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SIGHTS FOR LIGHT ANTITANK WEAPONS

Dominick J. Giordano

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Aberdeen Proving Ground, Maryland

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A field experiment was conducted to measure and compare ten candidate weapons sights for an individual antitank weapon slated to replace the M72 Lightweight Antitank Weapon (LAW). Nine range-finding (stadia) sights and one post-and-peep (rifle) sight were tested in two test phases, where four groups of five gunners simulated firing a shoulder-fired antitank weapon at targets presented at five ranges, three speeds, and three aspect angles. The subjects' ranging and aiming precision and accuracy, and time to fire against an M60 tank, were measured as a function of the target range, speed, and presentation angle. The effects of optics and weapon muzzle velocity on performance were also examined, and user preference was evaluated. Separate

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20. Abstract (Continued)

mathematical analyses investigated the hit probabilities for standard length/width stadia sights and fixed-QE firing techniques, and range-finding bias and upper limit of range-finding accuracy induced by the target's aspect angle. Some sources of reduced superelevation or range-measurement biases were identified; sources of other biases were hypothesized. None of the tested sights improved accuracy or reduced firing time appreciably, as compared to conventional firing where the gunner uses iron sights and estimates target range without an aid. It was recommended that the proposed Short-Range Man-Portable Antitank Weapon Technology (SMAWT) weapon should use a simple sight, integral to the weapon, such as a post-and-peep with adjustable range increments, in which fixed QE and conventional firing are combined.

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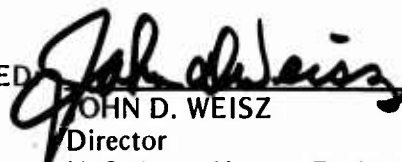
SIGHTS FOR ANTITANK WEAPONS

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April 1976

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

GENERAL

This experiment was conducted by the U.S. Army Human Engineering Laboratory (HEL) as a part of the U.S. Army Materiel Development and Readiness Command (DARCOM) Short-Range Man-Portable Antitank Weapon Technology (SMAWT) Program. SMAWT aims to document the major design characteristics and performance parameters for an individual antitank weapon system which can replace the M72 Lightweight Antitank Weapon (LAW). The design parameters for the future weapon, relevant to the design of sights and mockup weapons used in this experiment, are 1200 feet-per-second muzzle velocity, 81mm diameter, and 8-pound (approximate) weight.

This experiment compared the performance of nine range-finding sights and a post-and-peep (rifle) sight, to select a sight for the future weapon. This report describes the investigation of these ten potential sight designs.

OBJECTIVES

1. The main objective was to measure and compare the performance of gunners using various sighting and ranging methods incorporated into 10 sights for a shoulder-fired antitank weapon.

2. Ancillary objectives with respect to length/width stadiametric range-finding sights were:

      a. To measure how muzzle velocity and the resultant stadia-slope characteristics affect human performance; and

      b. To determine, through a separate theoretical mathematical analysis, the range-finding biases, and the upper limit to range-finding precision as a function of the target's aspect angle.

PROCEDURES

Four groups of five gunners, tested sequentially, simulated firing a shoulder-fired antitank weapon at an M60 tank. Ten weapon sights were evaluated in two test phases: five sights with the first two groups of gunners in Phase 1, and five different sights with two other groups of gunners in Phase II (Figures 2 and 3, and Table 1). The gunners fired from booths using an unsupported bench-rest firing position. Each gunner in a group was tested with all five sights. For each gunner-sight combination, the target was presented at five ranges, three speeds, and three aspect angles; each combination of conditions was replicated twice. The firing was conducted during daylight hours. The target was presented in the open and, when moving, proceeded in a straight-line path.

RESULTS

The results of the experiment showed that none of the sights tested provided much improvement—either in accuracy or time to fire—when compared to conventional firing, where the gunner uses iron sights and estimates range without an aid.

Of the stadia-sights tested, the length/width stadia sights gave the better performance; the three-power sight yielded the best performance. For the current state-of-the-art design, however, even the best stadia-sight gave only slightly higher hit probability than conventional firing can achieve. The relatively poor performance of length/width stadia sights is attributable to a number of sources of superelevation or range-measurement bias.

Other types of stadia sights were less effective than the length/width stadia sights.

The RPG-7 sight, which uses target height for ranging, caused higher superelevation errors than the length/width stadia sights, especially at the longer target ranges.

The variable-power optical sights used target height, target length and width, and the relative size of a man-silhouette for ranging. They were larger and heavier than the other sights, so that the weapon tended to be unstable when the gunner adjusted it during ranging. Using them required almost twice as much time as for the other sights, and the superelevation errors were larger than for the other stadia sights.

The three-power fixed-QE turret stadia sight—which combined two fixed-QE's with stadia gates based on a turret width—did not improve the gunners' range estimation over that of an unaided gunner. Also, the crossover ranges between QE's were sensitive to changes in apparent turret width, caused by presenting the target at the three aspects in the experiment.

A theoretical analysis (Appendix A) showed that, for a perfect gunner, target range measured with length/width stadia varies as a function of the target–aspect (or presentation) angle. The effect of target aspect on ranging performance is shown in Figure 20. For the target used in this experiment, an M60 tank, the range could be in error by more than plus-or-minus 10 percent.

These should have been—and, in fact, the experiment did show—different superelevations for the three target aspects. The magnitudes, however, were not exactly as theorized. More important, all of the sights gave a substantial mean superelevation bias (low) which could not be accounted for in terms of instrumentation, boresighting, or experimental error. Figure 35 shows a good example of the differences in mean superelevations between target aspects and the overall reduced superelevations. Some sources of superelevation bias were traced to their origin, and the sources of other biases were hypothesized.

Rifle sights with three fixed QE's can theoretically provide the gunner with more accurate performance than conventional techniques (Figure 61). However, this assumes that in classifying range into three brackets the gunner has a range-estimation error of about 21 percent, and there is no range-estimation bias. Further testing is necessary to verify these assumptions before relying on any theoretical improvement in performance over conventional firing.

Because none of the sights tested offered any sizable improvement in performance compared to conventional firing, other possible firing methods were examined theoretically, using aiming errors recorded for the rifle sight and the three-power turret stadia sight, to determine if a one-fixed-QE firing technique, or fixed QE combined with conventional firing, could improve performance over conventional firing.

Aiming errors recorded for the rifle sight and the three-power sight (turret stadia sight) were approximately 1.2 and 0.9 mils, respectively. Hit probabilities for a one-fixed-QE firing technique

for various assumed values of aiming error were computed by AMSAA (Figure 63). This figure shows that the three-power sight offers only a small increase in hit probability, as compared to the rifle sight. For conventional firing, a similar result can be expected.

For ranges less than approximately 300 meters, a one-fixed–QE firing technique provides a higher hit probability than the conventional firing technque (Figure 64). But beyond 300 meters, hit probability rapidly falls to zero.

The disadvantage of using only fixed–QE, or only conventional firing, can be overcome by combining fixed-QE and conventional-firing techniques in a sight, with range increments and a fixed-QE aimpoint.

Major Conclusion

Unless technology associated with the design of stadiametric range-finding sights can be improved, these sights do not offer any advantage over using a simple peep-and-post sight with the man estimating range and/or using a fixed-QE firing technique.

Major Recommendation

Therefore, it is recommended that the sight for the SMAWT weapon should be a simple sight, integral to the weapon, such as a peep-and-post with adjustable range increments, combining fixed-QE and conventional firing.

SIGHTS FOR LIGHT ANTITANK WEAPONS

INTRODUCTION

General

In recent years, the infantryman has been the subject of many studies to devise ways of increasing his battlefield effectiveness. One such effort is the SMAWT[1] Program. This program has as its objective the documentation of major design characteristics and performance parameters of an individual antitank weapon in such a manner that their interrelations can be quantified for trade-off analyses. At the conclusion of these analyses, it should be possible to prepare specifications for an improved ballistic antitank weapon system to replace the M72 LAW. The U.S. Army Human Engineering Laboratory (HEL) has participated in this program from its inception, addressing such subjects as weapon signature, length, weight and ruggedness. (Reports of those efforts are being published separately).

