Ordnance and Gunnery

A Text-Book

Prepared for the Use of the Midshipmen of the United States Naval Academy

BY

Officers of the U. S. Navy

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CHAPTER XXIII.

NAVAL RANGE-FINDERS.

1. General.—(1) The trajectories of guns being more or less curved, it is necessary to know the distance of the target in order to adjust the line of sight, with respect to the trajectory, (i. e., to set the sight), so that the projectile on its descending branch will hit the point of aim.

(2) *The curvature of the trajectory* and the angle of fall increase as the range increases; hence, when the range is great, accurate range-finding is more necessary than when the target is close to the gun. It will be shown that this is just where all our range-finding methods are at fault. It is easy to get the range when the target is near, and inaccuracies in measuring are not serious; but these inaccuracies increase enormously with the range just where we would have them decrease.

(3) *Very high-velocity guns*, with their consequently flatter trajectories, give a smaller angle of fall and a greater danger space. For this reason, larger errors in sight-setting are permissible and the fire from such guns should be more accurate; this superiority of high-velocity guns is of even greater value in battle than their superiority in penetrating power as compared with low-velocity guns.

2. (1) **The danger-space** of a gun firing at a target of a certain height, is, for any particular range an interval of space between the point of fall and the gun, such that the target if situated at any point within the space, will be hit. For the same target and range, a gun with a flat trajectory will have a longer danger-space than will one with a high-curved path, as shown in the figures.

(2) The danger-spaces of a 50-caliber 6-inch gun, firing at a 30-ft. target, are given below. It is to be kept in mind that this is an exceptionally high-velocity gun, and that guns of older design have much shorter danger-spaces.

Range.		Danger-Space.
1000 yards	....	1000 yards.
2000 "	....	759 "
3000 "	....	381 "
4000 "	....	222 "
5000 "	....	141 "
6000 "	....	94 "
7000 "	....	65 "
8000 "	....	46 "

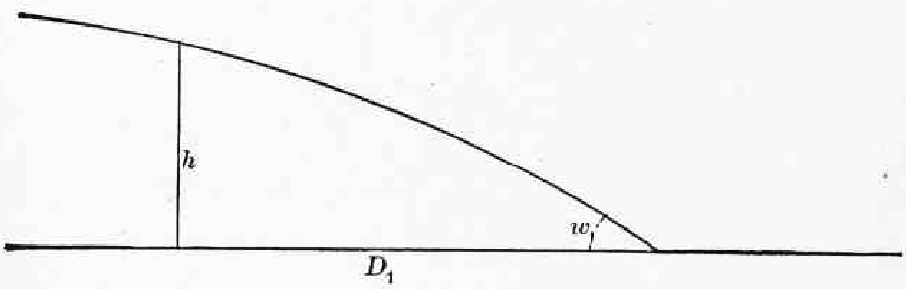


FIG. 1. ART. 2.

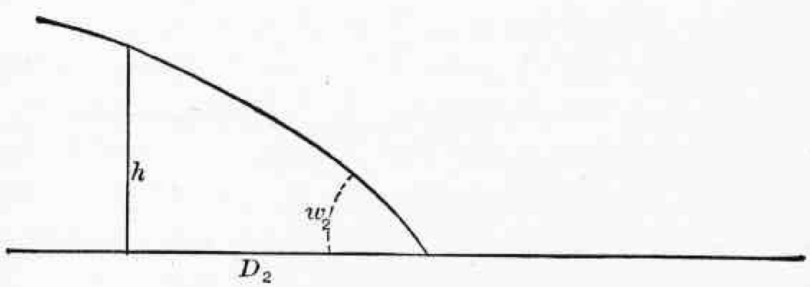


FIG. 2. ART. 2.

(3) Granting that the gun-pointer can fire with his sight exactly on the center of the target, this shows that the range at 8000 yards must be measured within 47 yards in order to hit the 30-ft. target. There is no known method of range-finding that can be relied upon to give such results; this fact alone demonstrates the extreme difficulty of making hits at these long ranges.

