument is the 4-horn type with exponential horns. Several models

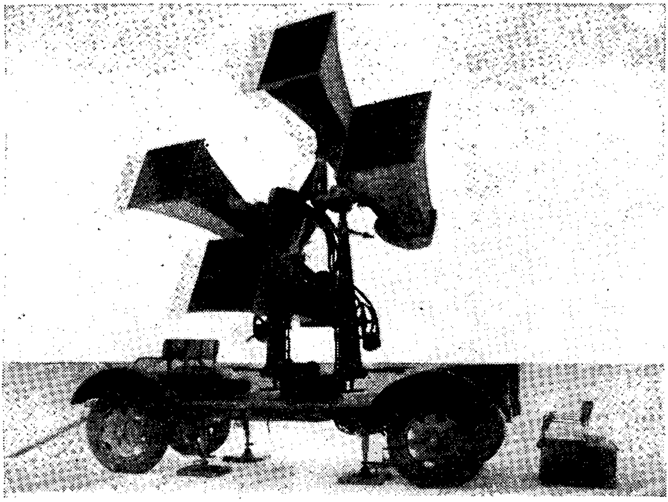


FIGURE 3.—Sound locator M1A8.

(M1A1 to M1A8) are found in the service, all of which are similar except for the types of trailers and acoustic correctors included therewith. For further description see FM 4–115, TM 4–210, or the notes on matériel, issued with the instrument. For information on setting-up, orientation, operation, and care see FM 4–115. For information on training instruments and methods see chapter 7 of this manual and FM 4–115.

CHAPTER 3

ACOUSTIC CORRECTIONS

SECTION I

GENERAL

■ 10. **GENERAL.**—*a*. In the preceding chapter we have seen how it is possible to locate a sound source in azimuth and angular height by means of the sound locator. Consider a specific example. An airplane is flying directly toward the sound locator at a speed of 300 miles per hour and at an altitude of 4,000 yards. At the instant when the plane is at a horizontal range of 8,000 yards (see fig. 4), the slant range to this point is 8,944 yards or 26,832 feet. Sound travels at

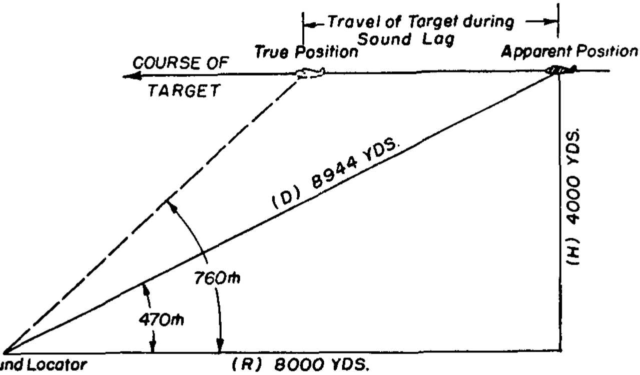


FIGURE 4.—Travel of target during sound lag time.

approximately 1,100 feet per second. It will take $\frac{26,832}{1,100}=24.4$ seconds for the sound to reach the listener. The time required for sound to reach the listener is called sound lag time (t_s) and is expressed in seconds. In 24.4 seconds the target will travel 24.4 times 150 or 3,660 yards, approximately. That is, the target will actually be at a horizontal range of 4,340 yards when the sound emitted at 8,000 yards is heard at the sound locator. The sound locator would indicate the angular height of the target as being 470 mils, whereas it actually would be 760 mils. This illustration shows only the vertical error due to sound lag because the course considered was an incoming course. Any other course would have errors because of sound lag in both azimuth and angular height.

b. The above illustration indicates the necessity of calculating corrections for sound lag and of applying these corrections before the data are transmitted to the control station for use in directing the searchlight to the target. These vertical and horizontal corrections for the travel of the target during sound lag are called σx and δx, respectively.

SECTION II

ACOUSTIC CORRECTOR FOR M2 SOUND LOCATOR

■ **11. SOUND LAG.**—*a.* Consider the azimuth travel of the target as shown in figure 5, the target traveling in the direction *A–B*. A listener at *O* will point the sound locator toward *A* when the target is at *B*. The sound lag angle is δx. The distance the target travels during the sound lag (*A–B*) is equal to t_s times *S* where *S* is target speed expressed in feet per second. The slant range to the apparent position of the target *O–A* can be expressed as t_s times 1,100. Then

$$\frac{AB}{AO}=\frac{t_s\times S}{t_s\times 1,100}=\frac{S}{1,100}$$

The speed of sound is considered constant, so the value of the above ratio depends only upon the speed of the target.

b. Note that the magnitude of the slant range to the target does not affect the value of this ratio. This can be proven graphically. Consider a course *A'–B'* parallel to *A–B* at one-half the slant range. The sound lag will be one-half that for the course *A–B*, but the travel of the target will be also one-half *A–B*. The triangles *OAB* and *OA'B'* are therefore similar, and the lateral sound lag angle is δ_x in either case.

■ 12. **Wind Error.**—In addition to the effect of sound lag, a serious error may be introduced by wind. Consider a normal wind blowing in the direction indicated in figure 6. The effect of the wind will be to change the apparent position of the target from *A* to *B*. As in the case of sound lag and in a similar manner

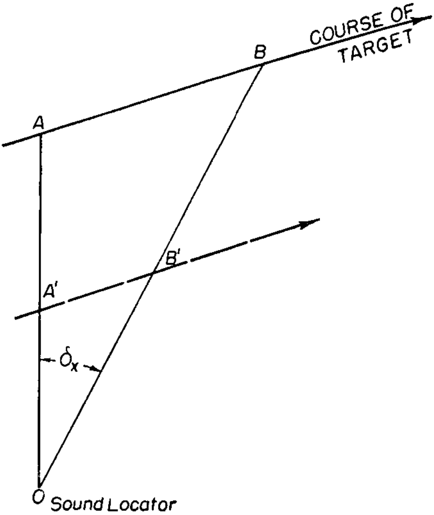


Figure 5.—Sound lag angle, horizontal projection.

$$\frac{AB}{AO}=\frac{W}{1{,}100}$$

(W=velocity of wind in ft./sec.). The angle δ_{2w} represents the error due to wind. A wind not perpendicular to the direction *OA* can be resolved into a component parallel to *AB* and a component parallel to *AO*. The effect of the component parallel to *OA* is so slight that it can be ignored.

■ 13. PARALLAX.—*a*. The sound locator for various reasons may be placed at some distance from the searchlight. Such displacement introduces a parallax error which may become serious. Figure 7 shows the analysis of the parallax error. The sound locator is at *O*, the searchlight at *O'*, and the true position of the target at *B*. If the azimuth of *B* from *O* were used to set the searchlight in azimuth, the searchlight would be pointed at *B'*. An azimuth correction equal to the angle *DO'D'* (known as the parallax correction) must be applied to the searchlight data to have the searchlight point at *B*.

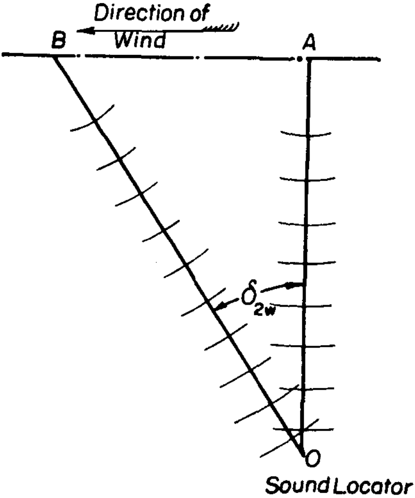


FIGURE 6.—Wind effect, horizontal projection.

b. When the slant range *OB* is very great and the angular height small, the parallax correction is practically negligible. The error increases as the angular height increases, until at a point directly over the base line between *O* and *O'* the error in azimuth is 180°.

■ 14. **PRINCIPLE OF OPERATION.**—*a*. (1) The principle of the acoustic corrector is illustrated in figure 8. The sound locator is at *O*, the apparent position of the target at *A*, and the true position of the target at *B*. *AB* is the travel of the target during the sound lag time. The sound locator determines the azimuth and angular height of the point *A*. The acoustic corrector determines the sound lag corrections δ_x (for azimuth) and σ_x (for angular height) which, when added to the azimuth and angular height of *A*, will give the azimuth and angular height of *B*.

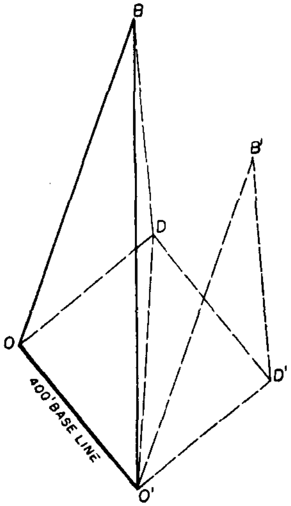


FIGURE 7.—Parallax error.

(2) In paragraph 11 it was shown that the ratio

$$\frac{AB}{AO}$$

varies only with the speed of the target. The ratio

$$\frac{AB}{AO}$$

and the direction *AB* determine the sound lag angles δ_x and σ_x.

b. (1) The acoustic corrector for the M2 sound locator solves the problem of determining δ_x and σ_x in the following manner (see fig. 8). The points *O, A,* and *B* are set up to a reduced scale. The distance *AB* is obtained by estimating the speed of the target. The miniature airplane course indicator (see par. 16) automatically and continuously determines the direction of *AB*. The point *B* is thus located to scale. The sound lag angles are determined by sighting at the point *B* from *O* in the miniature model and measuring the angular displacement (lateral and vertical) of point *B* from point *A*.

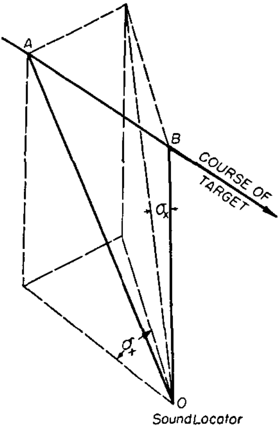


FIGURE 8.—Principle of acoustic corrector, M2 sound locator.