Another feature of an antitank weapon in which human factors play a significant role is the sighting subsystem. A perfectly engineered weapon which is designed to be short, light and lethal may still be useless unless the gunner can successfully bring the single round onto the target.[2] Influencing this achievement are not only the abilities and training of the gunner but also the design characteristics of the sight and the discrete human-performance tasks it requires. The experiment reported here addressed the latter two factors—sight design and the discrete performance tasks. It provides quantitative data relating 10 sight designs (and their attendant human-performance tasks) to performance of the man-weapon system.

Sighting Concepts and Their Attributes

The sighting and fire-control problem is particularly difficult for a one-shot, throw-away, individual weapon[3]. The sight must be effective, yet small, lightweight, inexpensive, and preferably an integral part of the weapon.

An infantry ballistic antitank weapon sight can use several means for the gunner to select the sight superelevation when firing a round at a known target range: (1) a graduated sight reticle, (2) an adjustable peep, or (3) a cammed surface between the sight and the weapon. In all three methods, the superelevation graduations or adjustments are based on trajectory information (i.e., range versus launch angle).

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[1] An acronym for Short-Range Man-Portable Antitank Weapon Technology.

[2] With an unsuccessful firing, the weapon can be harmful, as well as useless, if it discloses the infantryman's position.

[3] As a replacement for the M72, the SMAWT embodies this concept.

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When the target range is unknown, an alternative to the gunner's guessing the range is incorporating a range-finding aid into the sight. Almost all range-finding aids are based entirely on a stadiametric principle, relating the angle subtended by a know target dimension to a portion of a reticle interposed between the gunner's eye and the target. A sight combining this principle with trajectory information is a stadiametric range-finding sight, or stadia sight.

Stadia sights have an inherent source of error: they must be designed for a specific target size. If the target size the sight's design assumes differs from the actual target size, it causes a range-finding error—which, in turn, produces a superelevation error. The range-finding error is equal to the percent difference in target dimensions; with a larger target, range is under-estimated, and vice versa. The resulting superelevation error is a function of weapon ballistic trajectory; a low–trajectory (or high muzzle-velocity) weapon is less affected by range error than is a high–trajectory (or low muzzle-velocity) weapon.

A length/width stadia sight has two additional sources of range-finding error. First, the stadia lines are split down the middle for use against head-on (frontal) targets. If the sight is to achieve the same accuracy for a target head-on as it does side-on, the target's length-to-width ratio must be 2 to 1, which is seldom the case. Second, when the target-presentation (aspect) angle lies between head-on and side-on, the apparent target size changes, and the reference target dimensions are no longer appropriate. Figure 1 depicts the length/width stadia range-finding method. Appendix K presents a description of stadia-ranging errors.

A stadia sight based on target height avoids the errors arising from vehicle aspect and length-to-width ratio that are inherent in length/width stadia sights. The height stadia, however, introduces problems which arise from: (1) interpolating range from the stadia lines, and transferring the target image to the proper range line; (2) the target's vertical aspect error, especially for head-on or nearly head-on targets, when the target pitches forward or backward because of terrain features, and (3) the likelihood that terrain undulations and low brush or grass will partially conceal the bottom of the target.

A nonstadiametric approach to the sighting problem, currently gaining in popularity, is a fixed-QE (quadrant elevation) technique.[4] Here the gunner estimates whether a target is within one or more range brackets and uses a preselected sight superelevation mark as the aim point. The superelevation is preselected to maximize hit probability out to a specified range, beyond which the hit probability rapidly falls to zero. The maximum effective range is highly dependent on the round's trajectory, and flat trajectories extend the range. It is also obviously dependent on the target's height.

Optical Versus Non-optical Sights

Both optical and non-optical (simple) sights are currently used with antitank weapons: optical sights with crew-served reusable weapons, and non-optical sights with individual one-shot throwaway weapons.

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[4]The French-built STRIM antitank weapon uses a sight with one fixed QE.

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151. RULES FOR APPLYING STADIA MEASUREMENTS

a. When the tank is broadside to your rifle location, position the ends of the tank between the stadia lines (① of fig. 61).

b. When the tank is facing directly toward you or directly away from you, position it between either stadia line and the vertical center line of the reticle (② of fig. 61). Use one-half of the stadia since the assumed width of the tank (10 feet) is one-half of the assumed length (20 feet).

c. When the tank is at the oblique to, or from, your position, and the length dimension appears greater than the width dimension, position the entire outline of the tank between the two stadia lines (③ of fig. 61).

d. When your situation is the same as the one in c above, except that the width dimension appears greater than the length dimension, position the width of the front or rear of the tank between either stadia line and the vertical center line of the reticle (④ of fig. 61).

e. In each situation, read the range to the target directly opposite (horizontally) the point where the ends of the reference dimension touch the stadia line.

Caution: The stadia lines assist you in determining range only; they do not give you the sight picture to engage the target. You must correctly position the target in the sight reticle for range and leads after you have used the stadia lines to assist you in determining the range.
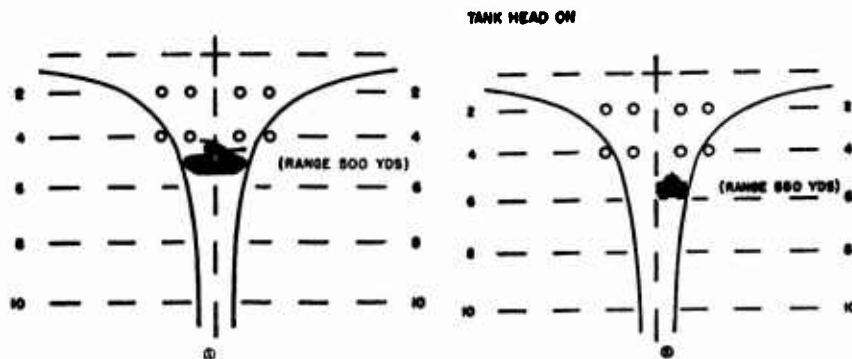
Figure 61. Examples of the use of stadia lines.

Figure 61. Examples of the use of stadia lines—Continued.
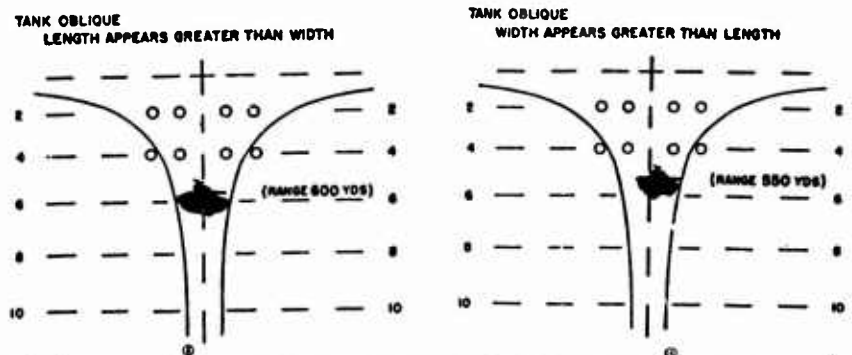
Figure 61. Examples of the use of stadia lines—Continued.

Figure 61. Examples of the use of stadia lines—Continued.

