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# ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

INDEXED

Third Partial Report

On

PROJECT NO. 37 - STUDY OF ERRORS IN FIELD ARTILLERY PRACTICE

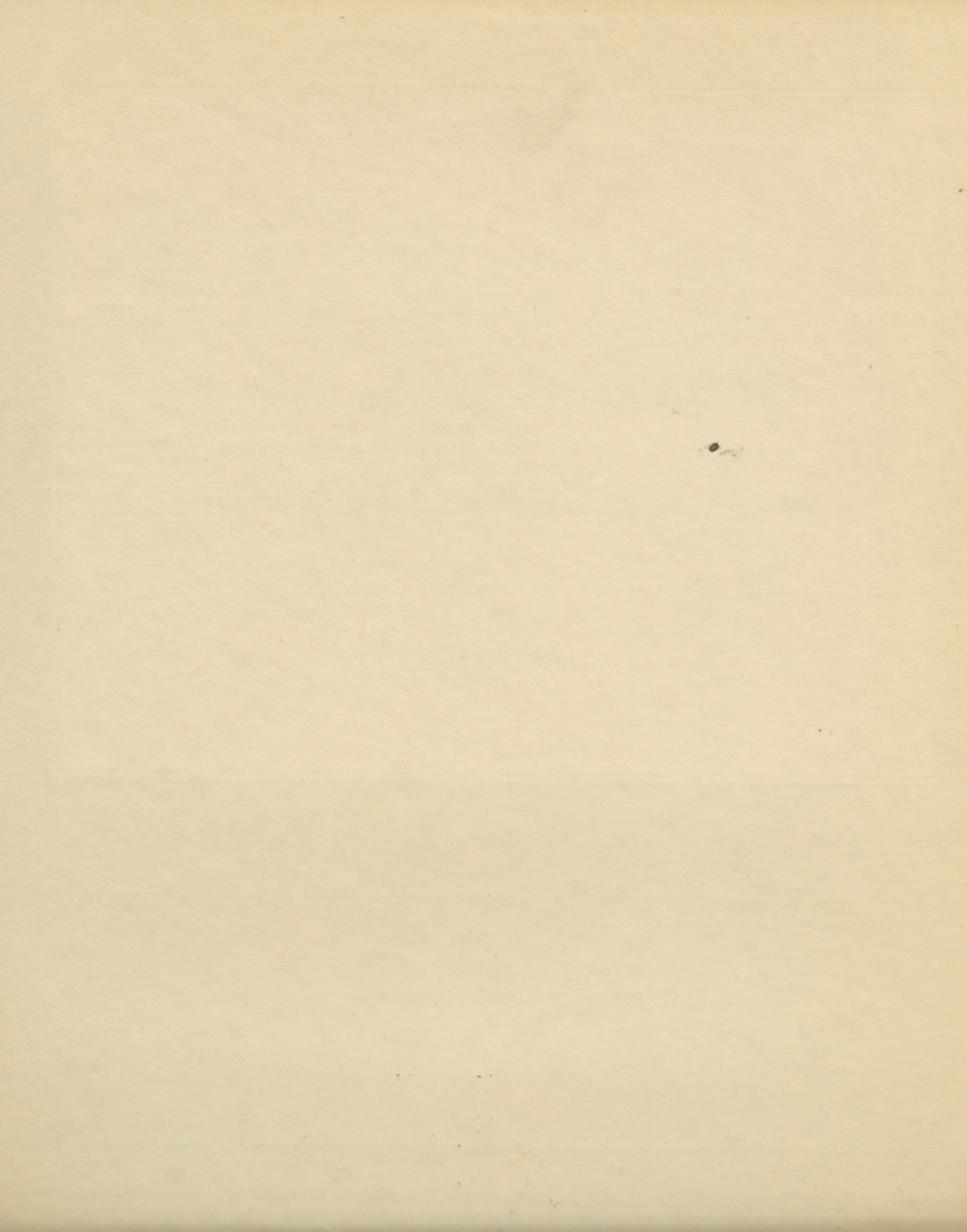
SUBJECT: ANALYSIS OF REQUIREMENTS FOR ELIMINATING  
ERRORS IN LAYING GUNS IN ELEVATION

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Project No. 37

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ARMORED MEDICAL RESEARCH LABORATORY  
Fort Knox, Kentucky

Project: AMRL No. 37; NDRC, SOS-11  
File 413.74-4

6 April 1945

THIRD PARTIAL REPORT  
ON  
STUDY OF ERRORS IN FIELD ARTILLERY PRACTICE

1. PROJECT: No. 37, Study of Errors in Field Artillery Practice, Third Partial Report; Subject: Analysis of Requirements for Eliminating Errors in Laying Guns in Elevation.

a. Authority: Ltr. AGF, 413.68 (R) (8 Apr. 1944) GNRQT-10/78261 dated 8 April 1944.

b. Purpose: To investigate sources of personnel errors in laying the gun in elevation and to recommend improvements in instrument design to minimize chances of error from this source in artillery practice.

