Chapter 6

POWER AND BASE LENGTH

6.1 MAGNIFICATION

A comparison of 12 and 24 power in ranging on fixed targets is reported by the Fort Monroe Princeton Laboratory. (344) The purpose of the study was to determine the comparative reliability of range determinations at the two powers provided in the M1 and M2 Height Finders; the comparative reliability of internal adjuster readings at these different powers and the net correction to RCS (Curve B) at different powers. Six experienced observers and three M1 and one M2 instruments were used. The results show that the ratio of 12-power discrepancy between duplicate readings to that of 24 power, over the test period of almost a month, was about 1.10. No significant corrections between the ratio and the individual man, the particular target, or the day could be established. The reliability of internal adjuster readings appeared to be about the same for both powers. This is somewhat surprising; it appears to indicate that factors other than pure visual perception of angles play an important part in the internal adjuster setting. Also, for most observers, the net correction to RCS is about the same for 12 as for 24 power. However, two of the better observers showed considerable difference between 12 and 24 power: the size of this difference was opposite for the two men. No explanation of this anomalous behavior is advanced.

Another set of experiments was performed by the Princeton Laboratory at Fort Monroe using aerial targets. (359) Height readings were taken on aerial targets with six standard M1 Height Finders using four combinations of power and aperture. Magnifications of 12 and 24 power were combined in all possible ways with 1-inch aperture and the normal 2.5 aperture of the wide-open instrument. Consistency at reduced aperture was found to be much better than at full aperture, using either 12 or 24 power. Precision with 24 power was not twice as good as that with 12 power, which ratio is theoretically expected when the observer's sensitivity is the controlling factor. These findings agree with those already noted for ranges taken on fixed ground targets using reduced power or reduced aperture separately. For example, with 1-inch aperture the average precision errors were 2.7 UOE for 24 power and 3.2 UOE for 12 power, and for the full-field instrument, 2.7 UOE for 24 power and 4.1 UOE for 12 power. The consistency errors were, for 1-inch aperture, 5.4 UOE with 24 power and 8.5 UOE with 12 power and, for the full field, 5.4 UOE at 24 power and 3.9 UOE at 12 power. Thus, the observer consistency is markedly worse than when both power and aperture are reduced. This is the combination giving an especially short eye distance, the distance of the exit pupil from the ocular.

The results of these two experiments are presented in a unified report of the Princeton Laboratory at Fort Monroe with the addition of other material on fixed targets. (366) The analysis shows that the precision, measured in yards of error, of readings taken with the M1 Height Finder was substantially better at 12 than at 24 power for range observations on fixed ground targets and was substantially better at 24 than at 12 power for height observations on aerial targets. The relative precision of observations taken at the two magnifications varied greatly from observer to observer, but not from instrument to instrument nor for different target distances. The ratio of precision error in yards at 12 power to that at 24 power, for the 35 observers in this test, ranged between 0.40 and 1.36 for fixed targets and between 0.64 and 3.67 for aerial targets. These ratios for the middle 19 of the 35 observers ranged between 0.63 and 0.90 for fixed targets and between 1.17 and 1.73 for aerial targets. The average ratio was 0.79 for fixed targets and 1.47 for aerial targets.

This document is attached as supporting data to a Report to the Services issued by the Fire Control Division of the NDRC. (19) The experimental data indicate that, under none of the circumstances tested was the precision error at 12 power, when measured in yards, twice as great as at 24 power, as would be predicted from the simple theory of geometrical optics. On aerial targets the ratio was more nearly 1.5; perhaps slightly greater at short ranges and slightly less at long ranges. That is, only about half the theoretical advantage of 24 power was realized. On fixed targets the ratio was actually less than 1; that is 12 power gave more precise readings in yards than 24 power. This was unexpected and the reason for it is not definitely established. It is probably associated with the atmospheric conditions at the time of the tests, though the subjective judgments of the conditions as noted down by the experimenters do not support this inference. However, if there were heat waves or atmospheric boiling between the instrument and the ground target, this would be magnified greatly when 24 power was used and well might affect the results. The possibility is suggested that an intermediate fixed power (say 18) might be preferable to the present variable power. The evidence is not conclusive enough, however, to justify a recommendation to that effect.