Fig. 1. Conventional length-width stadia range-finding method.
(Reprinted from Reference 1)

Choosing an optical sight for the SMAWT weapon would create problems. It would be difficult to make the sight an integral part of the weapon; even though the sight could be made relatively small, it would still protrude from the weapon and might be damaged (knocked off or misaligned). It is also relatively expensive to provide an optical sight for each round. A detachable sight could be carried in two ways: (1) stored inside the weapon in one of the end caps, or (2) stored in a pouch the gunner carries. Removing the sight from an end cap and mounting it to the weapon would delay firing. If the sight were carried in a pouch, there would be less firing delay, but there is a possibility that the gunner would have a weapon without any sight. In either case, it is likely that, once the weapon is fired, the sight would be discarded with the weapon.

A non-optical sight, similar to the one used with the M72 LAW, is better suited for a SMAWT weapon because: (1) it is relatively inexpensive and therefore expendable; (2) both the front reticle and rear peep are hinged for storage in a compartment on the weapon; and (3) firing preparation is minimal, since extending the weapon for firing automatically releases the sight from its compartment so it is ready for use.

Although offering advantages over an optical sight, a non-optical sight may not be accurate enough. A non-optical sight requires the gunner to align the rear peep and front reticle on the target while performing two incompatible tasks: focusing on the sight reticle and on the target simultaneously. This causes parallax and aiming error. Also, the relative positions of the gunner's eye and the rear peep affect range-measurement accuracy with a non-optical stadia sight.

With an optical sight, the reticle and target are focused in the same optical plane, and the gunner need only align one point on the target. The addition of magnification can increase resolution, effective range, and target visibility. The field of view, however, is restricted by aperture diameter and eye relief.

Sights Tested

The 10 different sights that were examined in this experiment included non-optical, fixed-power optical, and variable-power optical; stadia lines based on a target length and width, height, and the relative size of a man-silhouette; stadia lines based on a turret diameter combined with fixed-QE techniques; and unaided range estimation combined with fixed-QE techniques.

The tested sights which use standard length/width stadia ranging are the M72 sight, advanced LAW sight, reflecting sight, and modified M72 sight.

The tested sights which do not use standard length/width stadia ranging are post-and-peep (rifle) sight, RPG-7 height stadia sight, and ART man-silhouette range-finder sight. The operation of these sights is described in Appendix B.

Test Objectives

The main objective was to measure and compare the performance of the various sighting and ranging methods incorporated into 10 sights applicable to a shoulder-fired antitank weapon.

Ancillary objectives with respect to length/width stadiametric range-finding sights were:

a. To measure the performance effect of muzzle velocity and, hence, stadia- slope characteristics; and

b. To determine, through a separate theoretical-mathematical analysis, the range-finding biases and upper limit to range-finding precision—best precision under ideal conditions—induced by target-aspect angle.

METHOD

General

The experiment was divided into two phases, with five different test sights in each phase. In Phase I, standard U.S. Army length/width stadia sights and the rifle (post-and-peep) sight were tested; in Phase II, the other sighting concepts were tested. Both phases were conducted using the same procedures, but with some modifications to both the gunners' training and the target in Phase II. Table 1 lists the sights tested in each phase and their principal characteristics.

The experiment utilized an idealized firing scenario tailored so system analysts could use it readily to compare the sights and compute the most important performance parameter, hit probability. The experiment was conducted in a open field, and the target, when moving proceeded along a straight—line path at a constant speed. The gunners fired from only one position and all firing was done under daylight conditions.

Target Area and Test Conditions

The experiment was conducted at the Wirsing Test Area located near Phillips Army Airfield at APG, MD; a different area was used for pretest training. The firing point and gun-target line were selected to provide an unobstructed view of the target area (an open field with a tree line beyond the maximum target range) to a range greater than 450 meters from the firing point. The test area is diagrammed in Figure 2.

An unsupported benchrest firing position was chosen to achieve the low aiming error associated with prone firing, yet provide the gunners with a nonfatiguing posture. The firing was done from five booths mounted on a truck bed located at the firing point. The truck bed was braced to remove it from the vehicle suspension system, thus providing a level, stable firing platform. Each of the booths was about 1 meter wide and contained a score sheet, a seat, a contoured shelf, and hooks to hold the weapon between test trials.

The target vehicle was an M60A1 tank.

The target ranges were 130, 210, 290, 370, and 450 meters. Since the subject would fire at the same target range a number of times, two target positions were employed at each range. The nominal target locations were within a 20-degree arc downrange from the center firing booth.

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TABLE 1

Tested Sights and Their Principal Characteristics

Test Phase	Ident. No.	Type	Magnification (Power)	Muzzle Velocity (Ft./Sec.)	Range-Finding Technique
I	1	Post-and-Peep	-	1200	Visual Range Estimation (3 QE's)
	2	M72	-	475	7.1 x 3.55 Meters Width/Length Stadia
	3	Advanced LAW	3	1200	7.1 x 3.55 Meters Width/Length Stadia
	4	Reflecting	1	1200	7.1 x 3.55 Meters Width/Length Stadia
	5	Modified M72	-	1200	7.1 x 3.55 Meters Width/Length Stadia
II	1	RPG-7	2.5	-	Height Stadia
	2	ART [1]	3-9	1200	2.6 Meters Height Stadia
	3	Fixed QE	3	1200	2.8 Meters Turret Dia. Stadia (2 QE's)
	4	ART	3-9	1200	7.1 x 3.55 Meters Width/Length Stadia
	5	ART	3-9	1200	Relative Size of 5'10" Man Silhouette

[1] During Phase II, instead of using sight 2 of Phase II, group 4 used a modified version of sight 5 from Phase I, in which the lines in the reticle pattern were etched in the glass and filled with red paint to make them visible.

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TYPICAL TARGET LAYOUT

White ⭕ ∠ 6 m — Yellow ● ← 4 m

62.4°

8.6 m

Blue ● ↙ 10 m — White ⭕

3.7 m

4 m

Red ● ← 10 m — White ⭕

10 m ↓ White ⭕

← Gun Target Line

Note: Dimensions not to scale

Fig. 2. Test area diagram.