2. DISCUSSION:

a. In the First Partial Report of this Study (18 Sept. 1944) reports of frequency of errors at the battery showed that among troops in advanced training from 12 to 20% of the errors were in laying the guns in elevation. Of these errors, the most common were 100  $\mu$  in magnitude, but others ranging from 5 to 98  $\mu$  were also observed or reported. Errors in elevation were commonly referred to in conference with experienced artillery officers and it was evident that they stood out in the minds of these officers because of the actual or potentially more serious consequences from errors in range than in deflection. Increasing demands for close artillery support to ground troops in combat has also placed greater emphasis upon errors from this source. These observations and reports clearly indicate the need for improvement in the technic of laying in elevation to reduce the chances of error.

b. An analysis of the present form of instruments employed for elevation setting shows that they are basically similar to the panoramic sight and possess the same inherent weaknesses from the standpoint of potential error in use. Laboratory and field studies of the present panoramic sight (See Second Partial Report, 22 March 1945) have emphasized certain clear-cut causes of error in reading, and studies of a modified instrument have indicated the possibility of eliminating these difficulties for the most part, through the application of new principles in design. These principles are equally applicable to elevation-setting instruments and form the basis of the recommendations presented below.

c. A more complete discussion of the problem is presented in Appendix I and the essential principles of design of improved instruments are considered in Appendix II.



### 3. CONCLUSIONS:

a. Field observations and reports indicate the need for improvement in design of instruments employed in laying guns in elevation in order to reduce the occurrences of errors from this source.

b. Analysis of present instruments shows that they possess the same inherent weaknesses from the standpoint of errors in use as are found in the panoramic telescope and that the same principles of design may be employed to give improved function.

c. Increasing use of time fire indicates the need for more universal provision of separate means for setting artillery pieces in elevation and for adjusting angle of site.

d. Examination of fire control equipment on present artillery pieces reveals wide variation in the characteristics, method of mounting and of use of the instruments for control of elevation. Development of a few standard instruments of proper design would greatly lessen problems in training, supply and field use.

e. Leveling vials on the instruments have the limiting lines painted on the glass. Many of the lines have become indistinguishable, primarily because the paint has been chipped or worn out of the grooves.

### 4. RECOMMENDATIONS:

a. Provide separate means for laying guns for elevation and angle of site on all artillery pieces which employ time fire.

b. Provide elevation and angle of site indicating instruments of direct-reading types, as outlined in Appendix II, wherein the entire angular value is obtained as a continuous number read from left to right and requiring minimum interpolation on the scale.

c. Improve gunner's quadrant, M1, as outlined in Appendix II.

d. In any program for future developments in artillery materiel, that consideration be given to maximum possible standardization of fire control equipment so as to reduce the number and variety of instruments for laying guns in elevation.

e. Provide leveling vials with the red lines permanently fused into the glass.

### 5. ACKNOWLEDGEMENT:

This project is a joint undertaking with NDRC and the field tests reported herein were jointly conducted with the staff of NDRC, Project SOS-11, Dr. John P. Nafe, Director.



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- #1 - Appendix I
- #2 - Appendix II
- #3 - Figures 1 and 2





1. Improvement in elevation-setting instruments. Field observations and reports (See Project No. 37, First Partial Report, 18 September 1944) indicated that errors in gun laying occur in elevation as well as in deflection and for the same basic reasons, namely, displacement of the coarse and fine scales and lack of certain relation between the two, sparse numbering of scales, etc. The frequency of errors in elevation setting of the piece is definitely lower, however, than is the case in laying in deflection. There are a number of reasons for this, of which the most important is the fact that elevation commands are given throughout adjustment as complete values and only changes in angle of site are commanded in terms of shifts. Another reason for fewer errors in elevation setting is the smaller magnitude of changes in adjustment as compared with deflection shifts. Despite the lower frequency of errors, however, improvement of instruments to insure even fewer mistakes is desirable, especially when it is recalled that an elevation error on the negative side may endanger friendly troops. The increasing emphasis upon close artillery support for advancing troops correspondingly increases the demand for maximum accuracy of laying in elevation.