To test this suggestion further an eyepiece assembly with 18 and 36 power was provided and tests were made at Camp Davis by the AA Board comparing the full range of 12, 18, 24, and 36 power. These data have been taken but up to the present (September, 1944) have not been calculated, analyzed, or reported.

The Princeton Laboratory has reported a number of individual studies on power made at Fort Monroe which are largely the basis of their several more formal reports. The first is a preliminary report on the effect of change of power on the spread of range finder readings on fixed targets. (462) The reproducibility of range finder determinations on fixed targets with the two powers is reported in another study. (463) Another paper deals with the relation of RCS and power. (464) Were the visual angle alone in control, it would be expected that the standard deviation of settings at 24 power would be half that at 12 power. Such is not the case. Indeed the question may be raised as to whether there is any evidence that the ratio differs from unity. Of some 15 ratios for 8 observers only one is statistically significantly different at the 5 per cent level. There is a preponderance of ratios greater than 1—12 out of 15. The range of the ratios runs from 0.68 to 1.32. Another study, dealing with net correction to RCS as effected by power, indicates that five of the seven observers show substantially the same net correction for both 12 and 24 power. (465)

A preliminary study is reported on the comparison of 12 and 24 power on aerial courses, which gives in more detail the aerial data summarized above. (466) A final Fort Monroe Princeton Laboratory report deals with the effect of power on the stability of range readings on fixed targets. (467) Here it was discovered that the average of the mean absolute deviations was less for 24 power when either clear visibility or haze was reported, and less for 12 power when heat waves were reported. It is also pointed out that there may be an instrument factor which makes for either longer or shorter ranges on 12 power as compared with 24 power. All observers read shorter on 12 power on a particular height finder, nearly all shorter on 12 power on another, and nearly all longer on 12 power on a third instrument. It is possible, therefore, that some factor peculiar to the individual instruments may be responsible for a changed level of range readings when the power is changed.

A statistical study of the precision of a stereoscopic range finder upon the magnification employed is reported by the Applied Mathematics Panel of NDRC. (66) The data utilized in this study consist of acceptance-test records available in the files of the Naval Inspector of Ordnance-Optical Materials. The records utilized related to instruments manufactured by the Bausch and Lomb Optical Company and those by Keuffel and Esser Company. In each instance, the records were those of the tests carried out by the staff of the Naval Inspector of Ordnance and are not the inspection records of the company's inspectors. The present analysis deals with the records of the Mark 45 Stereoscopic Range Finder and involves the inspection data on 39 instruments. The results indicate that the precision of the instrument when 24 power was employed to the precision when 12 power was used was in the ratio 1.22 to 1. According to the theory of geometrical optics, these precisions should be in the ratio of 2 to 1. Thus it would seem that under the observing conditions at the Bausch and Lomb plant, an increase of magnification from 12 to 24 power resulted in an increase of precision which was roughly one-fifth of the increase expected from the theory of geometrical optics.

6.2 BASE LENGTH

Another report of the Applied Mathematics Panel of NDRC is concerned with the dependence of the precision of stereoscopic range finders on base length. (67) This again is based on a statistical analysis of acceptance-test records for stereoscopic range finders varying in length from 18 to 46 feet. The analysis suggests that, under acceptance-test conditions, the precision increases with base length. The rate of increase seems to depend on the observer to a certain extent. However the results again indicate a breakdown of the theory of geometrical optics, according to which the precision of a stereoscopic range finder should be proportional to the base length. From an examination of the inspection records relating to the Mark 45, Mark 37, Mark 46, and Mark 52 Stereoscopic Range Finders, which have base lengths of 18, 26.5, 43, and 46 feet respectively, it appears that the precision is not up to theoretical expectation.

A laboratory study at Harvard University was made under laboratory conditions in which it was found that the full theoretical effect of neither magnification nor base length was realized in actual observation. (267) The readings in this study were all on fixed targets under artificial, but excellent, laboratory conditions.