Trees

Trees

Tgt 6

Tgt 5

Tgt 7

Tgt 4

Tgt 8

Tgt 3

Tgt 9

Tgt 2

Tgt 10

Tgt 1

450 m

370 m

290 m

210 m

130 m

Stream

10°

10°

1 m 10°

Booth   1   2   3   4   5

TARGET AREA LAYOUT

17
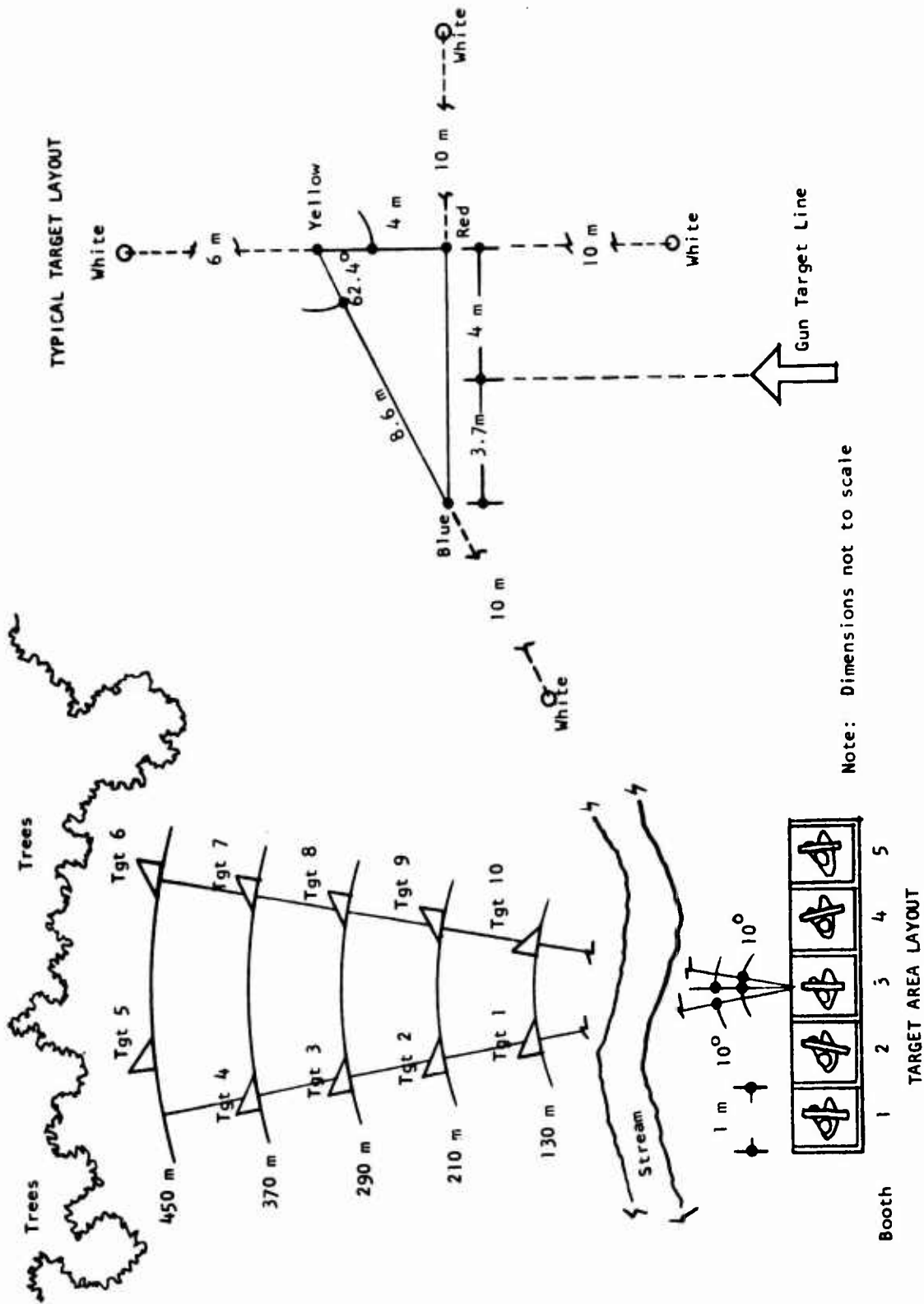
Target engagement (aspect) angles of 0 and 90 degrees (corresponding respectively to frontal and side-on targets) were selected to force the gunners to use half and full stadia with the length/width stadia sights. A third aspect angle of 62.4 degrees was chosen to investigate the effect of change in apparent target size on superelevation.

Target speeds were 0 (stationary), 7, and 14 miles per hour. No lead was applied to the sights for the moving targets. For the 14-mph targets, the closest target range (130 meters) was not used, and the target aspect was limited to side-on only.

Each target location contained surveyed-in 6-inch high colored stakes which could not be readily seen by the gunners. Three of these stakes, at the vertices of a right triangle, were used to predetermine target aspect; the others were guide markers for positioning the tank. To locate the tank in the proper aspect, the driver positioned the tank beyond the stakes so that the two selected aspect-locator stakes and guide-marker stakes were aligned with the tank's centerline. On signal, he drove over the stakes while maintaining this alignment, stopping at the correct aspect-locator stake for the stationary-target conditions.

Tested Sights and Reticles

Frankford Arsenal designed the reticle patterns and furnished all sights except the post-and-peep (rifle) sight and RPG-7 sight. The reticles were designed from ballistic data provided by the U.S. Army Materiel Systems Analysis Agency (AMSAA) and were manufactured by the W. and L.E. Gurley Co., Troy, N.Y. Reticle measurements made by Frankford Arsenal are contained in Appendix E.

Length/width stadia sights are typically designed for a 20- by 10-foot target (1, 2, 4); the 2-to-1 length-to-width ratio is necessary because the stadia are split down the middle. The sights in this experiment were designed for the actual target, to minimize range-estimation bias caused by differences between the typical and actual target sizes. Since the M60 target size (6.95 by 3.63 meters, or 20.39 by 10.65 feet) did not have a 2-to-1 ratio, the averaged target size dimensions—7.10 by 3.55 meters—were used in the reticle design.

The stadia-lines in the Phase I sight reticles were designed for differing minimum and maximum ranges. The approximate minimum and maximum ranges are shown in Figure 3.

The reticle patterns which are shown in Figures 3 and 4 contain range lines and lead lines but, except for the RPG-7, no range numbers.

The subjects fired at each target range at least 12 times with each sight. Range numbers were eliminated from the sights to preclude the possibility that subjects might remember target ranges and transfer this information from sight to sight. Also, the purpose of the experiment was to measure the ranging capability of the sight. Addition of range numbers would have confounded the ranging capability of the sight with the subject's visual range estimation.

The simple stadia sights (M72 and modified M72) were manufactured using the peep portion from an M72, as illustrated in Figure 4. The separation between rear peep and front reticle was the same as for the M72, 19.78 inches. The front sight was made of glass, rather than the plastic used in the M72.

	Sight No. 2 M72 (Simple Stadia)	Sight No. 3 3X ADVANCED LAW	Sight No. 4 1X Reflecting	Sight No. 5 Modified M72 (Simple Stadia)
Range Line Increments in Meters	25	100	100	100
Min. Range on Stadia (Approx.) in Meters	150	110	125	175
Max. Range on Stadia (Approx.) in Meters	350	650	700	600
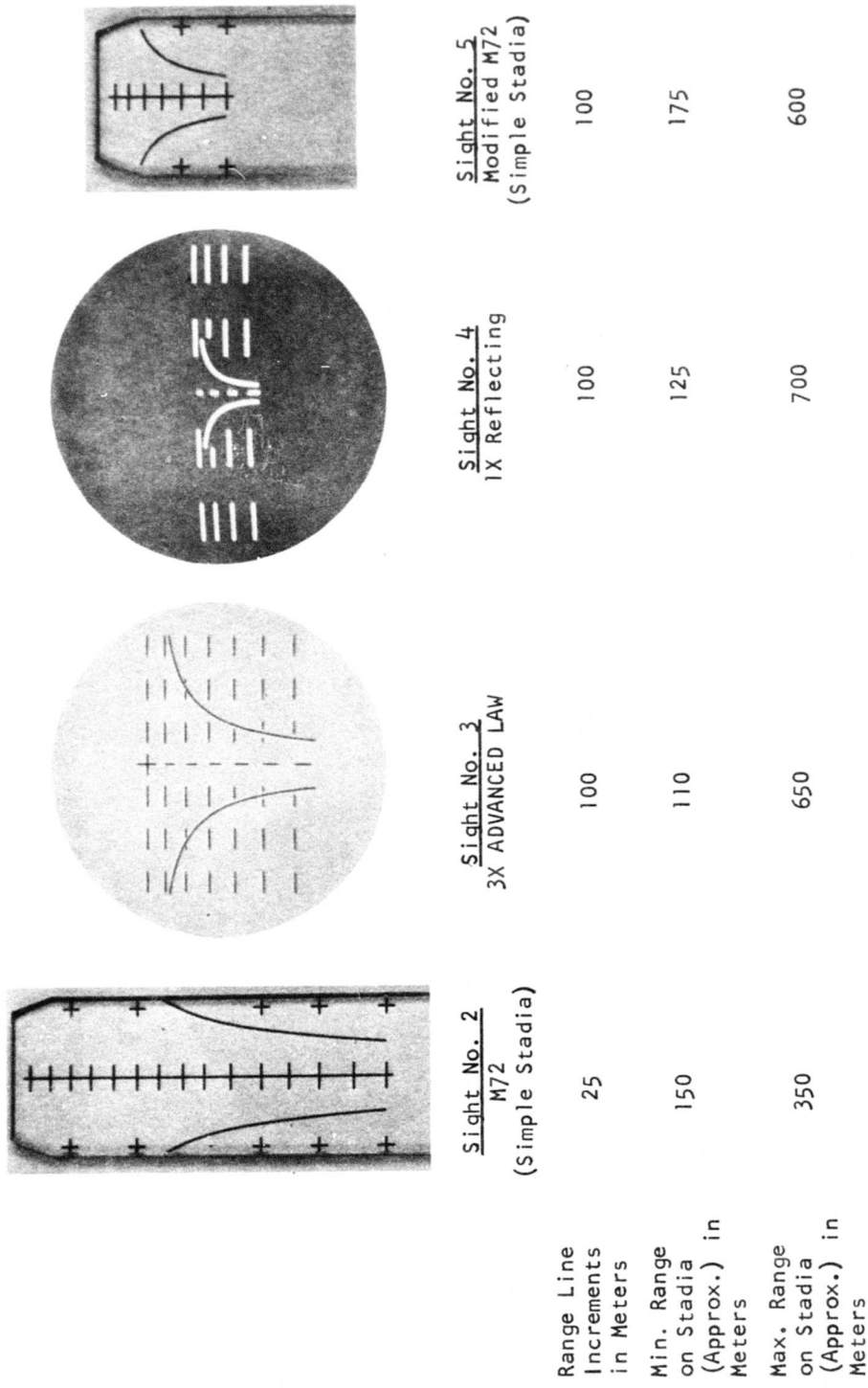
Fig. 3. Phase I—Length/width stadia sight-reticle patterns.