a. Analysis of the sources and magnitude of errors in reading and setting values on the panoramic sight (See Project No. 37, Second Partial Report, 22 March 1945) reveals certain correctable weaknesses in instrument design: (1) Coarse and micrometer scales displaced from each other and in a direction opposite to the order of reading, i.e., with the hundreds value obtained from a scale on the right; (2) coarse scale continuously moving with reference to the index mark so that for high micrometer readings the index appears to coincide with the next higher hundreds value, thus leading to the well-known 100  $\mu$  error; (3) errors in interpolation on micrometer scale, arising from the fact that the scale is numbered at only 10  $\mu$  intervals; (4) insufficient fineness and clarity of engraving, leading to confusion in scale reading. These sources of error apply equally to the elevation quadrant and the same approach is required in correcting and improving instrument design. Specifically, it is recommended that the hundreds and micrometer scales be brought together so that the complete elevation setting is read from left to right as one continuous number. The units and tens portion of the scale must be enlarged so that every second value, at least, can be numbered, thus minimizing the necessity for scale interpolation. The size and clarity of the numbers and lines must be such as to insure maximum ease of reading. The instrument must also be rugged and capable of withstanding the severity of field use. Proposed designs incorporating these specifications are presented in Appendix II.

b. The final adjustment of the piece is accomplished by means of leveling vials. In a large number of levels seen on the guns, the red paint employed to emphasize the etched lines on the vials had been chipped or worn off. As a consequence, leveling was not being accurately accomplished. The errors resulting were of small magnitude, but are of considerable importance in time fire and in the close support of infantry. This deficiency can be readily corrected by fusing the marking material into the lines of the glass vial.



2. Separation of angle of site and elevation. The rapid advances in the development and use of time-fire technic has emphasized the need for independent setting of elevation and angle of site. Such independent adjustments are found at the present time only on the light field pieces (75 mm and 105 mm howitzers, 76 mm and 3" AT guns) and on the 1918 models of the 155 mm gun and howitzer. The modern medium and heavy artillery (4.5", 155 mm, 8" and 240 mm) are not provided with this feature. As a consequence, it becomes necessary, in the case of time-fire, for FDC personnel to maintain continuous records of the separate elements (elevation and site) of the total elevation command and to apply corrections properly to these two elements in the course of computations in fire adjustment in order to determine the correct quadrant elevation commands to be sent to the battery. In contrast, when separate commands are given for elevation and angle of site such repeated separation and combination of figures is not necessary with consequent lesser confusion. Experience in the course of study of artillery errors indicates that all unnecessary confusion in procedures, computations, etc., should be reduced to a minimum in order to minimize frequency of errors. For this reason it is recommended that on all field artillery weapons which employ time-fire, provisions be made for separate setting of elevation and angle of site.

3. Variation in elevation instruments. The characteristics of the various types of elevation setting instruments provided with present day field artillery pieces are shown in Table 1. For the thirteen weapons listed there are eight different kinds of instruments. In five out of the thirteen cases, the elevation setting scales are incorporated in the telescope mount whereas the remaining eight are provided with separate direction and elevation instruments on opposite sides of the weapon. For seven weapons (75 and 105 mm pieces and 1918 model 155 mm gun and howitzer) separate setting of angle of site is provided. Only the light artillery pieces are equipped with range drums and in modern practice these are not commonly used. In two cases (155 mm gun M1 and 8" howitzer M1) no elevation scale is provided and complete dependence is placed upon the gunner's quadrant. In practice the gunner's quadrant is also commonly used in laying the 4.5" gun and the 155 mm howitzer M1 despite the fact that an elevation scale is incorporated in the telescope mount of these weapons. This practice arises in part from the awkwardness of one-man laying which was evidently intended in the original design since the elevation scale and panoramic telescope have a common mount. This difficulty is most conveniently obviated by having the elevation set in advance on a separate instrument (gunner's quadrant) which can be quickly positioned for laying in elevation after the gunner has completed the deflection setting.