(2) In the scale model used in the acoustic corrector, the slant range *AO* is kept constant at 7.5 inches. *AB* is adjustable for target speeds from 0 to 400 miles per hour. As previously stated in paragraph 11,

$$\frac{AB}{AO}=\frac{S}{1{,}100}$$

AO is constant, being 7.5 inches. For a target traveling 200 miles per hour, *S* will be equal to 293 feet per second. Then,

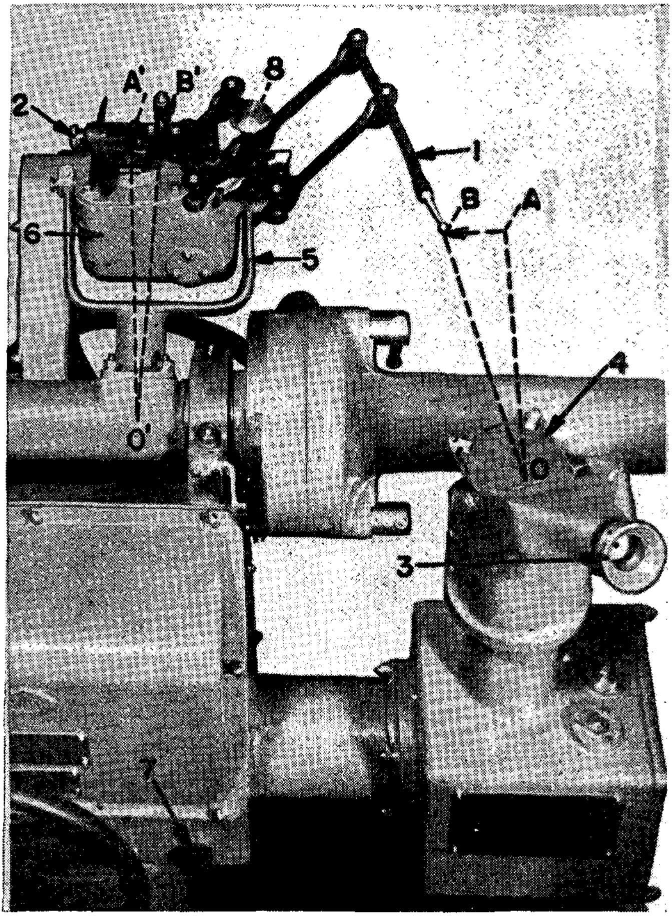
$$AB=\frac{293\times 7.5}{1{,}100}=2\text{ inches, approximately.}$$

Likewise, when *S* equals 100 miles per hour, *AB* equals approximately 1 inch.

(3) Figure 9 shows a view of the acoustic corrector on the M2 sound locator. The miniature airplane course indicator indicates a direction parallel to the course of the target (see par. 17). The target course computer (6) and multiplying pantograph (1) are mounted so that they remain horizontal while the yoke holding these mechanisms is elevated or depressed with the horns of the sound locator. *O'A'* extended will intersect the apparent position of the target. The length of *A'B'* is adjusted by the knob (2) according to the estimated speed of the target.

(4) For mechanical reasons it is impossible to sight from *O'* to *B'*, hence the multiplying pantograph is used to transfer the position of *B'* to *B* where it can be viewed. The points *O*, *A*, and *B* have the same significance as *O*, *A*, and *B* in figure 8. *OA* is constant at 7.5 inches. *AB* is approximately 1 inch for each 100 miles per hour of target speed. It should be noted that the use of the pantograph requires the offset *A' B'* to be parallel to but opposite in direction to *AB*. The true position of the target is therefore in the direction *OB* and not *O'B'*.

■ 15. SIGHT MECHANISM.—*a*. The ball (*B*) on the end of the pantograph (1) is viewed through the sight (3). (See fig. 9.) The sight consists of a sighting tube and a mirror which may be rotated in azimuth by a correction handle projecting underneath the tube supporting arm. Motion of the mirror in angular height is obtained by mounting the mirror on a tilting table which is connected by gearing to a rotatable knob on the end of the correction handle. By looking through the sighting tube and positioning the mirror by means of the correction handle and knob, the operator alines the image of the ball (*B*) on the end of the pantograph with the cross lines of the mirror. Thus the axis of the sight is made to coincide with the line *OB*, figures 8 and 9. The sight is connected to the sound locator so that its normal (zero correction for sound lag) axis coincides with the line *AO*. By positioning the sight so that the pantograph pointer coincides with the cross lines of the mirror, the sound lag angles δ_x and σ_x are introduced through differentials to the gearing connecting the azimuth and elevation drives with



1. Multiplying pantograph.
2. Target air speed setting knob on miniature airplane course indicator.
3. Sight.
4. Mirror.
5. Yoke.
6. Target course computer.
7. Self-synchronous push button switch.
8. Fixed elbow of pantograph.

FIGURE 9.—Acoustic corrector, M2 sound locator.

the azimuth and elevation transmitters. (See fig. 10.) The transmitters are therefore transmitting the azimuth and angular height of the true position of the target to the control station.

b. The line of sight *OB* (fig. 9) if extended would pass through the true position of the target. Therefore, when the searchlight is in action, the pantograph pointer (*B*) should be silhouetted against the searchlight beam. In daytime practice, or at night when the target is in the beam, the target should be visible beyond the pantograph pointer. (This is true only when no parallax correction is applied.) As an aid to daylight training a circle subtending 10° at the operator's eye incloses the cross lines on the mirror. With proper training the listeners should be able to keep the target image within this circle when the pantograph pointer is centered on the cross lines.

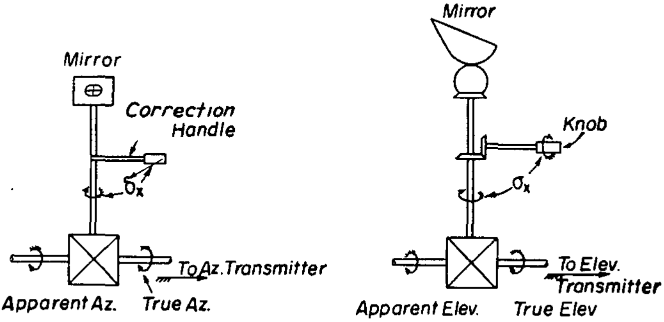


FIGURE 10.—Schematic sketch, sight mechanism.

■ 16. MINIATURE AIRPLANE COURSE INDICATOR.—*a.* In paragraph 14*b* it was stated that the miniature airplane course indicator automatically and continuously determines the direction *AB* in figure 9.

b. (1) Figure 11 shows projected upon the horizontal plane a target course *L–M* along which the target has the velocity V_T. The sound locator situated at *O* is pointed in azimuth in the direction *OA*, where *A* is the apparent target position.

The angle which the target course makes with the sound locator azimuth heading or vertical listening plane is represented by α.

(2) Considering only a straight course at constant altitude, the target velocity V_T may be resolved into two horizontal components V_R and V_L, the former lying in the listening plane and the latter normal to the listening plane. In terms of these two components, the course angle is

$$\alpha = \tan^{-1}\frac{V_L}{V_R} \qquad (1)$$

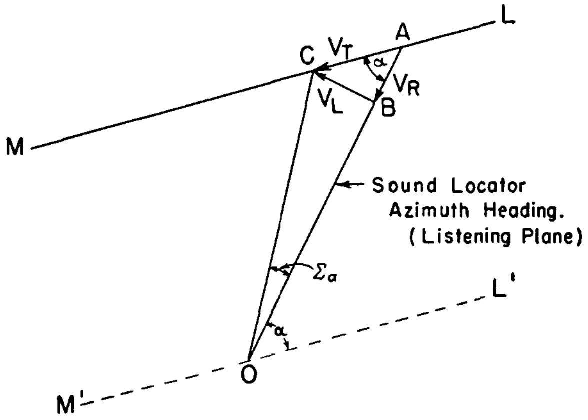


FIGURE 11.—Projection of target's course on horizontal plane.

(3) Figure 12 is a projection upon the listening plane of the same data whose horizontal projection is shown in figure 11. The sound locator elevation heading is *OA* where *A* is the apparent target position as in figure 11. The angular height of the sound locator is represented by ϵ.

(4) The miniature airplane course indicator is controlled by a caster connected to a ball analyzer which is mounted on the sound locator in such a way that the axis of rotation of the resolving ball remains horizontal. The two driving rollers, at right angles to each other, are so located in the horizontal plane that the one which corresponds to component V_R tends

to rotate the resolving ball in the listening plane, while the second driving roller which corresponds to V_L tends to rotate the resolving ball in the plane normal to the listening plane. Figure 13 shows this arrangement schematically. The roller corresponding to V_L is termed the lateral driving roller and that corresponding to V_R is termed the radial driving roller. The resultant motion of the ball depends upon the relative speeds of these two rollers. If the speeds of the lateral and radial driving rollers are proportional to V_L and V_R, respectively, the resulting plane of rotation of the ball is parallel with the target course and the caster alines itself parallel with the target course and indicates the correct course angle.

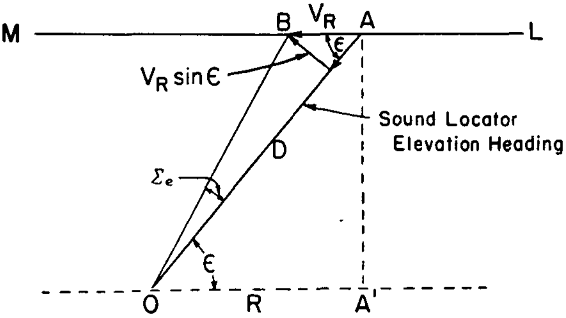


FIGURE 12.—Projection on listening (or vertical plane) through sound locator and apparent target position.

(5) The problem is to make the ratio of the speed of the lateral driving roller to the speed of the radial driving roller proportional to V_L/V_R. It is convenient to derive the driving roller speeds from the azimuth and elevation angular velocities of the sound locator due to tracking the target. However, as will now be shown, the ratio of these velocities is not proportional to V_L/V_R.

(6) Referring to figure 11, the azimuth angular velocity of the sound locator due to tracking the target is

$$\Sigma_a = \frac{V_L}{R} \qquad (2)$$

where R is the horizontal range applying to figure 11, as shown in figure 12.

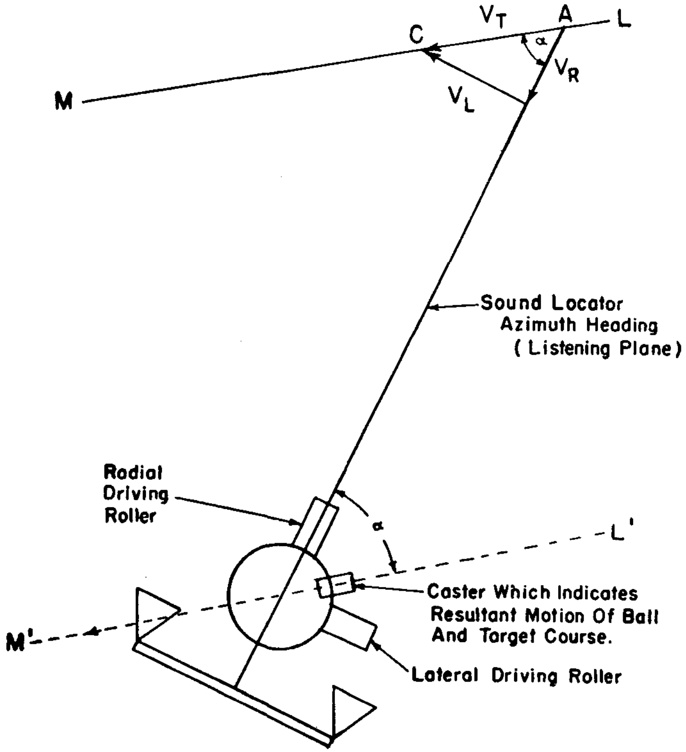


FIGURE 13.—Projection on horizontal plane showing resolving ball attached to sound locator.