Sight No. 3
3X Fixed QE
Turret Width Stadia

Sight No. 5
3-9X ART
Man-Silhouette Stadia

Sight No. 2
3-9X ART
Height Stadia

Sight No. 4
3-9X ART
Length/Width-Stadia

Sight No. 1
2.5X RPG-7
Height Stadia

Fig. 4. Phase II—Sight-reticle patterns.

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The rifle sights were manufactured to the dimensions of the M16 rifle for front post and rear peep. The quadrant-elevation selector was a three-position rotary switch operable from either side of the peep. The three positions were labeled "near," "mid," and "far," corresponding to rotating the switch away from the gunner. For ease of fabrication, the change in superelevation was only simulated by the range-switch setting; i.e., the rear peep remained fixed.

Mockup Weapons

Mockup weapons, shown in Figures 5 and 6, were fabricated from design drawings provided by the U.S. Army Missile Command (MICOM). This design includes a shoulder stop and trigger, similar to the Swedish-built Mini-Man antitank weapon. The trigger, a thumb-operated pushbutton, is in line with the bore of the weapon, rather than counter to it (as with the M72). The center of gravity for the weapon is about 1 inch forward of the shoulder stop.

Instrumentation

Affixed to the rear of each weapon was a magazine-loaded, windup 16mm motion picture camera. The camera was positioned so that the lens looked through the barrel. Figures 5 and 6 show the assembled weapons with sights attached. Four of the weapon cameras were equipped with 150mm lenses. The camera on the other weapon, whose sight (M72, sight 2) in Phase I was designed for a 475 ft./sec. muzzle velocity, was equipped with a 100mm lens to increase the field of view.

The sights for the first four weapons above were offset approximately 10 mils from the point-blank range line of sight; this compensated for the weapon elevation, so that targets were within the camera's field of view even at the far target ranges. The M72 sight, because of its larger superelevation, was offset approximately 55 mils.

Operating the weapon trigger completed an electrical circuit, illuminating a light located on the side of the camera and starting the camera. Measured time between circuit closure (as indicated by the light) and full opening of the camera shutter was approximately 30 milliseconds. The cameras operated at 16 frames per second. A timer located on the weapon automatically shut the camera off approximately 0.5 second after trigger operation. Two fiducial markers were inserted in each camera's film plane, to provide fixed reference points for subsequent data reduction.

Another camera was located behind the gunners to provide time-to-fire data. This camera, operating at 7.5 frames per second, photographed the subjects and recorded when the light on the end of the weapon camera was lighted.

Subjects

Four groups of five enlisted infantrymen, two groups in each test phase, were the subjects in the experiment. The subjects had all received prior training with the M72 LAW and had served in Vietnam.

Fig. 5. Phase I weapons with sighting systems.

Sight Nos. 2 & 5
Simple Stadia
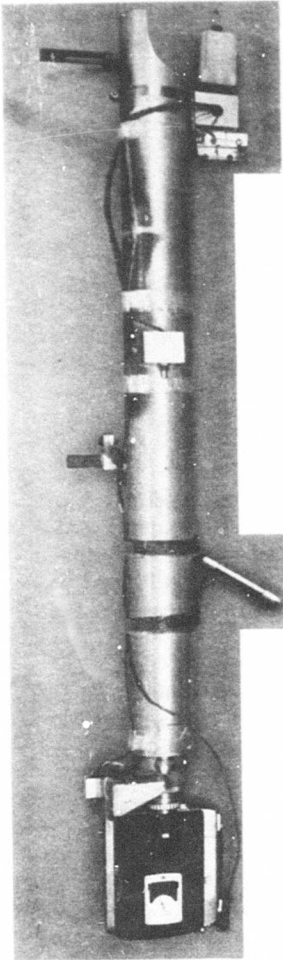
Sight No. 3
3X Advanced Law
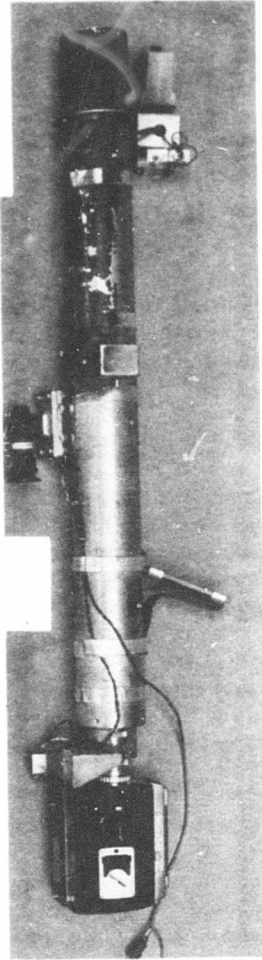
Sight No. 4
1X Reflecting
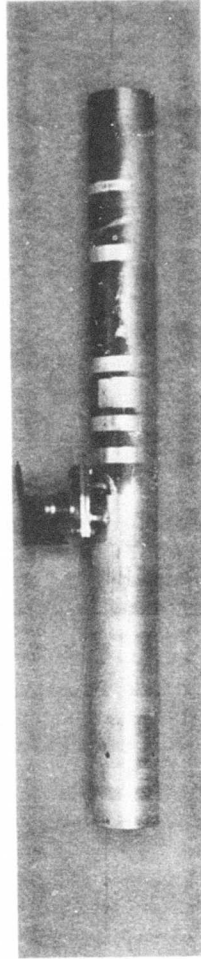
Sight No. 1
Rifle Sights

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Fig. 6. Phase II weapons with sighting systems.

Sight Nos. 2, 4 and 5   ART

Sight No. 1   RPG-7

Sight No. 3   Fixed Q.E.
Turret Stadia

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Questionnaires

Two different questionnaires which solicited "user preference" were administered to the subjects. The questionnaires required the subjects to rate (questionnaire 1) and rank (questionnaire 2) the sights with respect to specific performance criteria. Sample questionnaires are shown in Appendix F.

Procedure

General

Five sights were examined in each phase of the experiment, and two different groups of five subjects each were used in each phase. The subjects in each group were assigned numbers from 1 to 5 for identification. Testing on each group was divided into six test days, numbered from 0 to 5. During day zero (0), the subjects were trained on the sighting procedures and pretest measurements were obtained. Days 1 through 5 were the main part of the experiment.

Phase I

(1) Training

The subjects were told that their performance in the experiment would influence selection of the sight on a new weapon. In addition, they were told that they would be asked to rate the performance of each sight, so questions concerning the merits of each sight could not be answered until completion of the experiment.