a. It is recognized that there are structural and operational differences between weapons which make it necessary to employ a variety of instruments for laying in elevation. A consideration of these differences is outside the scope of the present project. From the standpoint of causation of errors in field artillery practice, however, it is desirable to reduce to a minimum the number of different types of instruments employed and to provide in every instrument those basic features of design which insure maximum ease and certainty of reading and setting. It is therefore recommended that in the consideration of changes in design of elevation and angle of site instruments, as proposed in Appendix II, concurrent consideration be given to the standardization



of methods of employment of these instruments and their attachment to the various weapons. It may be possible, for example, to provide one basic instrument for all light artillery and another for the medium and heavy weapons, thus simplifying supply, interchangeability of parts, development of training aids, training of gun crews, and shifting of gun crews in the field. It would appear desirable, also, to establish a definite policy with regard to separation or combination of deflection and elevation setting instruments so that proper provisions can be made for convenient access to the instruments in laying for elevation and direction.



TABLE 1

## CHARACTERISTICS OF ELEVATION-SETTING INSTRUMENTS FOR FIELD ARTILLERY WEAPONS

Weapon	Carriage	Elev. Setting Instrument	Part of Tel. Mount	Elev. Scale Range, Mils	Range Drum Provided	Separate Angle of Site Scale
75 mm How. MIAI	M8	Mt., Tel., M3	Yes	0-800	Yes	Yes
75 mm How. MIAI	M3A3	Quad. Range M3	No	0-800	Yes	Yes
75 mm Gun MI897	M2A3	Quad. Range M4	No	0-1200	Yes	Yes
105 mm How. M2AI	M2A2	Quad. Range M4	No	0-1200	Yes	Yes
105 mm How. M3	M3M3AI	Quad. Range M8	No	0-800	Yes	Yes
4.5" Gun MI	MIAI	Mt., Tel., M25*	Yes	0-1100	No	No
155 mm How. MI	MIAI	Mt., Tel., M25*	Yes	0-1100	No	No
155 mm How. M1918	M1918A3	St., Quad., M1918AI	Yes	0-1600	No	Yes
155 mm Gun MI	MI	Mt., Quad., MI	No	Uses Gunner's Quad.	No	No
155 mm Gun M1918MI	M3	St., Quad., M1918AI	Yes	0-1600	No	Yes
8" How. MI	MI	Mt., Quad., MI	No	Uses Gunner's Quad.	No	No
8" Gun MI	M2	Quad., Elev., MI	No	-200-1200	No	No
240 mm How.	MI	Quad., Elev., MI	No	-200-1200	No	No

\* Provided with attached base for gunner's quadrant





## APPENDIX II

### 1. Design requirements for elevation and angle of site indicators.

a. The following characteristics of scale design have been demonstrated as essential for maximum certainty of correct setting and reading fire-control instruments:

- (1) Direct reading of total angular value from left to right.
- (2) Positive relation between coarse and fine scales with the sharpest possible transition zone for the coarse scale value when the micrometer completes its rotation and starts over again with the next higher coarse-scale value.
- (3) Maximum use of numbers so as to require the least possible interpolation on scales.
- (4) Maximum clarity and readability of instrument—requiring numbers of adequate size, sharpness and accuracy of engraving.
- (5) Rugged construction with a minimum of moving parts, accessibility for maintenance, inspection and adjustment.

b. Unlike the panoramic telescope, the elevation and angle of site instruments require no provisions for rapid motion; this simplifies construction since the micrometer worm is never disengaged from the coarse gear. Design requirements are further simplified by the limited range of tube travel in elevation. For angle of site, a total scale reading of 600  $\mu$  is sufficient and 1200  $\mu$  on the elevation scale includes the range of elevation provided by the gun carriage.

c. A micrometer drum with spiral edge operating in conjunction with a secondary dial carrying the hundreds values provides a simple and compact means of meeting the essential operating characteristics outlined above. Specifically, it provides a reading of the total value of the angle setting at one position, with the coarse and fine scale values always in correct relation to each other, the transition zone being less than 1  $\mu$  on the micrometer scale when the coarse scale value shifts from one hundreds value to the next higher value. Continuous numbering of the hundreds and alternate numbering of the units reduces the interpolation to a minimum. This principle of design has been applied with success to the panoramic telescope (Second Partial Report, Project 37, 22 March 1945) and may be employed with equal facility on the elevation quadrant. The essential features of design are indicated in Fig. 1, which shows the layout for application on the right-hand side of the elevation quadrant but it is also equally applicable with suitable modification for use on the left-hand side.