The elevation angular velocity of the sound locator due to tracking the target is

$$\Sigma_{\epsilon}=\frac{V_R \sin \epsilon}{D} \qquad (3)$$

where ϵ is the angular height and D is the slant range, as shown in figure 12.

(7) If the lateral and radial driving roller speed ratio is proportional to the azimuth and elevation angular velocity

ratio of the sound locator, then the course given by the resolving ball is

$$\tan^{-1}\frac{\Sigma_a}{\Sigma_e} \tag{4}$$

Substituting (2) and (3) in (4)

$$\tan^{-1}\frac{\Sigma_a}{\Sigma_e}=\tan^{-1}\frac{\dfrac{V_L}{R}}{\dfrac{V_R\sin\epsilon}{D}} \tag{5}$$

Expressing the horizontal range in terms of slant range, $R=D\cos\epsilon$, and substituting this in (5)

$$\tan^{-1}\frac{\Sigma_a}{\Sigma_e}=\tan^{-1}\frac{\dfrac{V_L}{D\cos\epsilon}}{\dfrac{V_R\sin\epsilon}{\mathrm{D}}}$$

$$=\tan^{-1}\frac{V_L}{D\cos\epsilon}\times\frac{D}{V_R\sin\epsilon}$$

$$=\tan^{-1}\frac{V_l}{V_R}\times\frac{1}{\cos\epsilon\sin\epsilon} \tag{6}$$

(8) Equation (6) shows that when the driving roller speed ratio is proportional to $\Sigma a/\Sigma e$, the resultant course given by the resolving ball is not

$$\tan^{-1}\frac{V_L}{V_R}(1)\text{ but is }\tan^{-1}\frac{V_L}{V_R}\times\frac{1}{\cos\epsilon\sin\epsilon} \tag{6}$$

and it is therefore incorrect. To make the course correct we must multiply the numerator of equation (6) by the factor $\cos\epsilon\sin\epsilon$ to cancel this factor in the denominator. We then get the following relationship

$$\alpha=\tan^{-1}\frac{\Sigma_a}{\Sigma_e}\cos\epsilon\sin\epsilon \tag{7}$$

which gives the correct course angle. This can be accomplished by inserting in the drive connecting the lateral driving roller to the azimuth movement of the sound locator a variable speed drive of the speed ratio characteristic, $\cos\epsilon\sin\epsilon$.

(9) For practical purposes, however, since the useful operating range of the sound locator lies between angular

heights of from 15° to 75° we can replace the factor $\cos \epsilon \sin \epsilon$ with the constant 0.4 and still get a reasonably accurate solution of course angle. Equation (7) now becomes

$$\alpha = \tan^{-1} 0.4\frac{\Sigma_a}{\Sigma_e} \qquad (8)$$

$$= \tan^{-1} \frac{1}{2.5}\frac{\Sigma_a}{\Sigma_e} \qquad (9)$$

(10) For simplicity in design, in the apparatus as actually constructed, equation (8) is satisfied by making the radial driving roller speed 2.5 times faster than the lateral driving roller speed for the same angular velocities of the sound locator in azimuth and angular height.

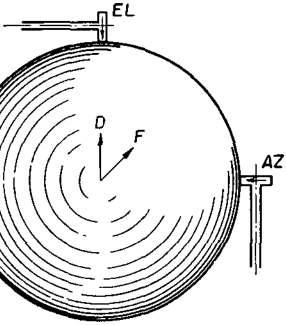


FIGURE 14.—Ball analyser, plan view.

c. What has just been accomplished graphically, that is, the determination of the direction of the course of the target using the angular velocities in azimuth and angular height, can be done mechanically by a ball analyser. (See fig. 14.) The ball is free to rotate in any direction and is caused to rotate by the two rollers *EL* and *AZ*. The axes of these two rollers are at right angles and in the horizontal plane. Thus any rotation given to the ball must be about an axis in the horizontal plane. As the rollers *EL* and *AZ* revolve in the direction shown in figure 14, the top of the ball will be displaced in the direction *F* if the rates of the rollers are equal. If the *AZ* roller is stationary, the ball will roll in the direction *D*. The direction of the rotation of the ball is dependent therefore on the relative rates of turning of the two rollers *EL* and *AZ*. Pressing on the ball is a caster which is free to rotate about a vertical axis through the point *A*. (See fig. 15.) The caster will swing about the axis so as to point in the direction of rotation of the ball. That is, the caster indicates the direction of the resultant of the two vectors which are the rates of turning of the *EL* and *AZ* rollers. The *AZ* roller is connected directly to the azimuth drive of the sound locator. The elevation roller is connected through gearing to the angular height drive so that the angular velocity is multiplied by 2.5 before it rotates the roller. The caster is therefore indicating the direction of the resultant of the two vectors Σ_a and 2.5 Σ_e which was shown in *b* above to be the direction of the course of the target.

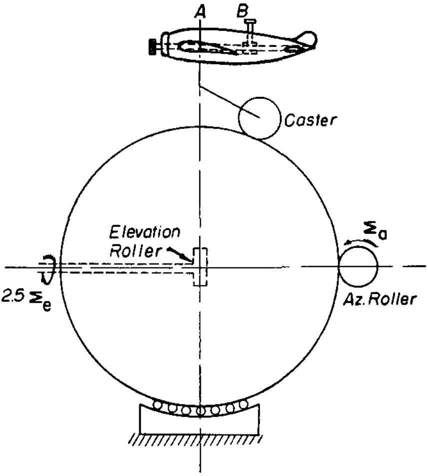


FIGURE 15.—Miniature airplane course indicator.

d. A small model airplane is mounted on the caster so as to give a realistic picture of the direction of the course. The model plane also provides a method of introducing the target speed. The pin *B* (fig. 15) is adjustable by turning the knob on the model where the propeller would be located. A scale graduated in miles per hour target speed is provided, allowing speeds up to 400 miles per hour to be applied.

■ 17. CORRECTION FOR WIND.—*a*. In the preceding discussion concerning the determination of the sound lag angles, the air speed of the target has been assumed equal to the ground speed.

b. In paragraph 12, it was shown that the wind acts in the same manner as target speed to cause a difference between the apparent position and the true position.

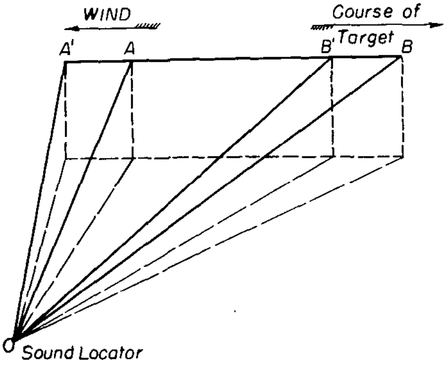


FIGURE 16.—Wind correction.

c. A study of figure 16 will show how the acoustic corrector can correct for wind. Assume first that there is no wind and that the target is flying a rectilinear course as shown in figure 16. The plane will travel from *A* to *B* during the sound lag. Now consider a wind blowing in an opposite direction to the course of the target. Then the listener will determine the apparent position of the target as *A'*. The target travel with respect to the ground will be from *A* to *B'* as the head wind will reduce the ground speed of the target. The distance between the apparent position and true position has not changed due to the wind, that is $AB=A'B'$. Both the sound and the target are borne by the same medium, air. If the air is moving, as is the case when the wind is blowing, both the sound and the target will be displaced equal amounts.

d. It must be remembered that the ground speed of the target is affected by the wind but that the air speed of the target is entirely independent of the wind. From the above discussion it is seen that the effect of wind is automatically corrected for if we use the air speed of the target in making the setting on the miniature airplane course indicator.

■ 18. CORRECTION FOR PARALLAX.—*a.* The parallax error is dependent upon the slant range to the target, the azimuth and angular height of the target, and the direction and displacement of the searchlight from the sound locator. When the searchlight and sound locator are set in position, the displacement becomes a constant.

b. In figure 17, the relation of target, sound locator, and searchlight is shown as reproduced to scale in the acoustic corrector. The pivot of the sight mechanism is at *O*. The solid circle with radius *AB* represents the possible locus of the pantograph pointer for some particular target speed. The searchlight is at *L*. The distance *AO* is 7.5 inches, which is the distance to scale that sound travels in 1 second (1,100 feet). As

$$\frac{AB}{AO}=\frac{S}{1{,}100}$$

(see par. 11) it follows that if *AO* is the distance that sound travels in 1 second, *AB* must be the distance that the target travels in 1 second. The distance *AB* remains constant so long as the target speed is unchanged.

c. Let us assume that the course of the target (*A–B*, fig. 17) is as shown parallel to the base line and that the apparent position of the target is *A*. The true position of the target is *B*. The azimuth of the point *B* from *O* must be corrected by the parallax correction angle *OCL* (equals *C′LC*) if the searchlight is to be directed at the point *B* by the data furnished by the sound locator. If we could shift the pivot of the sight from *O* to *L* and then aline the sight with the pantograph pointer, the parallax correction would be included in the transmitted data to the control station.

d. Due to problems of construction, it is simpler to move the pantograph pointer from *B* to *B′* rather than move the pivot of the sight. The locus of the pantograph pointer for a particular target speed is therefore the dotted circle of radius *A'B'* equal to *AB*. This shifting is accomplished by mounting the fixed elbow of the pantograph (8) on an adjustable offset pivot. (See fig. 9.) The axis of the offset is parallel with the base line at the time of instrument orientation. It is always kept in such alinement by gearing connected to the azimuth drive. In this manner *A* is offset to *A'*, and *A'* revolves in a circle about *A* as the sound locator traverses in azimuth, the direction *A A'* being always parallel to *LO*.

e. The true position of the target is actually in the direction *OB*, but the parallax correction makes the sight point in the direction *OB'*. Since *OB'* is parallel to *LB*, the searchlight is trained on the true position of the target. If the corrector operator were able to see the target in the mirror of the sight, it would no longer be in line beyond the pantograph pointer (*B'*, fig. 17) but at position *B*.

f. At 0° elevation the $\angle OBL = \angle OCL$. As the angular height increases (assuming slant range is constant), $\angle OCL$ and likewise $\angle OC'L$ increase, but $\angle OBL$ remains constant. When the target is directly over O the direction *LC'* will have moved counterclockwise to lie in the direction *LO*. The parallax correction has therefore increased from the $\angle OCL$ to 90°, as the angular height increases from zero to 90°.

g. The offset *AA'* is chosen for an estimated slant range at 0° elevation. As stated in paragraph 14*b*, the entire corrector remains horizontal as the sound locator elevates or depresses. Therefore the offset *AA'* is maintained horizontal as the elevation of the line *OA* changes with the elevation of the sound locator. Consideration of the figure will show that *BB'* is always parallel to and equal to *AA'*.

h. In introducing the parallax correction, the vertical plane through the sight is shifted from *C* to *C'*, both of which are in the horizontal plane. As the angular height increases, the distance *OC'* decreases, thereby increasing the parallax correction angle *CLC'*. Hence it can be seen that the parallax correction angle is changed to the proper value as the sound locator changes elevation.

i. Figure 17 shows a course parallel to the base line in which only parallax correction in azimuth is involved. The construction of the instrument is such that *AA'* (and likewise *BB'*) is always parallel to the base line and horizontal. The parallax correction has been introduced by shifting the pantograph pointer (*B*) in direction and distance equal to the displacement (to scale) of the searchlight from the sound locator. Therefore, the parallax correction is made regardless of the direction of the course of the target, provided the slant range to pick-up point is properly estimated.