3. Eye-estimation of range.—(1) From the introduction of heavy guns on ship-board up to a comparatively recent day, the guns were so low-powered and inaccurate that they were effective only at very short ranges, and no very reliable range-finding method was necessary. Even after sights were fitted to guns, there was at first no way of setting them; they merely gave a line parallel to the bore, and the allowance for the range was made by the gun-captain, perhaps by pointing at some portion of the rigging.

(2) A little later it became the custom to set the rear-sight-bar for the range by direction of the gun-captain, or of the division officer, who merely estimated the distance by his eye. Some did it, by depending upon the quality of the so-called "nautical eye"; others had rules of their own, based upon the distinctness with which they saw various objects on the decks of the enemy. The ranges being very short such methods answered; now, however, the battle-ranges are long, probably never less than 3000 yards, and greater accuracy is required. The theory of "eye-estimation" is no longer tenable.

(3) Experiments have shown that it is quite impossible to estimate ranges above 2000 yards with anything like sufficient accuracy. There are various aids, such as holding a finger in front of one eye, at arm's length, and noting the amount by which it moves across the target when held stationary and viewed with the other eye. While such methods are more accurate than simple estimation, none is up to the requirements of modern gunnery. It was found experimentally that changes in the atmospheric conditions and the intensity of the light, resulted in large variations in the estimates; the wildest guesses were made by "practised" observers as to the relative distances of dissimilar objects which were really abreast of each other; after considerable practice, fairly close estimates were made as to the distance of a certain ship, to which the observer had become accustomed, only to have them all thrown out when the ship turned at any other angle than broadside to. On a dark night, the estimates of the distance of a single point of light will often be several hundred per-cent in error. Eye-estimation, then, is not at all to be depended upon, particularly when made by the gun-pointer through a smoke-obscured gun-port.

The Telemeter.

4. (1) A method once proposed and thought well of for a time, depends upon the velocity of sound, the range being obtained by measuring the time between the flash of one of the enemy's guns and the instant its report is heard by the observer. The Boulengé Telemeter is a simple instrument for measuring this interval; it depends upon the velocity with which a plunger falls through the liquid in a glass tube when the instrument is turned upright.

(2) It is clear that this method could not possibly be of any use in a modern action. A more promising method, but one not capable of practical use, would be to time the flight of a projectile, if its point of fall could be determined, and read the range from a prepared table with the time of flight as the argument. Granting that the time of flight could be accurately measured, the correct distance would be given only by a shot which hits the target; in this case the *sight-bar range* can be found by simply taking the reading of the firing gun's sight-bar; this is more valuable information than the exact distance and would be obtained directly.

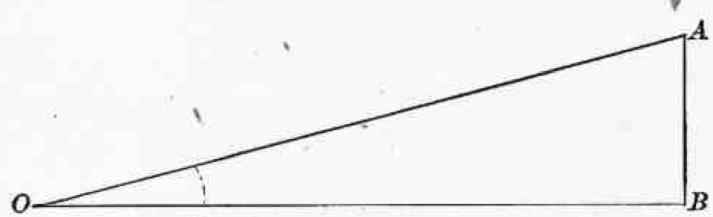


FIG 3. ART. 5.

Mast-head Heights.

5. (1) If the height AB of a mast-head or smoke-pipe of the enemy's ship above the water-line be known, the angle subtended by this height may be measured and the resulting right triangle solved for OB, the actual range. To give quick results, a table of ranges for various heights and observed angles may be prepared and the range given as soon as the angle is read.

(2) **The stadimeter,** an invention by Lieutenant (now Captain) B. A. Fiske, U. S. Navy, solves this triangle graphically and gives direct readings. The instrument was not designed for *long ranges.* It is, however, in constant daily use for measuring the distances of

ships of the fleet during maneuvers. Unless the water-line is distinctly seen, the method will have grave errors, and it will be an easy matter for the enemy to alter his mast-head heights at the beginning of war. The method cannot be conveniently used at night, and under the best conditions, at battle-ranges, the angle subtended by even a very lofty mast must be measured with an extreme of accuracy.