d. The design also shows two movable index marks on both the coarse and fine scales. These are simply suggested as possible additions, if desired, for example, to indicate minimum safe elevation and to aid in making shifts in



angle of site during fire adjustment.

e. No specific application of the instrument to any of the present elevation quadrants is shown, owing to the wide variety of instruments now employed. Taking the Quadrant, Range, M4, as an illustration, however, the angle of site instrument could be directly installed, with only minor changes, in place of the present micrometer dial and the instrument for indicating elevation might be substituted for the range drum, thus putting the two devices on opposite sides of the quadrant to avoid confusion. The two coarse scales and the elevation micrometer on the present quadrant would be removed. It is felt that the application of these instruments to elevation quadrants presents no difficulty and that appropriate designs can be readily worked out.

f. Another design which meets the requirements for certainty of reading is the continuous spiral, somewhat larger in diameter than the spiral which is now employed to indicate range on certain elevation quadrants. This design gives the angular setting at one position and is read from left to right as a total value. The relation of the hundreds to the tens and unit values is always correct and there is no transition zone whatsoever; the only scale interpolation is  $1 \mu$  between the alternately numbered units graduations and there are no moving parts which in any way limit or alter the accuracy of reading. Another advantage of this design is that much of the scale is always visible; thus, one gets a visual sense of the position of the setting in relation to the whole scale which aids materially in the rapid setting of the desired elevation. Owing to the limited capacity of only  $600 \mu$  required of the angle of site indicator, the continuous spiral could be employed in a very compact, rugged instrument. To provide for the elevation capacity of  $1200 \mu$ , however, would necessitate an instrument 7-8 inches in length. The simplicity, absence of accurate moving parts and ruggedness of construction are the chief advantages of an instrument of this type.

## 2. Design of gunner's quadrant.

a. The gunner's quadrant is commonly referred to as a primary test instrument for adjusting fire control instruments into proper relation to the gun tube and for checking instrument scales. Its employment for direct laying of the gun in elevation during firing is termed an emergency use. As a test instrument, there is very little interest in the gunner's quadrant from the standpoint of the present study since its limited employment would present few opportunities, if any, for contributing to the human errors in firing. Except for the reported wear on the gear teeth, there is no criticism of this instrument with respect to its accuracy. Contrary to the foregoing stated function of the gunner's quadrant, however, it is now commonly employed for actual laying of the larger artillery pieces in elevation and its possible contributions to errors in artillery practice is, therefore of interest\*. In passing, it is suggested

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\* The principal reasons for its use as a field instrument with the heavier artillery are that it can be set to  $1/5 \mu$  and by interpolation to  $1/10 \mu$  and can be removed from the gun before firing to avoid shock. It thus provides more accurate laying in elevation, provided the gun is level.