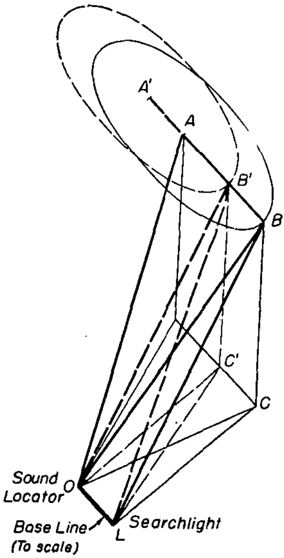


FIGURE 17.—Parallax corrections.

j. The three factors affecting the parallax correction have been discussed. The corrections in azimuth and angular height are automatic. (See *h* and *i* above.) The direction of the parallax offset is introduced by proper orientation when the sound locator is set up and is thereafter automatically maintained. Corrections for slant range and length of base line are made by changing the offset of the pantograph. A scale is provided for the offset graduated in arbitrary numbers from 0 to 10, there being no offset for 0 and the maximum offset for 10. The value set on the scale is selected from figure 18, using as arguments estimated slant range to pick-up point in feet, and base line length in feet.

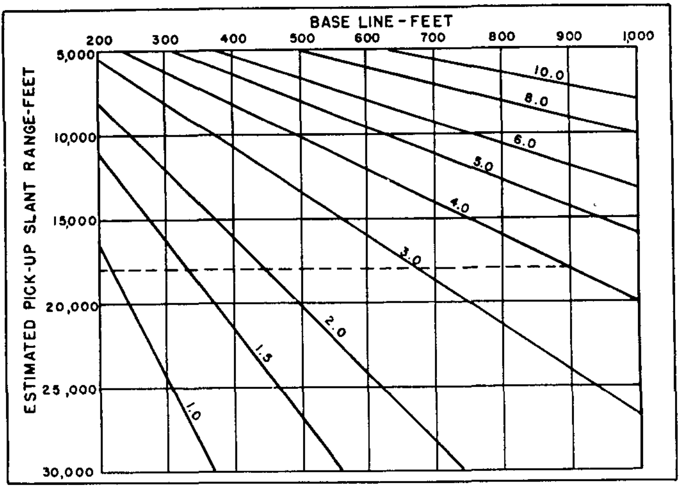


FIGURE 18.—Graph of parallax settings.

k. The estimation of the pick-up slant range is a matter of experience. The factors affecting the problem in general are—

(1) Type of target.

(2) Camouflage of target.

(3) Altitude of target.

(4) Atmospheric conditions at the moment (such as mist or clouds) and the degree of darkness.

(5) Type of searchlight being used.

The above factors can be evaluated and an estimate made of the approximate slant range at time of pick-up based on past experiences under similar circumstances.

SECTION III

ACOUSTIC CORRECTORS M1 AND M2

■ 19. **GENERAL.**—*a.* In section II the acoustic corrector for the M2 sound locator was discussed. This is the latest type of acoustic corrector. Two other types will be found in the service, the M1 and M2. Both the M1 and the M2 operate on the same principle, but in other features they are quite different. The principle of operation of the M1 and M2 is totally different from that described in section II. Note that the M2 acoustic corrector is *not* used with the M2 sound locator.

b. The M1 and M2 acoustic correctors were designed for use with the sound locators of the M1 series. Acoustic corrector M1A1 is similar to the M1 except that it delivers data in mils.

■ 20. **PRINCIPLE OF OPERATION.**—*a.* The angular velocities of the target in azimuth and angular height are obtained by the process of tracking the target with the sound locator. These angular velocities Σ_a and Σ_e are multiplied by the sound lag time (t_s) to obtain δ_x and σ_x, respectively.

b. The sound lag angles δ_x and σ_x are added, respectively, to the azimuth and angular height of the apparent position of the target as determined by the sound locator, giving the true position of the target, which is then transmitted electrically to the control station.

■ 21. **ACOUSTIC CORRECTOR M1 (M1A1).**—*a.* The principle by which this device works has been explained in paragraph 20. Figure 19 shows the instrument with the front cover removed. It consists, essentially, of the following components:

(1) Two single unit electrical data transmitters.
(2) Sound lag drum and chart.
(3) Two prediction mechanims.
(4) Corrected azimuth and elevation scales.

b. Two single unit synchronous electrical data transmitters are provided, one for azimuth and the other for angular height, to transmit the true position of the target to the control station. The rotor of each is connected with the azimuth or angular height drive of the sound locator. The transmitters would therefore transmit the azimuth and angular height of the apparent position of the target to the control station if no sound lag correction angles were added.

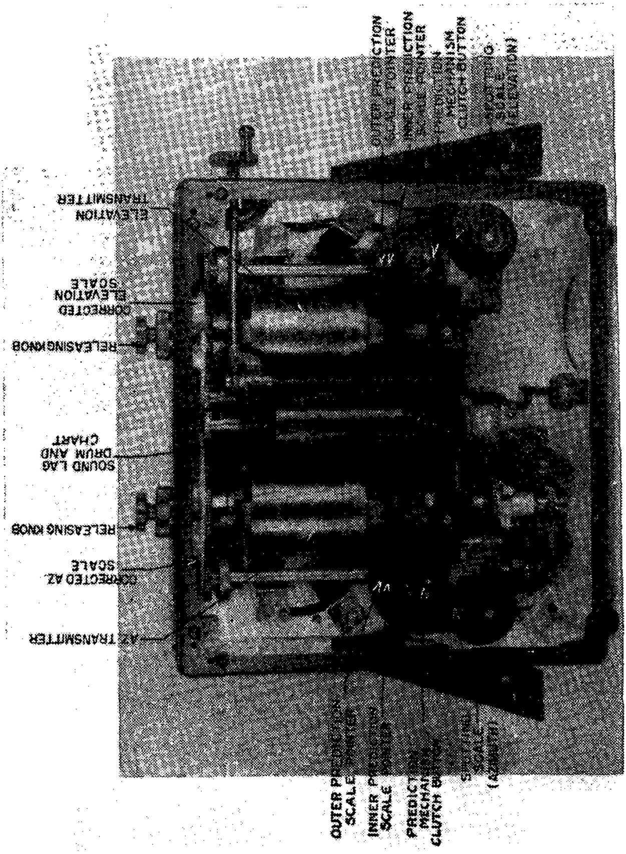


FIGURE 19.—Acoustic corrector M1.

c. The sound lag drum carries a chart upon which are plotted curves of constant sound lag time (t_s) using altitudes as ordinates and angular heights of the apparent position as abscissae. The drum is connected to the angular height drive of the sound locator and is therefore positioned in angular height of the apparent position. A pointer, which is set at the estimated altitude of the target, indicates a curve of sound lag on the cylinder.

d. (1) There are two prediction mechanisms, one for azimuth and the other for angular height. The azimuth prediction mechanism consists of a scale and two pointers. The inner pointer is connected by a clutch to the azimuth drive of the sound locator. Normally the clutch is disengaged. Pressure on the operating button engages the clutch and the inner pointer indicates the angle through which the sound locator has traversed while the clutch was engaged. The clutch is engaged by the operator for the period of time indicated by the sound lag drum. It will be seen that we have performed the multiplication $\Sigma_a \times t_s$ which as shown in paragraph 20 is δ_x. A knob is provided to zero the inner pointer after each prediction.

(2) The outer pointer of the azimuth prediction mechanism is geared to the frame of the azimuth transmitter. The outer pointer is matched to the inner pointer, thereby rotating the frame of the azimuth transmitter through the sound lag angle (δ_x). Since rotating the frame is equivalent to an added rotation to the rotor, the sound lag angle (δ_x) has been effectively added to the azimuth of the apparent position of the target. The azimuth transmitted to the control station will be this sum.

(3) Arbitrary corrections in azimuth are introduced by displacing the scale of the prediction mechanism. Therefore the correction will not take effect until a new prediction is made after the correction is applied.

(4) The curves on the sound lag chart are graduated with values of one-third the actual sound lag time in order to reduce the time necessary to make a prediction. For an actual sound lag of 18 seconds, the clutch would be engaged for 6 seconds. A suitable gearing is used between the prediction mechanism and the frame of the transmitter so that the full value of the sound lag angle (δ_x) is applied.

(5) The prediction is not continuously computed. The sound lag angle (δ_x) computed by a prediction remains con-

stant until a new prediction is made and introduced by matching the pointers.

(6) The prediction mechanism for angular height is identical with the azimuth prediction mechanism except that the inner pointer is engaged with the elevation drive by the clutch, and the matching of the pointers displaces the frame of the angular height transmitter the amount of the sound lag angle (σ_x).

e. The corrected azimuth and elevation scales indicate the azimuth and the angular height being transmitted to the control station, that is, the azimuth and angular height of the true position of the target. The releasing knobs on the top of the corrector clamp these scales to the rotors of the data transmitters and provide a method of orienting.