Buckner's Method.

6. Buckner's method was originated by Lieut. W. P. Buckner, U. S. N., and has given good results within certain limits. The

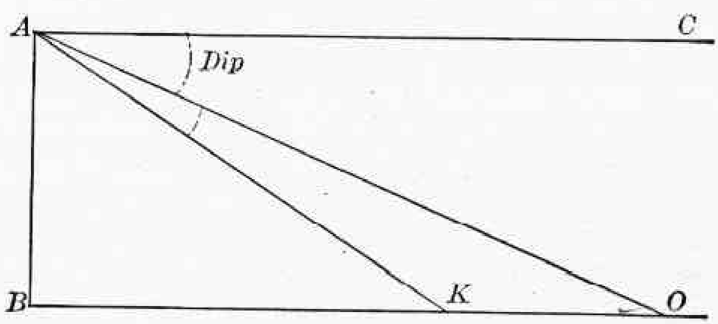


FIG. 4. ART. 6.

observer is stationed at a certain known height, which should be as great as possible above his own water-line, from which point he measures with a sextant the angle between the horizon and the target's water-line. In the figure, A is the observer, B his water-line, and K that of the target; the height AB is known. Now regard O as the horizon of A and, disregarding the earth's curvature, consider that the distance BO is in a straight line and that AC is parallel to it. The angle CAO is the dip from A, and its value has been tabulated for different heights. Now if the angle KOA is measured, we know the angle $KAB = 90° - (\text{Dip} + KAO)$. Thus in the right-triangle ABK we know AB and KAB and may compute BK, the required range. In practice, the observer is provided with a table from which he reads the range as soon as he gets the sextant angle; the greater the value of AB, the less will be the error caused by errors in observation.

Obviously, a clear horizon is essential and the method cannot be extended to use at night. Also, in rough water the target's water-line cannot be distinctly seen and *AB* varies as the observer's ship rises and falls or rolls to the sea. Granting perfect conditions, the limitations are made evident by the fact that at 2500 yards, with an observer's height of 100 feet, an error of two minutes of arc in observing, gives an error in range of over 100 yards; hence the method is inadequate for modern gunnery, even under the most favorable conditions. There are range-finding instruments which, depending upon this principle, give direct readings; such is the Searle and Saegmuller. Beyond convenience in observing, they appear to have no advantages.

Methods with Horizontal Base-Lines.

7. The methods given thus far depend upon a vertical base-line; it now remains to consider those that have horizontal bases. The sea-coast artillery system of position-finding is on this principle. Within limits, a very long base-line can be utilized, with observers at each end connected by reliable electrical communications. The base-line is not perpendicular to the line of fire and a rather complicated system results. However, from the nature of the work, the instruments and communications are permanent and can be made accurate and reliable. The actual observation of the target is simple and the system gives satisfaction.

8. Similar systems, notably that of Captain Fiske, have been used on ship-board, in spite of the fact that the longest obtainable base line is all too short. Only a measure of success resulted in practical service, although the systems are theoretically correct and gave accurate results under favorable conditions. The instruments are delicate and difficult to install and were, with their electrical connections, too much affected by service usage and the shocks of gun-fire. Thus, the question has narrowed to self-contained direct-reading instruments (to be handled by single observers), which necessarily have extremely short base-lines kept perpendicular to the line of fire while taking the observation.

9. The Zeiss range-finder is generally built as a portable instrument; it takes advantage of one's ability to see stereoscopically, utilizing the telescope to extend this power. It has advantages for use on shore, particularly for controlling infantry fire, but has not shown its suitability for naval gunnery; extensive training would seem to be required in the observer.

Barr and Stroud Range-Finder.