The mockup weapon systems were shown to the subjects, and each subject was given an opportunity to look through the sights and get the feel of the weapons. For each sight, the experimenter explained the relationship of the plexiglas training aids[5] to the sight, and the proper sight picture and aiming point on the target at each range and aspect. The subjects were then trained individually.

For the stadia sights, the subjects were instructed to touch the edges of the target to the inside edges of the stadia lines, except when using the reflecting sight against head-on targets. Here the subjects were instructed to place one edge of the target in the center of the wide (approximately 3 mils) vertical range-line.

The aiming method used with the stadia sights for target sizes that were too large (near target range) for the stadia lines, or too small (far target range), was:

(a) Near Targets—The zero-range cross was positioned at the target's center of mass, located 1 foot below the tank turret ring.

(b) Far Targets—The sight was elevated to maximum range and the bottom part of the vertical centerline of the sight positioned at the target's center of mass.

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[5]Reticle patterns of each sight were scribed on plexiglas overlays and used as training aids together with color photographs of an M60 tank shown at three aspects and six different ranges.

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After the sight training, a range-estimation course was conducted, because the accuracy of the rifle sights (post-and-peep) depended on the subject's ability to estimate range. The training method was the "100-meter unit of measure" (2), in which the subjects determined the number of 100-meter increments and fractions thereof to a landmark, then verified their estimates by pacing off the distance. The training was conducted at a premeasured area shown in Figure 1C (Appendix C). Five landmarks at different ranges were used and, after each distance was paced off, the true distance was revealed to the gunners. Next, a training exercise with the weapons was conducted at the same area.

To provide training with the real sighting systems, each weapon and sight was mounted on a tripod equipped with azimuth- and elevation-adjustment thumbwheels. The target tank was positioned at one of four ranges and each subject, in turn, adjusted the azimuth and elevation of the weapon to position the sight on the target. The experimenter checked the sight picture and informed the subject whether or not it was correct. If incorrect, the correct sight picture was described to the gunner, who then repositioned the sight to obtain a new sight picture.

Five different range-aspect combinations were used for each sight. Figure 2C (Appendix C) shows the training-area target layout and order of target presentation for each weapon. Target ranges used in this training were different from those used in the main test.

(2) Main Test

(a) Experimental Design

The main test was divided into five test days, to provide a counterbalanced experimental design in which each subject fired a different weapon each day. The weapons and firing booths were assigned to the subjects according to the orthogonal matrix shown in Figure 7. A different matrix was used for each of the two groups of subjects in order to balance (as much as possible) assignment of sequential pairs of weapons.

Each test day was divided into two replications of 15 stationary, 15 low-speed (7 mph), and 4 high-speed (14 mph) target presentations, in that order. An equal number of targets was presented at each target aspect for the stationary and 7-mph target speeds. Only side-on targets were presented for the 14-mph target conditions. The experimental variables for each test phase are shown in Figure 8.

The target sequences used each day are shown in Table 1D (Appendix D). The sequences were assigned to each day's target presentations according to the matrix shown in Table 2D (Appendix D).

(b) Scenario

At the beginning of each day the procedures were explained to the subjects, who were then assigned to firing booths and weapons. They were given the assigned weapon and sight for familiarization with the test procedures and the firing position, during which the test personnel asked them individually to explain the operation of the sight. When all subjects reported confidence in operation of the sights, the test was begun.

GROUP 1 MATRIX

DAY

	1	2	3	4	5
1	1A	2C	3D	4E	5B
2	2B	3E	5A	1D	4C
3	3C	5D	4B	2A	1E
4	4D	1B	2E	5C	3A
5	5E	4A	1C	3B	2D

(Row label: FIRING BOOTH)

GROUP 2 MATRIX

DAY

	1	2	3	4	5
1	3C	1E	5D	4B	2A
2	2B	4C	3E	5A	1D
3	1A	5B	2C	3D	4E
4	5E	2D	4A	1C	3B
5	4D	3A	1B	2E	5C

(Row label: FIRING BOOTH)

Fig. 7. Experimental design.

NOTE: Cell numbers designate subjects.
Cell letters designate sights where A-E
represent 1-5 respectively.

Independent Variables	Dependent Variables
Sights	Accuracy
(1, 2, 3, 4, 5)	Mean Superelevation
Subject Groups	Range-Estimation Ability[b]
(1, 2) (3, 4)	Precision
Target Speed	Superelevation (or aiming error) Standard Deviation
(0, 7, 14 MPH)	Azimuth Standard Deviation
Target Aspect[a]	Time to Fire
(0, 62.4, 90 Degrees)	Gunners' Sight Preference
Target Range	
(130, 210, 290, 370, 450 Meters)	

Fig. 8. Experimental variables.

[a]For 14 mph target speeds, only 90 degree target aspects were used.

[b]Superelevation of sights using Fixed-QE techniques was dependent on the estimated target range.

The subjects were seated in the firing booths in the ready position (Figure 9), facing away from the target area toward the test personnel. The tank was positioned at the proper target location. When the fire command was given, the subjects turned toward the target area while shouldering their weapons, aimed, and fired (Figure 10). Simultaneously with the fire command, the camera located behind the subjects began photographing and continued until all subjects had fired. After each target presentation, the subject using the post-and-peep sight (sight 1) returned the superelevation selector to the near-target position.

At the end of each target presentation, each subject placed a mark on a scoresheet located on the side of the firing booth. He identified the target range as either too close, in range, or out of range for the stadia sights (sights 2 through 5, Table 1); or near, mid, or far (corresponding to 0-300 meters, 300-400 meters, or 400-500 meters) for the rifle sight (sight 1).

If a weapon camera malfunctioned (the subject could tell if it did not run), a make-up was presented later on in the test sequence. The make-up target was at the same range and aspect as the missed target. All subjects fired at the make-up target presentation.