6.3 EFFECT OF MAGNIFICATION ON STEREOSCOPIC ACUITY

Further experiments at Harvard University have to do in part with the problem of magnification and its effect on stereoscopic acuity. (283) These are summarized in some detail in Chapter 2, Fundamental Studies. Both laboratory and field studies were conducted—the latter over both land and water. Magnifications were employed from 1x (the unaided eye) to 40x. Ranges varied from 50 yards in the laboratory to 6,400 yards over water. The results of all of these studies are similar. The relation found between magnification and stereo acuity indicated that the angular error at the eye was not constant, but increased in direct proportion to the increase in magnifying power. Expressed in per cent units ($=100\text{x} \triangle R/R$) the error was constant and independent of magnifying power. Moreover, the per cent error of the observations was unexpectedly low. For any of the ranges or magnifying powers employed, the average mean – variation and the mean – variation of the average adjustments was always less than 1 per cent. Experiments leading to the explanation of these findings are summarized in Chapter 2.

The Princeton Branch of the Frankford Arsenal reports an experimental study of direct and differential range estimation without the use of instruments. (255) Direct estimation is made without the aid of known objects at known distances. Differential estimation was accomplished when known objects at known distances were available to aid in estimation. Observation for differential estimation was made through binoculars by 50 gunners and tank destroyer commanders. The test targets were half tracks at ranges from 400 to 2,765 yards. It was found that the probable error of a single range estimate by direct visual estimation ranges from 17 per cent to 32 per cent in different groups of men. A figure of 25 per cent is probably representative. On the other hand, the probable error of single range estimates by differential estimation, determined on the set of 30 half-track targets, was 14 per cent in each of the two groups of 25 gunners and tank destroyer commanders. It was found that the scatter was relatively small where the target was near a reference point and increased with increasing separation of target and reference point. It is natural to consider that errors in range estimation may be of three kinds: (1) a tendency of individual men to range consistently long or short on all targets; (2) a tendency for all men to estimate a particular target long or short; and (3) to other causes, not associated with (1) or (2) above. An analysis of the results indicates that the actual errors are a compound from all three sources.

To determine the relative accuracy of visual range estimation and of range finders, two field experiments were performed by the Bausch and Lomb Company at Fort Knox. The purpose of the first experiment was highly practical—to determine which of several existing instruments should be selected for immediate adoption as a range finder for tanks and also to determine which sort of instrument and which type of field should be further developed for an improved instrument for this purpose. (108) Six instruments were available:

Keuffel & Esser—
  Invert coincidence (1M, 12x)
Keuffel & Esser—
  Superimposed coincidence (1M, 12x)
Keuffel & Esser—
  Stereoscopic reticle (1M, 12x)
Barr & Stroud—
  Mark VI (1M, 14x)
Perkins & Elmer—
  Superimposed coincidence (48″, 6x)
Polaroid—
  Stereoscopic with bright line reticle (43″, 1x)

Ten targets were selected on rolling terrain at ranges from 646 to 5,939 yards and included such realistic targets as barns, telegraph poles, sign, tank semi-hull down, buildings on distant ridge, an isolated cedar tree and finally, a pylon for purposes of calibration of the instruments. The subjects consisted of ten men from an enlisted detail of Tank Corps personnel selected from an original group of 25 on the basis of standard vision tests. All subjects were untrained at the start of the experiment and at no time had knowledge of results or of true ranges. A total of approximately 15,000 readings were taken during a period of 3 weeks.

The raw data were reduced to a common basis so that it was possible to compute a "figure of merit" for each instrument. It was found that, in terms of per cent of error, the three coincidence instruments gave the best performance, with the Barr and Stroud Mark VI very much better than either of the other two coincidence instruments. However, in terms of UOE, the Polaroid instrument held an unchallenged first place, with the Mark VI a poor second. In this connection it will be remembered that the Polaroid instrument had the advantage of unit power. As a result of this experiment the Fire Control Section recommended the adoption of the Barr and Stroud instrument as an immediate solution of the problem. This recommendation concurred with the opinion of the Armored Forces and the instrument was designated as the M7.