■ 22. ACOUSTIC CORRECTOR M2.—*a.* The acoustic corrector M2 is an improvement of the M1 corrector. The necessity of using a stop watch to measure the sound lag when making the prediction is eliminated. All operations are automatic except setting in the estimated altitude of the target and matching two sets of pointers. (See fig. 20.)

b. The instrument functions differently from the M1. The azimuth and angular height of the apparent position of the target and the lateral and vertical angular rates (Σ_a and Σ_e) are transmitted from the sound locator to the acoustic corrector. The elevation drive is connected to the rotor of the elevation transmitter and, through friction drives, to the pointer of the vertical rate indicator. The azimuth drive is connected to the rotor of the azimuth transmitter and, through friction drives, to the pointer of the lateral rate indicator. The sound lag time computing cam is translated along its axis in estimated altitude. The lift of the sound lag time computing cam is proportional to $1/t_s$. The lift of the time cam follower moves (in translation) through a rack and gear differential, a guide carrying two multiplying cams (lateral and vertical). These cams are positioned (in rotation) by movement of the lateral and vertical rate matching knobs. The lifts of the multiplying cam followers are proportional respectively to the lateral (Σ_a) and vertical (Σ_e) angular velocities of the target. The followers, through racks and pinions, position the outer pointers of the rate indicators.

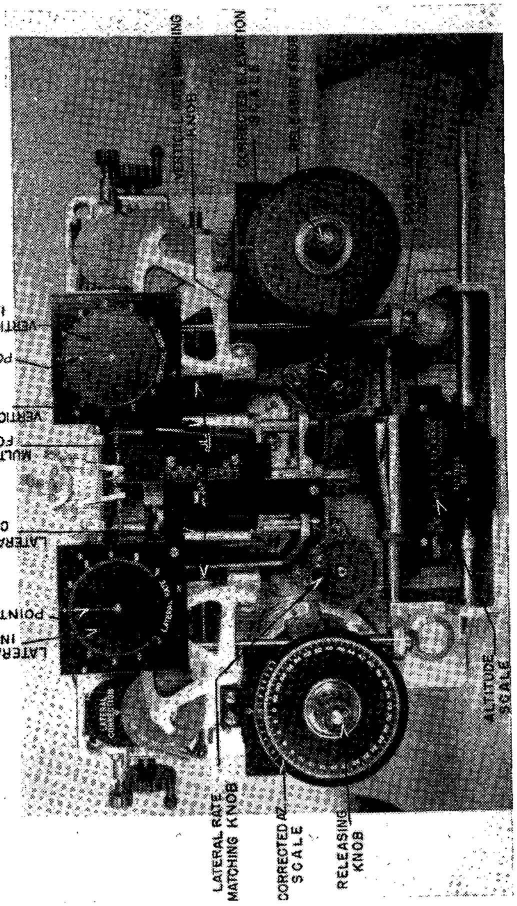


FIGURE 20.—Acoustic corrector M2.

c. What has been accomplished thus far may be explained mathematically as follows:

$$t_s \text{ (sound lag time)} = \frac{D \text{ (slant range)}}{V_s \text{ (velocity of sound)}} \qquad (1)$$

$$D = \frac{H_x \text{(estimated altitude)}}{\sin \epsilon' \text{ (angular height)}} \qquad (2)$$

Substituting in (1)

$$t_s=\frac{H_x}{V_s \sin \epsilon'} \qquad (3)$$

Inverting (3)

$$1/t_s=\frac{V_s \sin \epsilon'}{H_x}$$

$$\left\{\begin{array}{l}\text{Lift of follower on time cam and}\\ \text{translation of multiplying cams}\end{array}\right\}=\frac{\text{(rotation of time cam)}}{\text{(translation of time cam)}}$$

$$\sigma_x\left\{\begin{array}{l}\text{angular height correction}\\ \text{required by travel of target}\\ \text{during sound lag time}\end{array}\right\}=\Sigma_e\left\{\begin{array}{c}\text{vertical angular}\\ \text{velocity}\end{array}\right\}\times t_s \qquad (4)$$

Rearranging (4)

$$\Sigma_e=\sigma_x\times 1/t_s \qquad (5)$$

$$\left\{\begin{array}{l}\text{Lift of follower on vertical}\\ \text{multiplying cam, and in-}\\ \text{dication of index on verti-}\\ \text{cal rate indicator}\end{array}\right\}=\left\{\begin{array}{l}\text{rotation of ver-}\\ \text{tical multiply-}\\ \text{ing cam}\end{array}\right\}\times\left\{\begin{array}{l}\text{translation}\\ \text{of vertical}\\ \text{multiplying}\\ \text{cam}\end{array}\right\}$$

NOTE.—Equations (4) and (5) hold for the lateral elements δ_x and Σ_a also. The reason for the use of the reciprocal of the sound lag time $1/t_s$ is thus made apparent as it contributes toward simplicity in design.

d. The actual measurement of the target's angular rates (Σ_a or Σ_e) is accomplished automatically. The timing mechanism consists of a small constant-speed (governor-controlled) A. C. motor which drives a tripping cam at 6 revolutions per minute or 1 revolution in 10 seconds. The elevating and traversing shafts from the sound locator are connected to rate indicator pointers through friction clutches. The tripping cam, through slides and levers, actuates pawls which alternately engage, for a period of 4 seconds, and disengage, for a period of 6 seconds, the ratchet wheels which drive the rate indicator pointers (inner pointers on the rate indicator). When the pawls are disengaged, the tachometer pointers are engaged with their respective elevating and traversing shafts and measure their angular movements for 6 seconds. When the pawls are engaged, the tachometer pointers remain stationary for 4 seconds, to allow time for the operator to match the indexes with them, and then return to zero, after which the cycle of operation is repeated. The chronometric cam is so designed that there is a 5-second interval between the beginning of the cycles of the lateral and vertical rate indicators, which permits one operator to match alternately the two rate pointers. The linear scale factors and gear ratios are such that the operation of the mechanisms may be described as the periodic multiplication (at 10-second intervals) of the average angular velocity in mils per second (⅙ of the angular movement in 6 seconds) by the sound lag time in seconds.

e. The electrical transmitters which transmit azimuth and angular height to the searchlight control station are built into the instrument and function in the same manner as those in the acoustic corrector M1. The rotors are connected to the azimuth and elevation shafts from the sound locator. The stators are rotated through the sound lag correction angles (δ_x and σ_x) by the rate matching knobs. Provision is made for arbitrary vertical and lateral corrections.

f. The speed of the constant-speed motor may be checked by counting the revolutions of the tripping cam over a 1- to 5-minute interval using a stop watch. The speed may be adjusted through an adjusting screw just below the top cover plate.

g. Stops are provided which limit the motion of the operating handwheels. The acoustic corrector M2 operates within the following limits:

Slant range (*D*)	1,100 to 11,000 yards.
Altitude (*H*)	3,300 to 30,000 feet.
Angular velocity (Σ_a or Σ_e)	83 mils per second.
Sound lag correction (δ_x and σ_x)	±250 mils.
Arbitrary correction	±200 mils.
Prediction period	6 seconds.
Prediction interval	10 seconds.

CHAPTER 4

SEARCHLIGHTS

■ 23. **General.**—This chapter is devoted to searchlight phenomena. Information pertaining to searchlights will be found in TM 4–210 and the operator's manual issued with the searchlight. Information on setting-up, orientation, operation, and care will be found in FM 4–115.

■ 24. **Contrast.**—*a. General.*—(1) The range of a searchlight is the maximum distance at which an object in the beam is visible. The visibility of the object does not depend on its actual illumination but upon the contrast between its illumination and the illumination of the surrounding field.

(2) The contrast between an object and the surrounding field which is necessary for visibility depends upon the apparent size of the object, that is, upon the angle which it subtends at the eye of the observer and the area presented toward him. When the object is close, a contrast of a few percent is sufficient for visibility. When the object is far away and subtends a small angle, a contrast of several hundred percent is necessary to make the object visible.

(3) A specific example will illustrate the above fact. Consider the sun as a searchlight which is illuminating the moon and the planet Venus as well as the surrounding fields. During daylight hours the contrast between the moon and the surrounding field is about 2 to 1. The moon subtends an angle of about 25 minutes. Venus, due to its greater coefficient of reflection, has an actual contrast of about 12 to 1. Venus subtends an angle of about 1 minute. In spite of the great difference in contrast, the moon can be seen in daylight while Venus cannot. The apparent size of the two objects, the moon and Venus, is the determining factor in this case as to whether or not the object is visible.

(4) The area presented toward the observer affects the problem of contrast in the case of airplane targets. As can be seen from figure 21, an airplane presents less area toward

the observer as the angle of elevation decreases. The maximum area is presented at about 55°. Figure 21 is for a biplane. For a monoplane the curve becomes a straight line with a minimum value for 0° and increases to the maximum value at the zenith. The amount of light reflected to the observer from both the target and the field surrounding the target determines the contrast. The less area the target presents, the less light is reflected and the lower the contrast. A camouflaged plane may have a similar effect, for the contrast is reduced if the amount of light reflected from the plane is reduced.

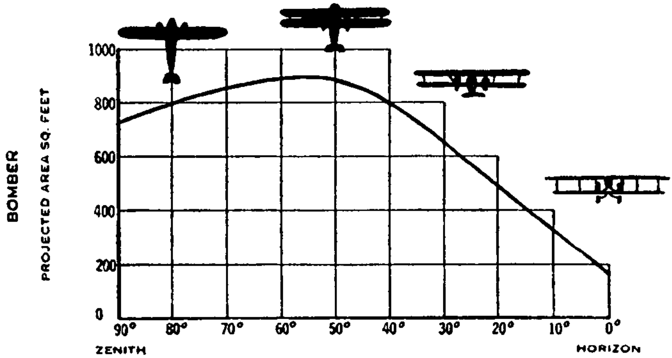
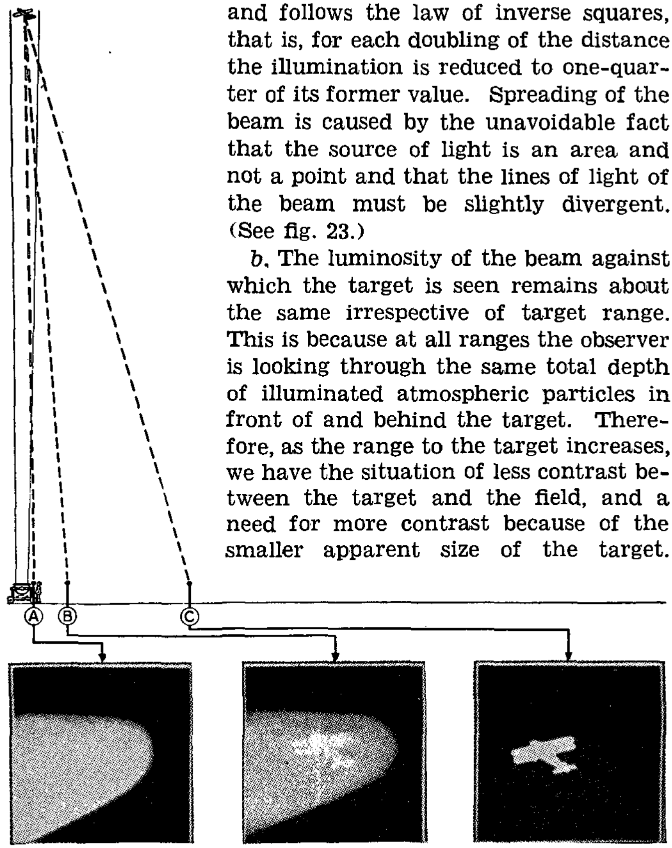


FIGURE 21.—Angle of aspect.

b. Improving contrast.—The most obvious way of improving the contrast is to move the observer away from the searchlight beam and thus decrease the depth of illuminated atmospheric particles through which he must view the target. This has the effect of decreasing the luminosity of the field without appreciably decreasing the amount of light reflected from the target. Figure 22 illustrates the value of moving the observer away from the beam.