Target position was controlled via two-way radio communication between the driver and the firing-point personnel. Target repeats were identified by target number and color code.
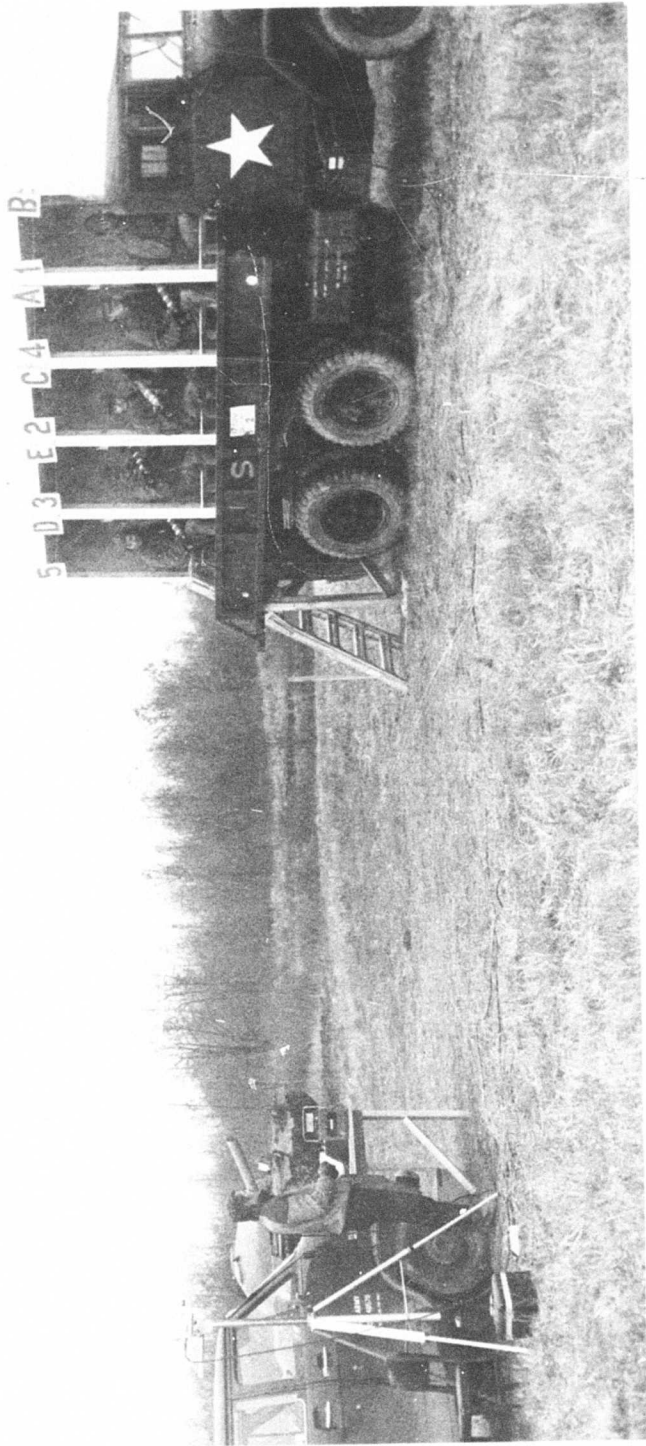
Fig. 9. Gunners ready to fire.
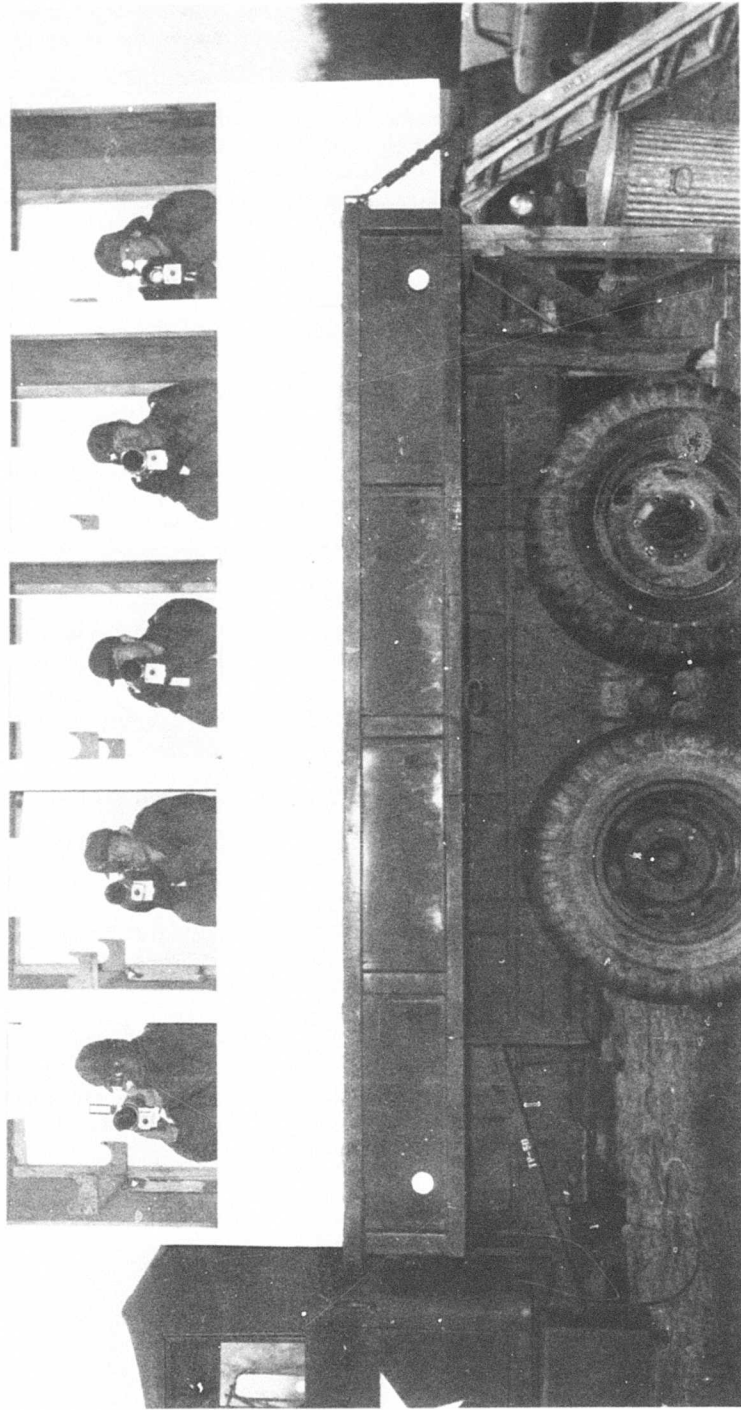
Fig. 10. Gunners firing--frontal view.

At the end of the second and subsequent test days, the subjects filled out questionnaire 1, in which they compared the sight they had just used with the sight used the previous day. The subjects answered the first questionnaire while seated in the firing booths with a minimum amount of supervision.

After the test, the subjects completed questionnaire 2 to rank-order all sighting systems. While answering the second questionnaire, the subjects were individually quesioned by an experimenter. For each question in questionnaire 2, the subject was allowed to refresh his memory by using the sights; and then he physically placed the sights in rank order in a container.

Phase II

The Phase II test procedures were the same as for Phase I except for the following:

The range-estimation training was eliminated, since none of the sights used visual range-estimation.

The training was extended to 1-1/2 days to accommodate the diverse ranging techniques among sights.

The M60 tank turret was replaced by a turret nominally 2.8 meters in diameter (Figure 11).

When the subjects practiced ranging to the target with the man-silhouette ART sight, the driver stood on and near the tank as a reference.

For the RPG-7 sight, the subjects used the range "2" mark (200 meters) in the sights (Figure 4) for targets too large for the stadia.

Group 3 was tested using the Phase II sights listed in Table 1.

The sight-reticle patterns are shown in Figure 4, and the mockup weapons with the sights attached are shown in Figure 6.