10. The Barr and Stroud range-finder belongs to the short-base, single-observer class, and is constructed to work on the "coincidence," in contradistinction to the "stereoscopic" principle. There are two types of this instrument in use in the service, the 4 ft. 6 in. base and the 9-ft. base (see Plate I). The latter will not be described, however, as there are but few in use and this type has been superseded by the Bausch and Lomb 9-ft. base instrument. Plate II shows the principles and details of construction of the 4 ft. 6 in. type. Figs. 1, 2, and 3 are diagrammatic representations of the instrument, details of construction being omitted for the sake of clearness in the explanation of the principle of operation. Figs. 4, 5, and 6 are front, rear, and end views of the outside.

11. The principle of the instrument depends upon the diverging angle at which the rays of light come from the target to the reflectors. Fig. 2 is a diagrammatic representation of the elements of the range-finder reduced to their simplest form. Two beams of light from the distant object are received by the reflectors and transmitted through the objectives towards the center of the instrument, where two small mirrors, M_1, M_2, are placed, one over the other, to reflect the rays outward through the *right* eye-piece. In this way, two partial images of the distant object are seen, one over the other, as shown in Figs. 8 and 9; the image seen in the upper half of the field of view being formed by the equivalent of a telescope directed towards the distant object from the right end of the instrument, and the image seen in the lower half being formed by the equivalent of a second telescope directed towards the distant object from the left end. The images are separated by a thin, black line called the *separating-line*.

12. To understand the mode of operation, suppose that a very distant object is viewed by rays L_1, L_2, and that the partial im-