■ 25. DECREASE IN ILLUMINATION.—*a.* As the target increases its range, the illumination falling on it decreases by reason of two factors, atmospheric absorption and spreading of the beam. Loss of light due to atmospheric absorption varies with the weather—from 10 percent per mile in clear weather to complete absorption in fog. Loss because of spreading of the beam is the same for all conditions and follows the law of inverse squares, that is, for each doubling of the distance the illumination is reduced to one-quarter of its former value. Spreading of the beam is caused by the unavoidable fact that the source of light is an area and not a point and that the lines of light of the beam must be slightly divergent. (See fig. 23.)

b. The luminosity of the beam against which the target is seen remains about the same irrespective of target range. This is because at all ranges the observer is looking through the same total depth of illuminated atmospheric particles in front of and behind the target. Therefore, as the range to the target increases, we have the situation of less contrast between the target and the field, and a need for more contrast because of the smaller apparent size of the target.



A. At light. B. 15-foot displacement. C. 50-foot displacement.

FIGURE 22.—Effect of location of observer on contrast.

These two factors impose sharp limitations on the range even though extremely powerful beams are used. (See fig. 24.)

■ 26. **Beam Candlepower.**—*a*. The searchlight mirror in effect magnifies the light source to the diameter of the mirror. Therefore, if it were not for the absorption of the light by the mirror, front door, and shadow-making obstructions in the searchlight, the beam candlepower would be equal to the intrinsic brilliancy (candlepower per sq. mm.) of the light source multiplied by the area of the mirror in square millimeters. Because of these absorptions and obstructions, the actual beam candlepower is about 60 percent of this product.

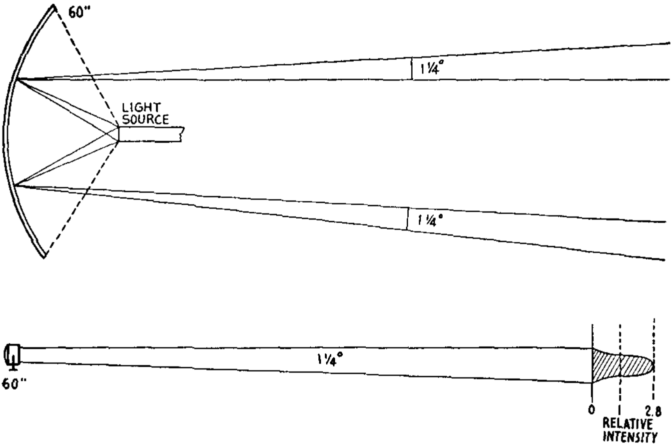


Figure 23.—Spreading of beam.

b. The intrinsic brilliancy of the light source is not uniform but is brightest at its center. Likewise the beam also has a central area of higher candlepower than the average over its entire area. It has been found in practice that the range of the searchlight is dependent upon the brighest central portion. The value given for beam candlepower is computed by multiplying the intrinsic brilliancy of the central area of the light source by the area of the mirror and deducting 40 percent for losses. If the mirror and the front door are perfectly clean, the losses are considerably less than the 40 percent which has been taken to cover average conditions in the field.

■ 27. **High Intensity Arc.**—*a.* In order to obtain a beam candlepower of 800,000,000 with an ordinary carbon arc, it would be necessary to use a current of 350 amperes and a mirror diameter of 125 inches. This is because the ordinary carbon arc has an intrinsic brilliancy of 160 candlepower per square millimeter.

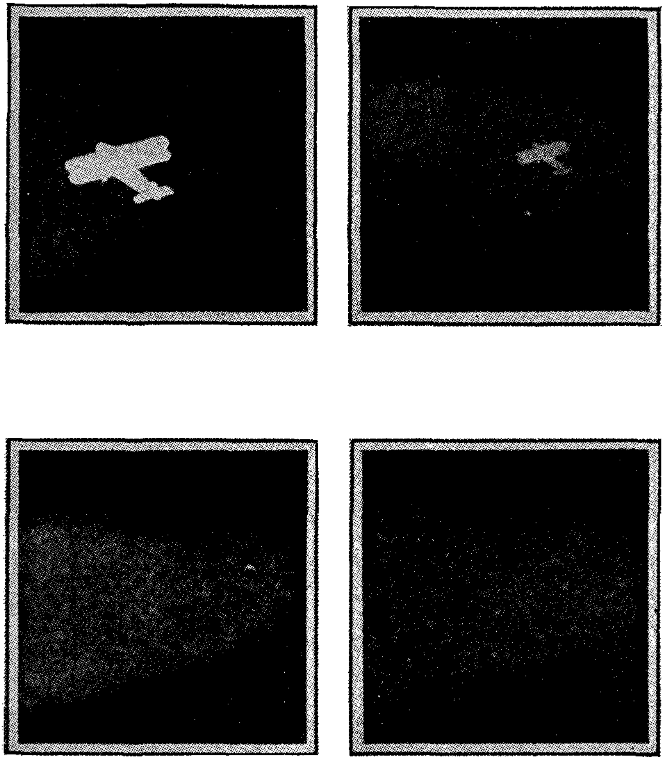


Figure 24.—Falling off of illumination due to range.

b. We know from observation of the sun that an incandescent gas is capable of much higher intrinsic brilliancy than 160 candlepower per square millimeter. The reason for this is that the gas is translucent and light is derived from the interior as well as the surface.

c. The incandescent ball of gas which forms the source of light in the high intensity arc is derived from the rare earths, cerium and lanthanum. By incorporating these earths in the relatively soft core of the positive carbon in precisely the right form and quantity and by forcing a high current density through the carbon, the earths are volatilized and projected into the crater.

d. To be useful as an intense source of light in the focus of the mirror, this brilliant gas must be confined to a very small volume. This is accomplished by compounding the materials of the core of the positive carbon so that they volatilize a little more readily than the hard carbon shell, and thus form a crater in the end of the positive carbon. To keep the crater uniform the positive carbon is rotated slowly. To confine and compress the light-giving gas in the positive crater, the negative carbon is so arranged that the electron stream sweeps across and impinges on the gas.

e. The high intensity arc has an intrinsic brilliancy of 750 candlepower per square millimeter. With this brilliancy, the beam candlepower of the searchlight is 800,000,000 (assuming a loss of 40 percent by absorption) when used with a 60-inch mirror. The total current required is 150 amperes.

■ 28. **Effect of Out-of-Focus Condition.**—*a.* The most important cause of loss of beam intensity is out-of-focus condition of the light source. The curves in figure 25 show the great loss in beam intensity caused by small errors in placing the light source at the focus of the mirror. Curve *A* shows the distribution of light in the beam when the light source is at the focus. Under these circumstances the center portion of the beam has a value of 800,000,000 beam candlepower and the spread is slightly over 1°. An out-of-focus condition of only ⅛ inch brings about the distribution of illumination shown in curve *B*. The maximum beam candlepower is reduced about 40 percent and the range at least 20 percent. An out-of-focus condition of ¼ inch brings about the distribution of illumination shown in curve *C*, which is approximately equivalent to the illumination of a 36-inch searchlight.

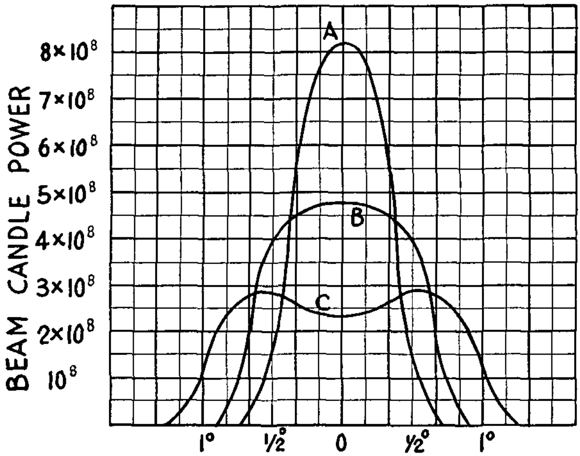


FIGURE 25.—Effect of errors in focusing on beam intensity.

b. From the above discussion it is evident that special attention must be given to keeping the light source within $\frac{1}{32}$ inch of the focus of the mirror. Such precision is better accomplished by automatic means incorporated in the searchlight than by hand control.

■ 29. OTHER LOSSES OF BEAM CANDLEPOWER.—Two other important sources of loss of beam candlepower under field conditions are sputtering or unsteadiness of the arc and deposits on the mirror and front door. Unsteadiness of the arc, which is caused almost entirely by excessive current density, is avoided by not allowing the current through the arc to exceed 150 amperes. The deposits on the mirror and front door are given off by the burning of the carbons. A ventilating system must continuously sweep the mirror and front door with fresh air but must not create a draft which will interfere with the arc.

CHAPTER 5

SEARCHLIGHT CONTROL

■ 30. **General.**—In paragraph 24 it was shown that the contrast and consequently the visibility of the target are improved by moving the observer away from the searchlight beam. Two methods are provided for controlling the searchlight.

a. The extended hand controller which places the observer about 15 feet from the searchlight beam.

b. The distant electric control in which the observer is 50 feet or more from the searchlight beam.

■ 31. **Extended Hand Control.**—This method is intended as an emergency method of controlling the searchlight in case of failure of the distant electric control. It consists of a long rod inserted in a receptacle on the side of the searchlight. By rotating the wheel at the end of the rod the searchlight is elevated or depressed. By pushing on the end of the rod in a horizontal direction the searchlight is traversed. As can be seen from figure 22, some advantage is gained in visibility by the 15-foot displacement of the observer.