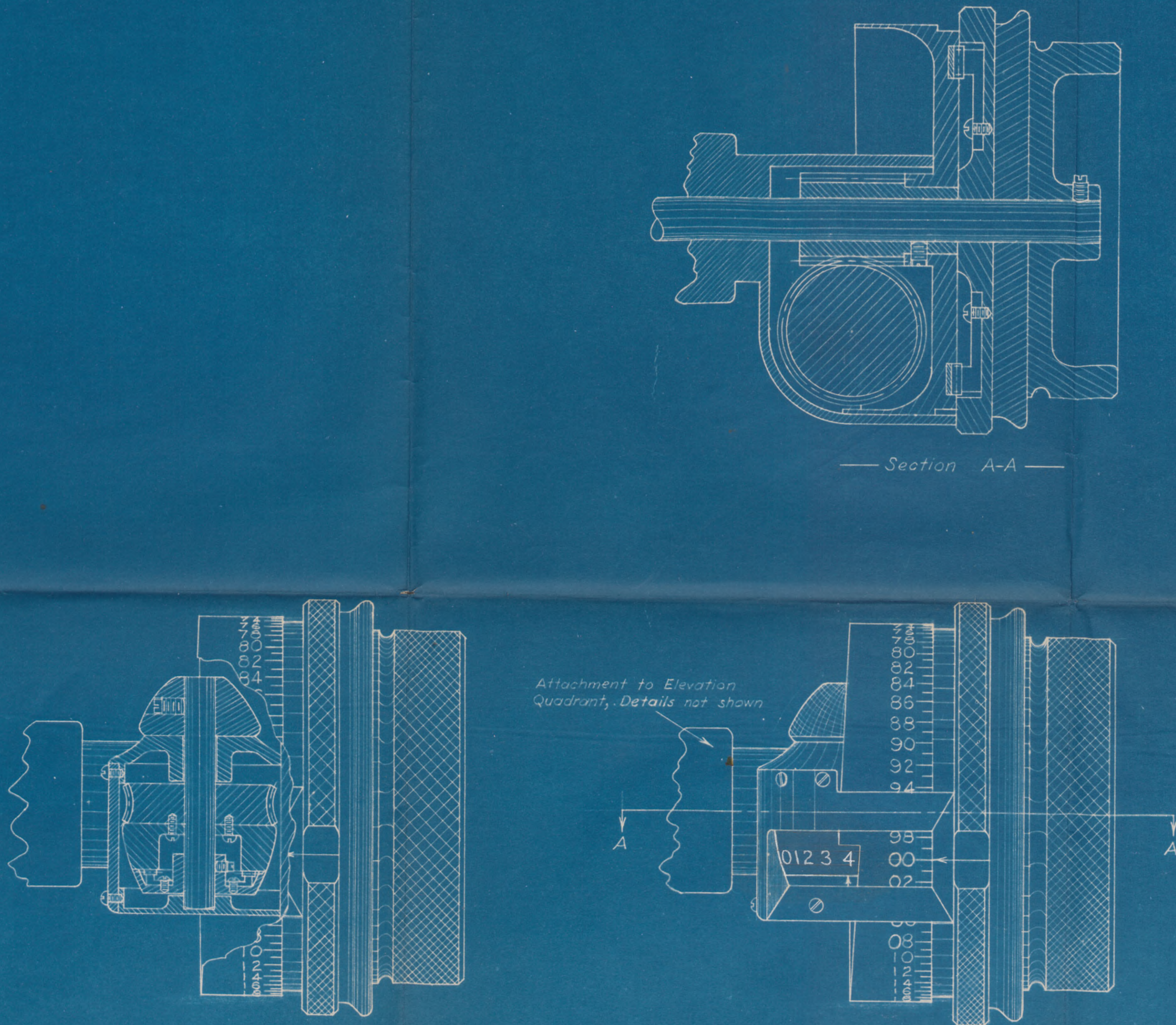


that the relatively fragile design and construction of the quadrant is more in keeping with its function as a test instrument than as a practical field instrument. If it is to be continued in field use, a more rugged design should be adopted and means for cross-leveling provided, in addition to improving the scale design to minimize errors in setting and reading. In the meantime consideration should be given to certain minor improvements in the present gunner's quadrant M1.

### 3. Improvement in gunner's quadrant, M1.

a. Like the panoramic sight and elevation quadrant, the gunner's quadrant suffers from the use of displaced scales and sparse numbering of the scale graduations (Fig. 2). Unlike the other instruments, the coarse scale position does not change with rotation of the micrometer. However, one single turn of the latter is exactly equal to  $10 \mu$ , which is the magnitude of the finest coarse scale graduation. Thus, a  $10 \mu$  error may be easily made when the micrometer is in its zero position unless one makes certain that the true micrometer reading is either zero or 10. This is determined by noting the position of a fine index mark on the micrometer bar relative to a similar index on the adjoining part. Only when these two marks coincide is the micrometer reading zero, at which time the coarse scale position gives the correct angular setting. When the two index lines are apart and the micrometer at zero, the correct micrometer reading is 10 and the true angular setting is therefore  $10 \mu$  greater than the coarse scale value. The resulting  $10 \mu$  error is most commonly referred to in criticism of the gunner's quadrant. In order to eliminate it, the pitch of the micrometer screw should be increased slightly so that  $10 \mu$  equals something less than one complete turn, and a stop provided to prevent turning more than  $10 \mu$ . Since both sides of the quadrant are utilized to give a total capacity of 1600 mils, it is necessary to provide two separate sets of graduations (0 to  $9.8 \mu$ ) as well as numbers on the micrometer for use with the two coarse scales. These are offset vertically and suitable masks provided to insure reading the correct scale in each case. Thus, the zero position will have only one value—zero—and the coarse and fine scales readings will always bear a correct relation to each other. Another suggested modification is the addition of a mask over the coarse scale to indicate more clearly the correct reading and to minimize the confusion from otherwise extensive scale interpolation. These modifications are indicated in Figure 2.