Nevertheless, the results obtained with the Polaroid instrument were of great enough interest to warrant further study with this type of stereoscopic field, utilizing a bright illuminated reticle of the Wandermark type. Another reason of importance was the finding that one could press the illuminated reticle into a material background, such as trees, which was not possible with the normal opaque reticle of the usual stereoscopic instrument. Hence, the Bausch and Lomb Company fitted three stereoscopic Navy Mark 58 instruments for further tests at Fort Knox. The first of these was unmodified and contained the usual Navy opaque reticle. The others were modified so that the reticle of the second was an illuminated line and the reticle of the third was an illuminated star. For comparison with the results of earlier tests, the Barr and Stroud Mark VI instruments was also included.

Four men of the original test group acted as observers and, at the end of the experiment, four men of the recorder group also took readings. Only two of the original targets could be seen because of foliage. In all, seven targets were used, at ranges from 1,190 yards to 2,793 yards. These consisted of the sign and pylon (from the earlier experiment), a hull down tank, a tank fully exposed head on, a truck with only a small part of the top showing through the trees, a truck partly obscured by shrubbery, and a bushy tree in the skyline.

The results indicate that, if equal weight is given to the various targets, there is a small, relatively consistent performance in favor of the Barr and Stroud invert coincidence field over the stereoscopic fields considered either from per cent error or UOE. However, if the results for a single target with very difficult background are eliminated, these differences in favor of the invert coincidence field tend to disappear. Evidence of considerable effect of target and background differences were importantly apparent. Little difference was seen among the three stereoscopic fields but the illuminated reticles were slightly better than the opaque reticle—the illuminated dot slightly better than the illuminated line.

These same four instruments were submitted to a factory test at the Bausch and Lomb Optical Company. (111) A Mark 57 B & L Coincidence instrument (1-meter base length) was added to the group. Three expert and three novice operators acted as observers. Six targets were employed at ranges from 1,013 to 8,137 yards, exhibiting differences in background and conformations both suitable and unsuitable for ranging with both types of instrument.

The results of this experiment indicate that the experts were better than the novices on all instruments. There is relatively little difference between these two classes of observer on the coincidence instrument. There were relatively great differences between the experts and the novices with the stereoscopic instruments. There was little difference in the results for all of the instruments when used by experts. The Mark 58 regular reticle range finder was poorest, for targets of this type, for both novices and experts. In a short subsequent experiment, to determine meteorological effects, the regular and illuminated star reticle instruments were ranged against a single target in very bad haze and rain. Under these adverse conditions, the star reticle gave considerably better accuracy of performance and slightly better precision.

Still another Bausch and Lomb report discusses the results of the several Fort Knox experiments. (110) This report also considers such general aspects, for the choice or development of such an instrument for Armored Force use, as ruggedness, stability and easy adjustability, convenience of use, portability, observer training, and the like.

Recommendations

As a result of these various experiments, the Fire Control Division of NDRC made certain recommendations to the Services. (39) (1) A fire control system involving the use of a range finder was recommended for units of the Armored Force and would be extremely useful for other arms of the Ground Forces. (2) The Barr and Stroud invert coincidence (1M, 14x) seemed to be the best immediately available instrument for use in the Armored Force situation. (3) In the further development of an instrument, consideration should be given to a stereoscopic instrument of the illuminated reticle type because such an instrument could be of extreme value for correction of range as well as obtaining initial range for opening fire. (4) With the increased accuracy of initial range to be expected with the use of a range finder, further investigation should be carried out to determine the most suitable fire control system. (5) With the stabilization of the gun in Armored Force units, consideration should be given to the development of a complete self-contained fire control system with linkage between the range finder and the gun.

Amplifying this last recommendation is a letter from the Chief of Section 7.4, NDRC, to the Office of the Chief of Ordnance. (579) The scheme contemplates the use of a range finder of stereoscopic type, the range knob of which is linked directly to the gun sight (or gun sight reticle) so as to introduce automatically the proper super-elevation. Two additional knobs (or perhaps preferably some form of joystick or course-and-speed indicator) are also provided. One knob would offset the gun sight by a fixed amount in azimuth; the other would offset it by a fixed amount in elevation, this latter amount