■ 32. **Distant Electric Control (D. E. C.)**—*a.* The purpose of the distant electric control is to provide a means of elevating and traversing the searchlight from the control station.

b. The distant electric control consists of a pair of transmitters at the control station and a pair of motors mounted on the searchlight. One motor drives the searchlight in azimuth and the other in elevation, each motor being controlled respectively by the transmitter at the control station. The motors, transmitters, and method of operation of both elevation and azimuth distant electric control are identical.

c. In the later types of searchlights, the D. E. C. motors are operated directly by the transmitters at the control station.

Another type of D. E. C. motor may be encountered in the service known as the brush shifting type. (See pars. 33 and 34.)

■ 33. THEORY OF DISTANT ELECTRIC CONTROL—STEP-BY-STEP TRANSMITTER (DIRECT).

—*a*. The transmitters may be described as rotary switches which, by changing the current flow in the field coils of the motors, accomplish a rotation of the magnetic fields in a step-by-step process. The rotor being of a constant polarity follows the rotating magnetic field in the field coils and thereby imparts a motion to the searchlight.

b. The transmitter is shown schematically in figure 26. It consists of a commutator with four segments, each subtending approximately 75° of arc with insulation between the segments. The polarity of the segments is alternately plus and minus as shown in the figure. Three contact rollers set 120° apart are kept in contact with the segments by spring pressure. The rollers are rotated inside the commutator by the observer's and zero reader (comparator) operator's handwheels at the control station. Each roller is connected electrically with certain stator windings of the D. E. C. motor at the searchlight. It is seen that the current flowing through each roller contact will be plus, zero, or minus depending on the position of the roller on the commutator.

c. The D. E. C. motor stator has a distributed winding of 12 coils. The wiring of the stator is so arranged that the coils form three groups of four coils (or poles) in each group. (See fig. 26.) The rotor of the motor is polarized, having four coils connected in series so that the adjacent poles have unlike polarity. This causes the poles of the rotor to have a strong constant polarity and gives the required torque necessary to control the searchlight at all speeds. The motor operates on direct current.

d. The manner of functioning is illustrated in the schematic diagram, figure 26. In this figure the transmitter and motor are shown in their relative positions as the transmitter is turned through 30°. It will be seen that every 15° change in the transmitter results in some change of the current flow through the stator of the motor resulting in

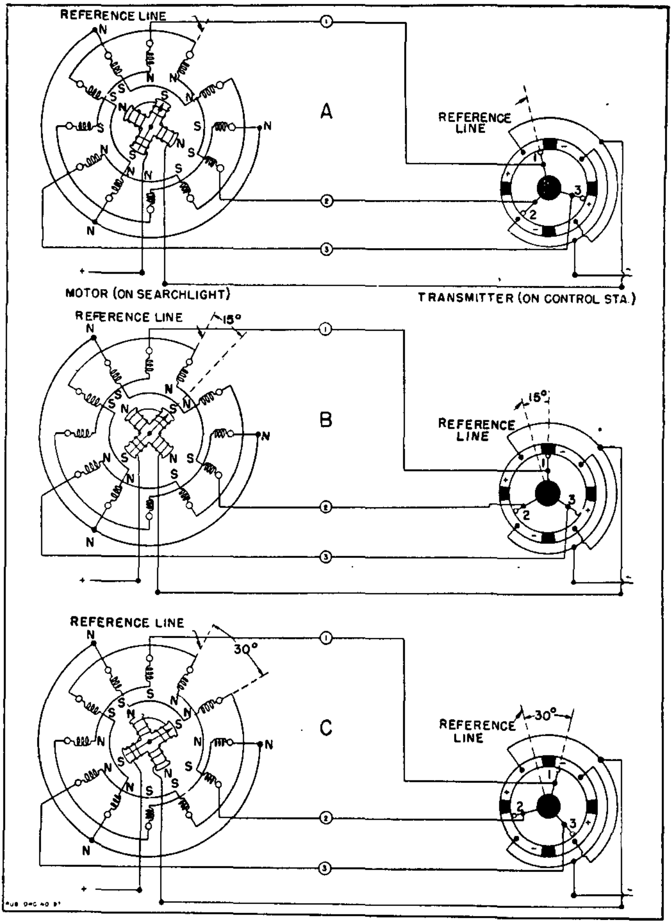


FIGURE 26.—Schematic diagram, distant electric control step-by-step transmitter (direct).

a shift of the magnetic field by 15°. The rotor follows the shift of the magnetic field and is, therefore, turned through 15°. Each change of 15° by the transmitter is called a step, hence the name "step-by-step" because the rotor is moved by steps. A complete revolution of the transmitter takes 24 steps; likewise the rotor moves a complete revolution in 24 steps.. The motor is geared to the searchlight so as to move the searchlight 6 minutes of arc per step or 2° 24′ per complete revolution of the motor.

■ 34. **THEORY OF DISTANT ELECTRIC CONTROL—BRUSH SHIFTING TYPE.**—*a*. This system employs a step-by-step transmitter which moves the rotor of the brush shifting motor in exactly the same manner as described in paragraph 33. However, the motor does not have sufficient torque to move the searchlight.

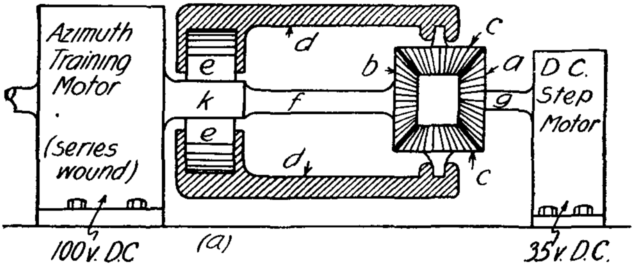


FIGURE 27.—Principle of brush shifting type, distant electric control.

b. The brush shifting motors are operated on 35 volts D. C. As the name implies, the motor shifts the position of the brushes of the training motor in the same direction as the rotation of the contact rollers of the transmitter. The actual rotation is accomplished through a differential.

c. The training motors are 100-volt direct-current series wound motors. The brushes are normally 90 electrical degrees from the brush position of the ordinary motor. In this position there is no torque. The brushes are mounted in the housing of a differential. Hence, when the brush shifting motor operates under the control of the transmitter, the housing of the differential and the training motor brushes will be rotated from the no torque position to a torque position. (See fig. 27.) The training motor, having torque, commences to rotate. Its rotation has two effects: first, it turns the searchlight, and second, it turns the other input shaft (*f*) of the differential. The differential functions as a canceling differential and the rotation of the input shaft (*f*) backs off the amount of rotation which was initially applied by the brush shifting motor through the input shaft (*g*). When the amount of rotation of shaft (*f*) equals the amount of rotation of shaft (*g*), the output of the differential (which is the rotation of the housing (*d*)) is zero. The brushes which are carried by the housing have been returned to the no torque position and the motor ceases to rotate. See FM 4–110 for further information on differential action. It is seen that the training motor has rotated the same amount as the brush shifting motor which in turn rotates the same amount as the step-by-step transmitter.

CHAPTER 6

CONTROL STATION

■ 35. **General.**—The control station establishes the connecting link between the searchlight and the sound locator. It usually contains the following items:

a. The distant electric control (see ch. 5) which is used to traverse and elevate the searchlight in azimuth and angular height.

b. Either a comparator (pars. 39 and 40) or a zero reader (par. 36), which are devices employed to insure that the searchlight is pointed at the azimuth and angular height transmitted from the sound locator.

c. The later models (1934–1940) are provided with a mount which holds the binocular night glass. These glasses aid in picking up and tracking the target.

■ 36. **Zero Reader.**—This device indicates directional synchronization between the sound locator and the searchlight, that is, it indicates when the searchlight is directed at the true position of the target as determined by the sound locator and acoustic corrector. This is accomplished by electrically detecting angular displacement of the searchlight from the sound locator by means of a phase detector. Synchronization is indicated by the centering of the needles of the azimuth and elevation zero reader meters.

■ 37. **Theory of Operation of Zero Reader.**—*a.* Figure 28 shows an A. C. self-synchronous transmitter connected to a self-synchronous receiver in the usual manner (see FM 4–110) except that the receiver rotor is not connected to the A. C. power supply.

b. The transmitter rotor sets up an A. C. magnetic field along the axis *A–B*. By transformer action, voltages are set up between leads 1, 2, and 3 of the stator which, when connected to the receiver stator, produce an A. C. magnetic field along the axis *A′–B′*. When the transmitter rotor is rotated, as is the case when transmitting angular data, the axis of the field A′–B′ in the receiver exactly follows the movement of the transmitter rotor.

c. With the conditions as shown in figure 28, the field A′–B′ of the receiver is at right angles to the rotor winding and hence no voltage is induced in the rotor. If the transmitter rotor is set at a new position, the field A–B (and consequently the field A′–B′) will shift and the rotor of the receiver will no longer be in the neutral (no voltage) plane. A voltage will be induced in the receiver rotor which will be of such phase as to tend to move the rotor to the neutral plane. Hence it will be seen that the phase of the voltage induced in the receiver rotor will depend upon whether the searchlight leads or lags behind the sound locator. The voltage output of the receiver rotor varies as the sine of the angular displacement of the rotor with respect to the field A′–B′.

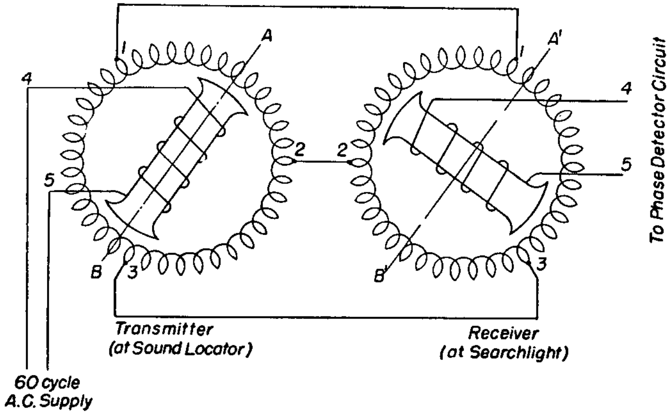


FIGURE 28.—Principle of zero reader.

d. If the transmitter is geared to the sound locator and the receiver is geared to the searchlight and adjusted so that there is zero voltage when the sound locator and searchlight are in synchronism, then so long as the voltage output of the receiver rotor (at the searchlight) is zero, synchronism is maintained. When the two are not synchronized, the receiver rotor will have a voltage output which varies as the sine of the angular displacement of the transmitter, and the phase of the voltage reverses as the searchlight lags behind or leads the sound locator.

e. The reversible-phase voltage output of the receiver rotor is fed into a simple phase detecting circuit, so that the lag or lead of the searchlight may be indicated by the right or left deflections of an ordinary zero center D. C. voltmeter. The throw of the zero reader needle will be approximately proportional to the angular displacement between locator and searchlight.

f. Zero readers are furnished for angular height and for azimuth. Both units are the same. The operators of the zero readers keep the searchlight synchronized by using the D. E. C. handwheels at the control station. The handwheel rotation and deflection of the zero reader are correlated in such a way that right deflection of the zero reader requires counterclockwise rotation of the handwheel to center it and vice versa. The operation is similar to that of steering a car, and in practice the motion becomes instinctive.

g. It should be noted that the above mechanism will indicate zero readings when the searchlight is exactly 180° out of synchronism in azimuth. This is detected by noting that when the azimuth distant electric control handwheel is moved clockwise, the needle moves off center to the left instead of the right as it should. Synchronism is restored by turning the searchlight by means of the azimuth D. E. C. through 180°, at which time the zero reader will again be centered.