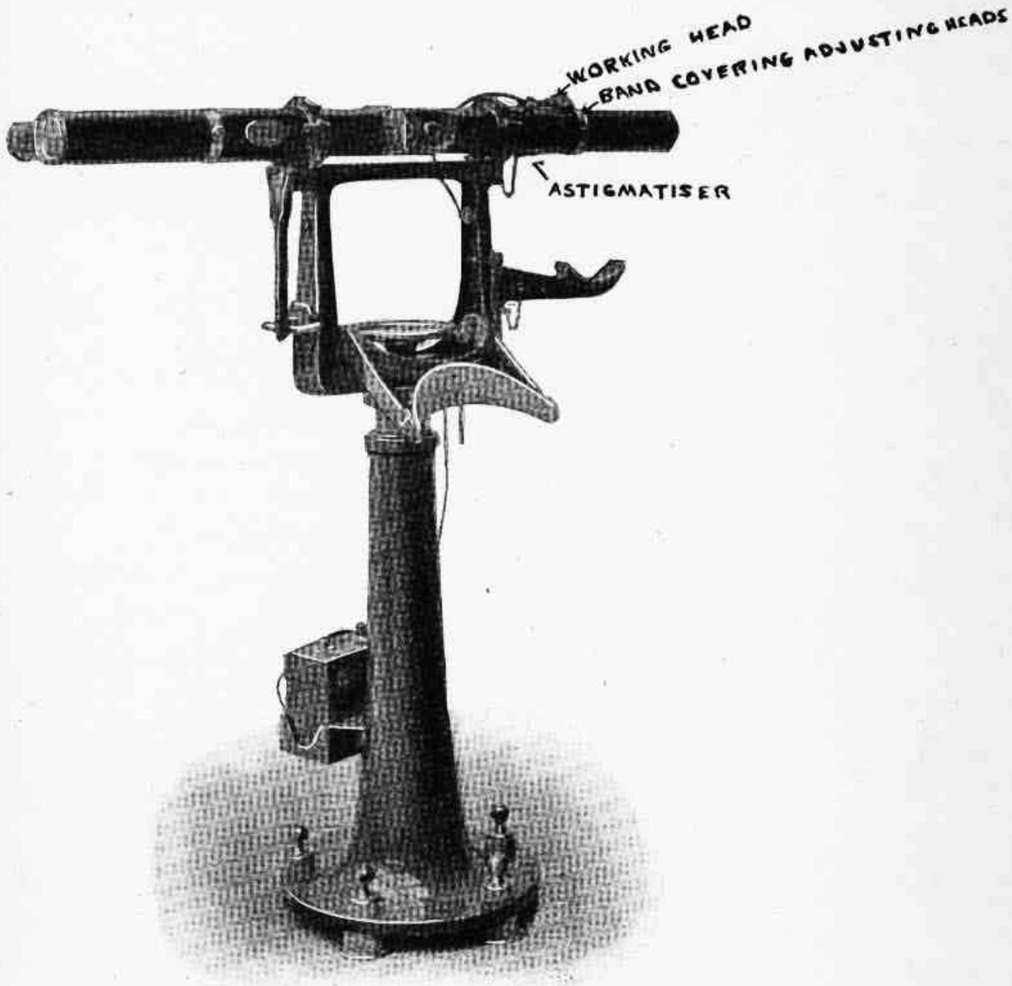


FIG. 1.—Barr and Stroud Range-Finder, 4 ft. 6 in. base.