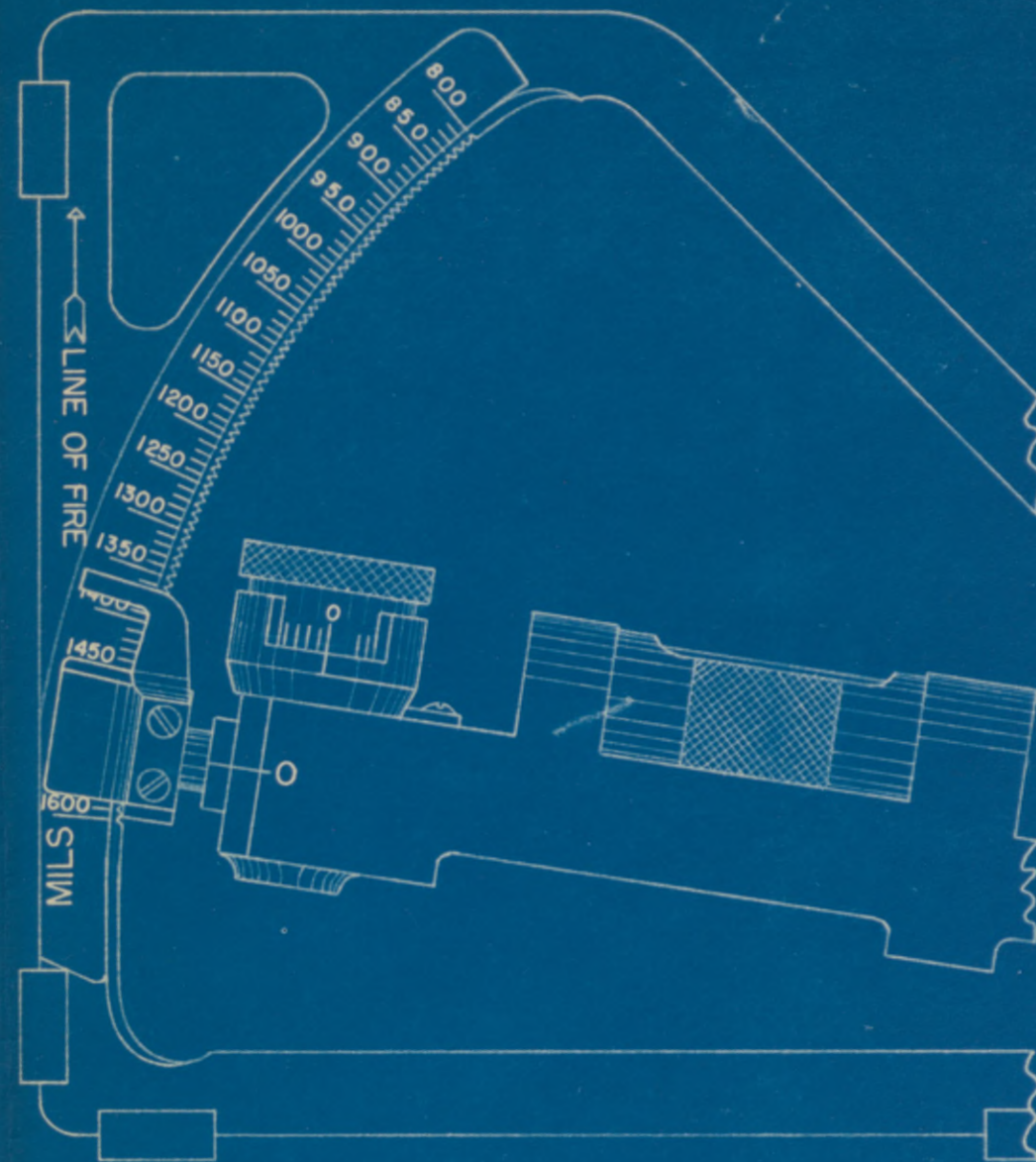
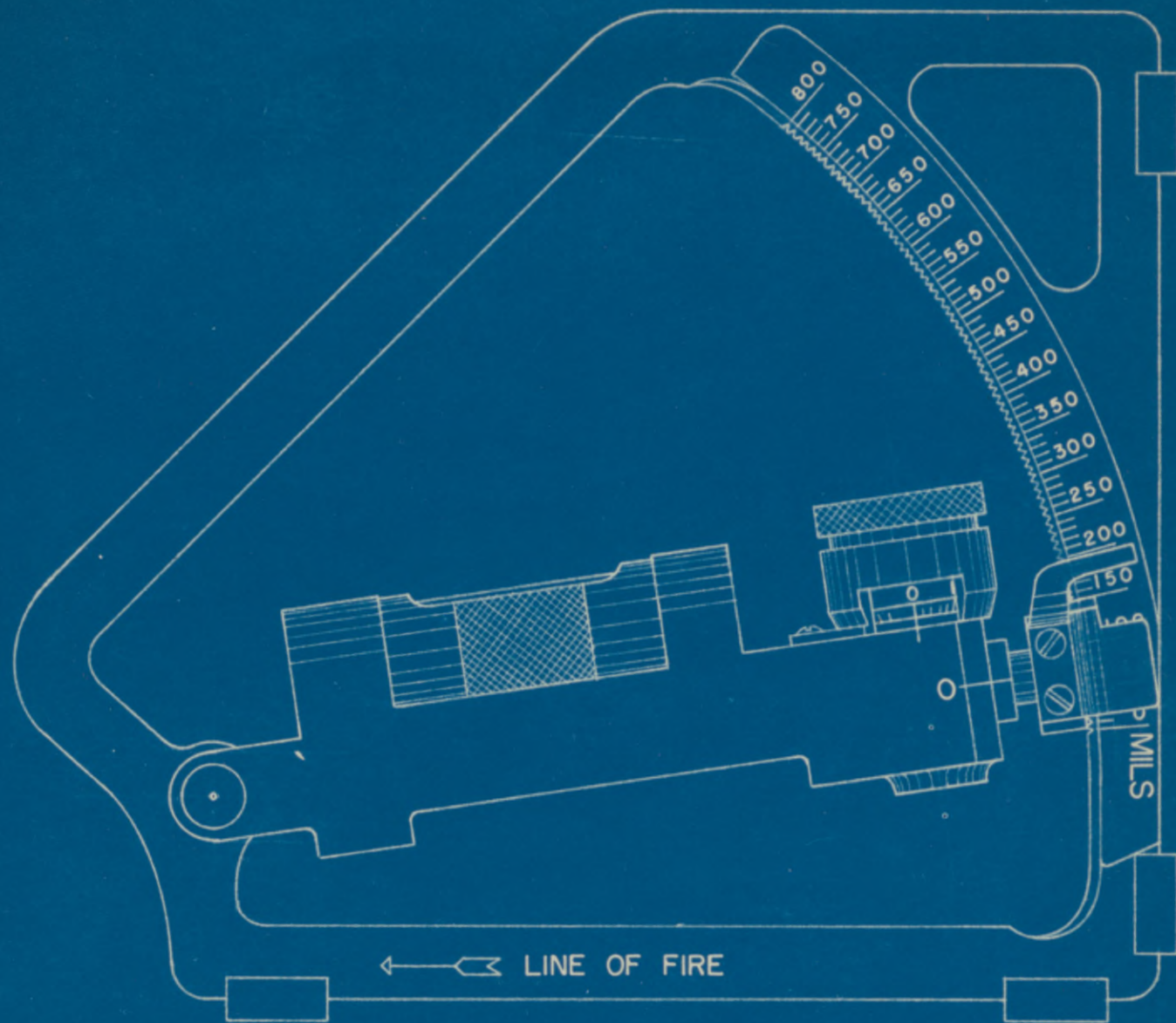
- Notes: ① Design shows right-hand mounting on Quadrant  
Instrument plan can be reversed for left-hand mounting  
② Gear ratio for auxiliary hundreds dial - 1:20

FIG. 1

PROPOSED INDICATOR FOR ELEVATION AND FOR ANGLE OF SIGHT	
ARMORED MEDICAL RESEARCH LABORATORY FORT KNOX, KENTUCKY	
LT. COL. F. S. BRACKETT	
SCALE DOUBLE SIZE	DATE MARCH 27, 1945







Micrometer Scale (Unrolled view)  
 Note Gap from 9.8 to 0

FIG. 2

GUNNER'S QUADRANT, M1  
 With proposed modifications