■ 38. **PHASE DETECTING CIRCUIT.**—*a.* The phase detecting circuits for both azimuth and angular height are identical. It is shown schematically in figure 29. It consists of two small center-tapped resistors *R*1 and *R*2 of 500 ohms each. *K*1 and *K*2 are similar 6-disk copper oxide rectifiers. A small transformer supplies 10 volts A. C. polarizing voltage.

b. As the transformer and the transmitter at the sound locator use the same source of power, the rotary converter, the voltages will be in phase. Assuming that there is no voltage output from the receiver rotor, *K*1 and *K*2 rectify the polarizing voltage equally, and as the zero reader voltmeter is connected across the points *A–B* of the same potential there is zero deflection. When the searchlight lags behind the sound locator, the voltage output of the receiver rotor adds in phase with the polarizing voltage across *K*1 and opposes the polarizing voltage across *K*2. *K*1 will pass more rectified current than *K*2, *A* is positive with respect to *B*, and the meter will deflect, for example, to the right. When the searchlight leads the sound locator, the voltage output of the receiver rotor opposes the polarizing voltage across *K*1 and adds in phase with the polarizing voltage across *K*2. *B* is then positive with respect to *A* and the meter will deflect in the opposite direction—to the left.

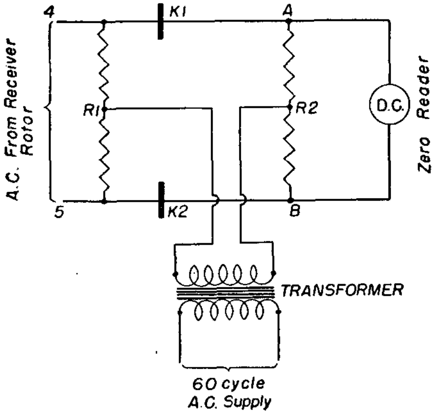


FIGURE 29.—Phase detecting circuit.

c. The phase detecting circuits are located on the searchlight. Meters to read the lag or lead of the searchlight are located both at the searchlight and the control station.

■ 39. COMPARATOR.—*a.* Another type of synchronizing device, known as the comparator, will be found in the service. The comparator uses the A. C. self-synchronous data transmission system. (See FM 4–110.)

b. Inside the comparator case will be found four self-synchronous data receivers. The rotors drive two sets of concentric dials, one for azimuth and the other for angular height. The outer dials in each set indicate the azimuth and angular height as transmitted from the sound locator. The inner dials in each set indicate the azimuth and angular height of the searchlight. Azimuth and angular height data transmitters are located in both the sound locator and searchlight and automatically transmit the data to the comparator. The operators at the control station traverse and elevate the searchlight by means of the D. E. C. until the pointers on the dials are matched. At this time the sound locator and searchlight are synchronized.

■ 40. COMPARATOR, MECHANICAL (A. C.).—A variation of the comparator described in paragraph 39 is also in the service. The searchlight dials of the comparator are driven by direct gearing from the D. E. C. handwheels. Hence the dials indicate the angular height and azimuth of the searchlight without using the data transmission system between the searchlight and comparator. The sound locator dials are positioned by data transmitted electrically from the sound locator to the comparator as described in paragraph 39.

CHAPTER 7

BINAURAL TRAINING INSTRUMENTS

■ 41. GENERAL.—Binaural training instruments are necessary for the following reasons:

a. Making the initial selection of listeners for further training.

b. Developing and improving as a result of practice the accuracy of the binaural sense.

c. Providing a means of training available at all times and not dependent upon such factors as weather conditions, suitable targets, and availability of the other members of the sound locator section. The use of binaural training instruments in no way obviates the necessity of actual practice on the sound locators with actual targets. Frequently, a training instrument will be the only available means of practice for a listener.

■ 42. BINAURAL TRAINER M1.—*a.* The binaural trainer M1 is still in service although no new units are to be manufactured. The entire instrument has been incorporated in the binaural trainer M2.

b. The binaural trainer M1 consists of an electric turntable and magnetic pick-up to play phonograph records of aircraft in flight, a receiver unit which serves as a source of sound, a phase control unit which varies the length of the sound paths to the ears, and a helmet for the use of the listener. The complete unit is shown in figure 30. The unit is designed to reproduce the conditions experienced in the operation of sound locators insofar as binaural sense is concerned. A numerical scale is provided which reads the error from exact binaural balance.

c. The internal construction is illustrated in figure 31. The sound (transmitted electrically from the phonograph) is reproduced in a receiver unit where it passes into the phase

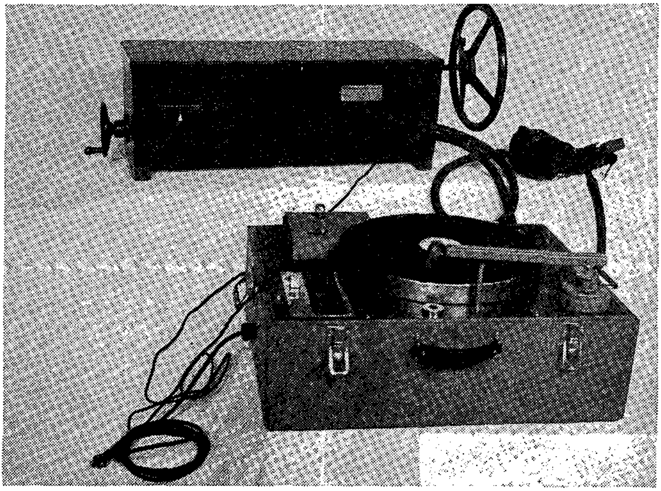


FIGURE 30.—Binaural trainer M1.

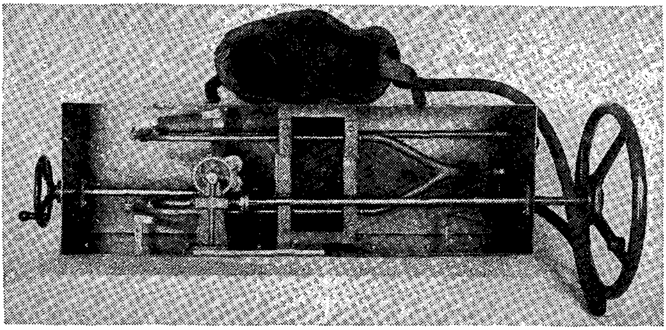


FIGURE 31.—Interior of binaural trainer M1.

control unit. The phase control unit is connected to the two handwheels at opposite ends of the instrument so that rotation of either handwheel will lengthen the acoustic tract to one ear and shorten it to the other ear. This results in a difference in distance from the sound source to each ear, and as was shown in paragraph 6 results in a difference in phase which the ears are able to distinguish. By varying the relative lengths of the acoustic tracts, the listener gets the same effect as turning his head with respect to the sound source. The phase control unit is unbalanced by turning the small handwheel. The listener then tries to center on the sound by turning the large handwheel. In figure 31, the phase control unit is shown balanced. For further information on the binaural trainer M1 see the notes on matériel, Sound Locators M1 Series, issued with the instrument. For information on the selection and training of listeners see FM 4–115.

■ 43. BINAURAL TRAINER M2.—*a.* This instrument is designed for training of sound locator listeners under conditions which very closely simulate those of actual aircraft tracking. Changes in sound intensity, azimuth, angular height, and contrast between aircraft sound and ambient noises can be made to approach actual listening conditions. The listeners work on the sound locator when using this training instrument, or use the portion of the unit similar to the binaural trainer M1. (See par. 42.)

b. The out-of-doors portion of the instrument utilizes an overhead wire along which a horn assembly is moved. The horn assembly is actuated by an amplifier and reproduces a phonograph record of an airplane in flight. By manipulation of the volume control of the amplifier combined with a variation in rate of movement of the horn assembly along the overhead wire, the target can be made to approach, to recede, and to execute other simple types of maneuvers.

■ Figure 32 shows the mechanism set up in position ready to operate. As excess humidity will damage the horn assembly, the device should not be operated in the rain or left out of doors at night. The phonograph and amplifier operate on

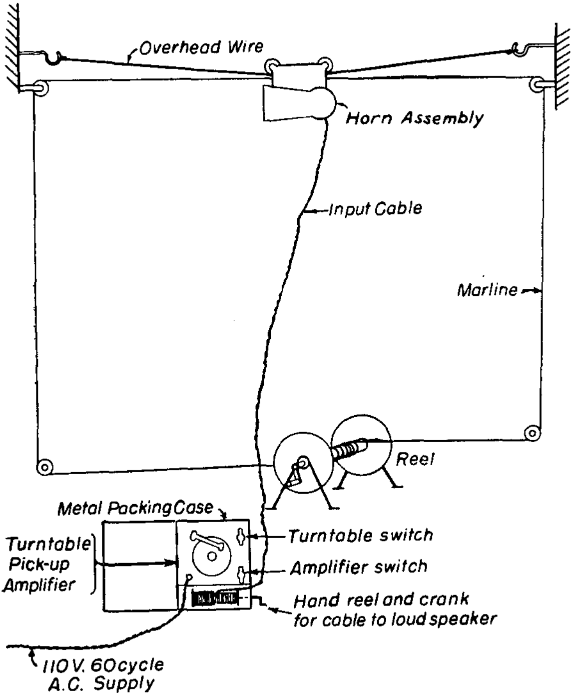


FIGURE 32.—Schematic diagram, binaural trainer M2.

a 110-volt 60-cycle A. C. For further information see the instruction manual issued with the instrument.

c. The indoor portion of the instrument consists of the same devices used in the binaural trainer M1. The electric turntable and magnetic pick-up are used for both the indoor and out-of-door portion of the instrument.

INDEX

INDEX

INDEX