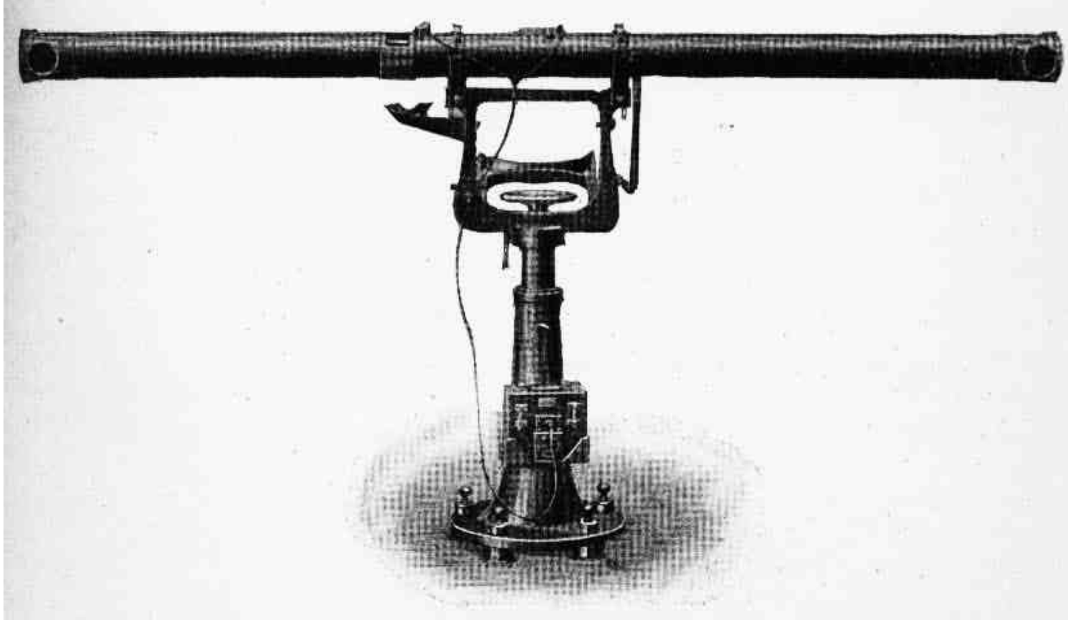
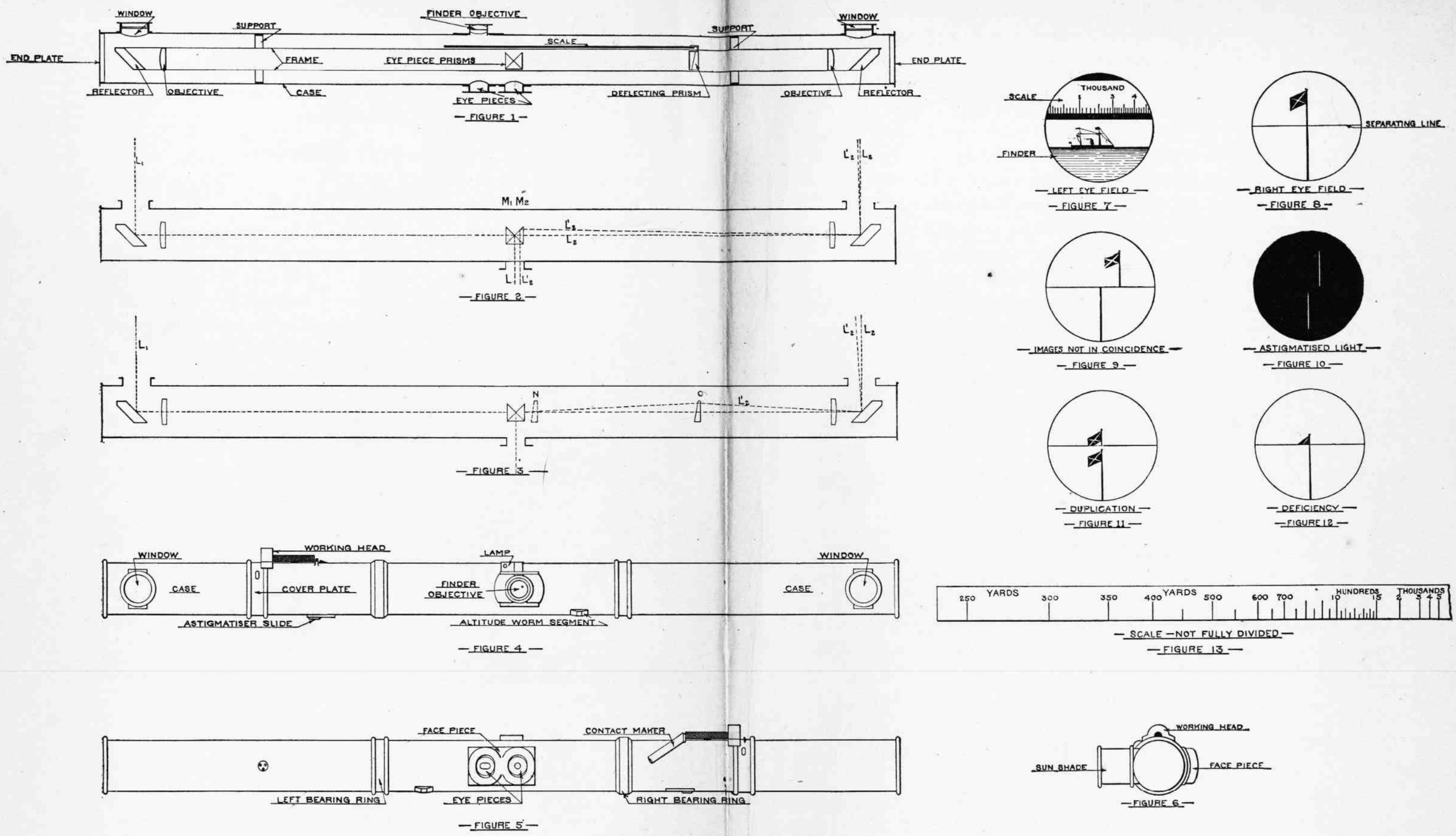


FIG. 2.—Barr and Stroud Range-Finder, 9 ft. base.



BARR AND STROUD RANGE-FINDER.
DETAILS OF CONSTRUCTION.
4 FT. 6 IN. BASE TYPE.

ages are seen in proper coincidence, or alignment, as indicated in Fig. 8. If the object now approaches the instrument in the direction of the beam L_1, the beam L_2 will have a new direction, such as is indicated by the line L_2', and the partial images will no longer be seen in the eye-piece in proper coincidence, but will occupy some such relative position as that shown in Fig. 9. A measurement of the separation of the partial images from each other might serve as a means of determining the distance of the object viewed, since the nearer the object the greater will be the separation; but the measurement would be very difficult to make with sufficient accuracy under any circumstances, and it would be impossible to make it even roughly when the range-finder (or the object) is in motion. Accordingly, means are provided (1) for altering the path of one of the beams as it approaches the central mirrors, so as to bring the partial images into correct alignment or coincidence; and (2) for indicating on a scale the distance that is moved in sympathy with the motion of the mechanism which produces the alignment of the images. The alignment of the partial images is effected by causing one of the beams (in its course from the objective to the central reflectors) to pass through a deflecting prism of small angle, which is movable in the direction of the length of the tube, and is moved into the required position by the operation of a working-head situated on the outside of the tube. The action of the prism is illustrated in Fig. 3.

The scale (see Fig. 1), which consists of a straight piece of translucent ivory, is seen through the left eye-piece, and is caused to move past a fixed pointer which indicates the range of the object whose images have been aligned in the right eye-field of the instrument. The observer need not move his eyes away from the eye-pieces to keep a moving object in view and read its distance as often as he desires.

An optical appliance known as the "*astigmatizer*" is supplied, which can be introduced at will into the beams of light. It draws the images of *points* out into *vertical lines* or streaks, which can then be aligned in the same manner as the images of a mast or pole. This enables the range of single points of light, or small, ill-defined objects, to be taken with ease and accuracy. Fig. 10 shows the appearance presented by the astigmatized image of a single point of light.

13. The construction.—The 4 ft. 6 in. type consists of an outer tube carrying the eye-pieces and windows, and containing an inner frame carrying the main reflectors and other optical parts. The inner frame is constructed in the form of a lattice girder. The outer tube consists in reality of two tubes, one inside the other, with an air-space between them, in order to retard the access of heat to the inner frame, and to distribute it evenly around the inner frame. A very slight difference of temperature in the various parts of the frame would cause the latter to bend, and would thus disturb the relative positions of the optical parts.

The end reflectors are single reflectors of highest quality, firmly soldered to carriers fixed between the top and bottom members of the frame. Close to the reflectors are placed the object-glasses, in special holders designed to enable them to be firmly held without distortion.

The eye-piece prisms reflect the beams of light outwards to the eye of the observer, and at the same time erect the images and cause them to pass through a "*separating prism*," so that they appear to the observer to be cut by a clean line of separation, as shown in Fig. 8.

The *deflecting prism* is placed in the beam of light from the right-hand reflector, and is securely fixed to a holder, and moves in conjunction with the graduated scale. The eye-pieces are fitted with a rubber buffer for protecting the eyes and steadying the head of the observer and cutting out external light. The distance between the eye-pieces is adjustable to suit the eyes of different observers.

14. The "finder" is to facilitate finding the target; it forms, with the left eye-piece, a low-powered telescope of large field. The upper portion is obscured by the scale, also to be read by the left eye. For night observations, a low-powered electric lamp is fitted near the finder objective (see Fig. 4), which shines through the ivory scale with just enough light to make the graduations visible. The lamp is turned on and off by the "*contact-maker*" (Fig. 5).

15. The 9-ft.-base type, as regards the general method of working and the principles of its operation, is similar to the older type, but differs in details of construction. The chief difference lies in the disposition of the optical parts; for whereas in the earlier type all the optical parts (with the exception of the eye-pieces and windows) are carried on an inner frame, in the later type the main reflectors at the ends of the instrument are carried on the outer tube.

16. Adjustments.—(1) It is found that the instrument seldom needs adjusting unless it meets with an accident. Two adjustments are provided for, both of which are made by small milled heads that are ordinarily covered by a ring near the right-hand end.

(2) *The adjustment for halving* is to cause the lenses to be in such positions that the partial images will form a complete representation of the target; there must be neither "duplication" (see Fig. 11), nor "deficiency" (see Fig. 12), in which a part of the target does not appear in either upper or lower image. This adjustment can be tested on any object over 250 yards distant; distance need not be known, and something of irregular form and little height is most suitable.

(3) *The "coincidence" adjustment* corresponds to the index correction of a sextant; on its perfection depends the accuracy of the instrument in measuring ranges. It is conveniently tested, or made, by observing the moon, when bright and clear, or the sun when it is low down and not too bright for the naked eye. Set the instrument at "infinity" by the scale and note if the edges of the luminary are in coincidence; if not, turn the milled head until they are. The adjustment is also readily made by observing a clear-cut object at a known distance, which must be at least 800 yards. This adjustment should be very carefully made and all the error taken out, for any residual error *increases as the square of the range.* For this reason it is inconvenient, at least, to have an index correction as with a sextant.

17. The mounting.—It will at once be noticed that the mounting does not enable the observer to keep the axis of the instrument horizontal; this is not necessary, because the effect of any inclination, such as that caused by the heel of the ship, merely makes the object appear inclined as regards the separating-line. It is possible for the observer to keep the objectives on the target under the most unfavorable conditions, and the mounting is cleverly designed with this requirement in view. The outer case is mounted in bearing-rings (see Plate II), and is rotated by the handle, in the left hand. The first instruments, and the one here shown, were also connected to a heavy weight which was designed to swing in water in the tank and act as a pendulum to keep the instrument level, thus assisting the observer's left hand; the water was to damp the swing of the pendulum. This feature does not appear in the later instruments, and the observer has to do all the leveling himself; with but a little practice this is rather easier than to keep a telescope pointed. The observer rests his breast against a support on the frame and rotates the entire upper part of the mounting on its pedestal to keep the target in the field. It has been proved by trial that the instrument will give fair results when there is so much motion on the ship as to make accurate gun-pointing out of the question. There should be several range-finders on each ship, because all-round views can rarely be given for its mounting.

18. Uses in navigation.—The Barr and Stroud range-finder lends itself readily to use in navigation. The distance of a point of land in daylight or that of a light at night is given with one observation, in a few seconds. It can be used to determine the turning-circle of a ship by steaming around a pole floating upright; the speed of a ship can also be gotten, for a short distance, with an accuracy of at least one per-cent, and the effect of current is eliminated if the pole is floating at about the same depth as the ship. It is said that by using the astigmatizer the points of light shown by a torpedo craft under the search-light can be drawn out into streaks that are plain enough to permit a fairly reliable observation for range. In this particular instance, there is certainly no other method that is applicable, and eye-estimation under the conditions is merely the wildest guess-work. The standard of accuracy is rather higher than any other method, now known, will give. At 3000 yards, the average errors are less than 0.5 per-cent.

At the long ranges, the errors are less than those of the gun with its ammunition.

19. Sight-bar range.—Thus far, only the range, or actual distance, of the target has been considered, while the range that the officer charged with the control of the fire is called upon to give to his sight-setters is the *sight-bar range*. For the same actual range this sight-bar range will vary for the different calibers of the battery, for the different indices of powder for the same calibers, and even for the same index when fired under varying conditions of the atmosphere and temperature. If a few of the variants give accumulative errors, the sight-bar range may differ hundreds of yards from the actual range. Most dependence is likely to be given to watching the trajectory and point of fall of the projectiles, estimating the amount by which they miss the target. It is then not essential that the actual distance be known, if the sights can be changed by increments such that the mean point of impact is brought on the target. This science of fire-control, really sight-bar range-finding, is about the most important and the most difficult branch of the profession; our experiments and systems are confidential. Suffice it to say that any range-finding instrument, however accurate and reliable at long ranges, can be no more than an aid to fire-control, and only a part of the problem is solved when the actual distance of the target is known.

NOTE.—The Bausch and Lomb range-finder has been adopted for the naval service, but its description had not been completed at the time this book went to press.