Group 4 was tested using the Phase II sights listed in Table 1, except for sight 2. The height-stadia ART (Adjustable Ranging Telescope) sight (sight 2) was replaced by the modified M72 sight (sight 5 from Phase 1) with a new front reticle. During Phase I, the subjects reported that the stadia-lines of the M72 and modified M72 sights were sometimes difficult to see, or disappeared completely. The reticle patterns in these sights were made of a thin film of mirror-like metal on the glass. In an effort to determine the resulting degradation in performance, HEL had new reticles fabricated; to make the lines in the reticle pattern more visible, they were etched into the glass and filled in with red paint. These new reticles were not available until the last group of subjects (group 4) was tested during Phase II.
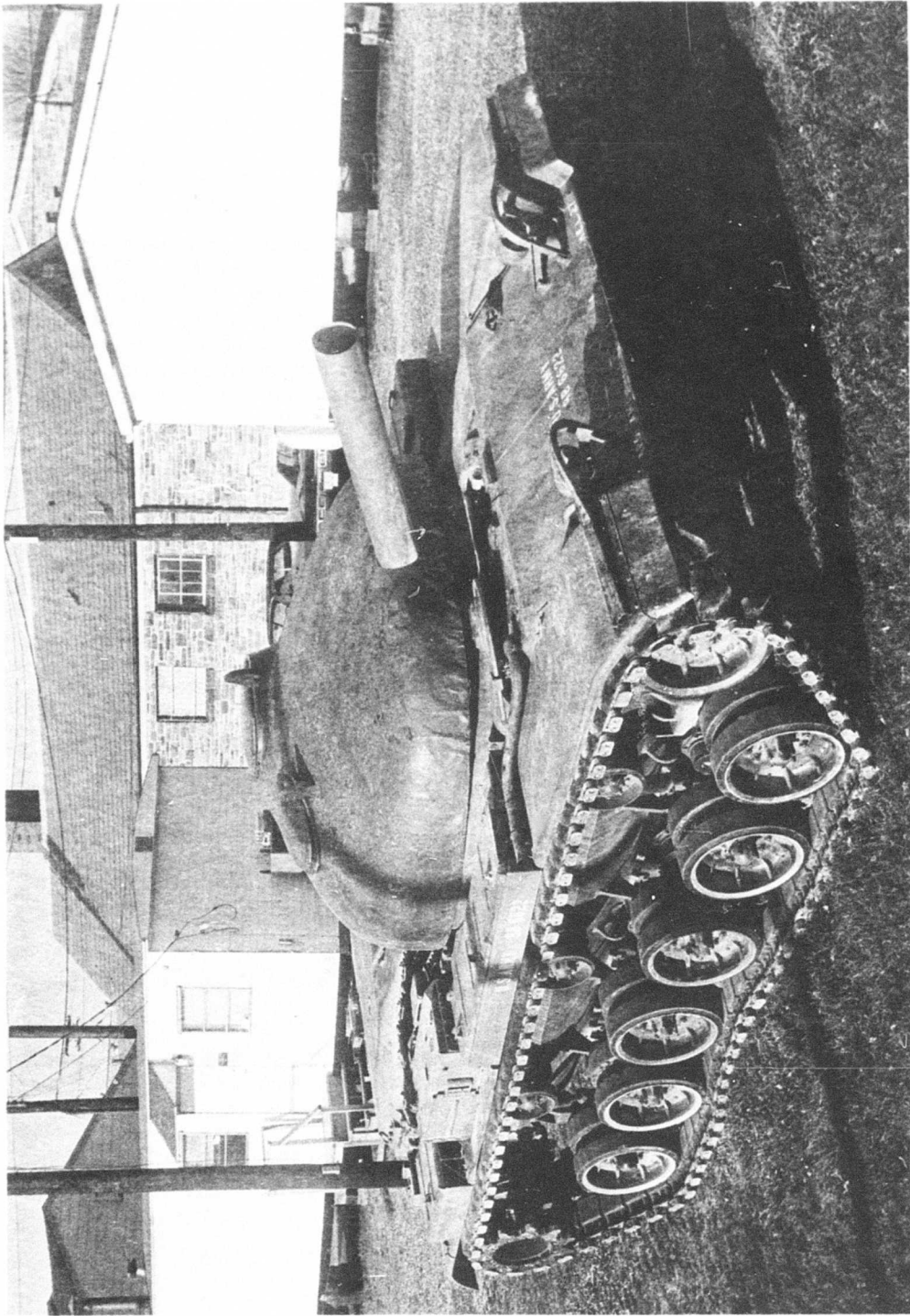
Fig. 11. M60 tank target with modified turret used during phase II.

RESULTS

Ranging and Aiming Performance Measures

General

(1) Data Reduction

Each time a subject operated the trigger, the weapon camera photographed the position of the target tank. To obtain ranging and aiming data from these photographs, the film was projected onto a rear-projection screen equipped with a two-axis digitizer. The digitizer's output was punched tape which was entered into a computer for analysis. Measurements for each trigger operation were taken from the first frame of the series of pictures obtained on a trigger operation. Ancillary information and measurements digitized for each trigger operation consisted of identification codes and locations of camera fiducial markers, horizontal extremes of the target tank, and the center of the turret ring.

The measurements were referenced to the camera fiducial markers and the boresight readings. They were then converted to superelevation and azimuth in mils, using a calibration factor for each lens and camera combination and the nominal target range.

All superelevation measurements were with respect to an aim point located 1 foot (0.3 meters) below the turret ring, where hit probability was maximized.

Raw superelevation and azimuth data were tabulated by sight for all target presentations. Means and standard deviations (SDs) for each subject, group, and sight were computed for selected independent variables of range, speed, and aspect, using the programs of reference 3. These data are tabulated by group in Appendix G and are presented graphically in Figures 18, 19, and 21 through 46.

(2) Gunner Errors

Obvious gunner errors were eliminated from the computations and are reported separately. The gunner errors in Phase I were sorted into four categories:

(a) Half Stadia. The gunner positions a non-head-on target as he would a head-on target, in half of the stadia, causing a reduced superelevation.

(b) Full Stadia. The gunner does the opposite of the first type of error, thus increasing the superelevation.

(c) Out of Range. The gunner determines incorrectly that the target appears smaller than the minimum separation of the stadia lines (maximum superelevation) and fires at the maximum superelevation, marking his scoresheet accordingly.

(d) Outlier. A large deviation from the mean value which does not fall into any of the previous categories. The rifle sights could only incur the fourth type of error.

In Phase II, group 4's errors with sight 2 were classified into four categories and listed under Phase I. The rest of the Phase II errors were sorted into only two categories: out-of-range and outliers.

The out-of-range errors were obtained by examining the gunner's scoresheet and the measured superelevation. Next, the means and SDs were examined according to subject and group, noting where the SDs appeared to be inflated. Then the data were scanned to find the suspected error. If the target was head-on and the superelevation appeared to be that which would have been obtained by fitting an equivalent target size in the full stadia, it was classified as a full-stadia error (and vice versa for half-stadia errors). If the suspected error could not be explained by any of the other classifications, it was considered to be an outlier.

The means and SDs were recomputed with the suspected gunner errors removed. If removing errors did not significantly change the recomputed statistics [as in Grubbs (8)], the data were retained as valid.

Tables 2 and 3 show the frequencies of occurrence for each classification of gunner errors in Phase I and Phase II of the experiment.

In Phase I, subject 3 from group 2 used full-stadia ranging for all target aspects. Therefore, this subject's data for head-on targets were removed from all but the rifle-sight data. The total number of gunner errors for any of the Phase I sights (not including the above subject's full-stadia errors) was less than 2 percent of the total number of 680 possible data points.

There were more gunner errors in Phase II than in Phase I. The sights in this phase used various target dimensions for rangefinding, whereas four of the five sights in Phase I used length and width. It is possible that, in switching from one sight to another, the subjects were more prone to making mistakes. There were also additional errors in Phase II with sight 3, which will be discussed later.

(3) Length/Width Stadia Sight Rangefinding and Superelevation Biases

(a) Investigation of Possible Causes

Early in the data-reduction process, it was determined that superelevations for most of the sights were biased lower than those predicted from ballistic data. Investigation ruled out the possibility of error during the data collection and reduction procedure. A thorough examination of the sights finally revealed the causes of the biases.

Some superelevation biases for the length/width stadia sights were caused by the way the sights were designed, and others were caused by the way the gunners used stadia sights. It must be emphasized, however, that the design of these sights reflected the current state-of-the-art, and that the gunners were more highly trained in using the stadia than the average infantryman is.

A possible error source for the length/width stadia sights was suggested by the difference in stadia line thickness between the three-power sight (which had narrow stadia lines and the highest superelevation) and the unity-power sight (which had wide stadia lines and the lowest superelevation). The following analysis isolated the effect of stadia-line thickness on rangefinding.

(b) Rangefinding Bias Caused by Stadia-Line Thickness

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TABLE 2

Phase 1   Gunner Errors

Sight	Group	Subject	Range	Aspect	Speed	Half Stadia	Full Stadia	Out of Range	Outlier
1	1	1	1	1	2				1
			1	3	1				1
		3	4	3	3				1
		4	1	2	2				1
			5	3	2				1
		5	3	3	1				1
	2	3	1	3	2				1
			4	1	1				1
		4	1	1	1				1
			2	1	1				1
			2	2	2				1
		5	2	3	3				1
2	1	2	2	1	2		1		
			4	2	1	1			
			4	1	2			1	
		1	3	3	3			1	
	2	1	4	3	2			1	
			4	1	2			1	
		2	4	3	1			1	
			4	3	2			1	
			4	3	3			2	
		3	(A)	1	(A)		15		
		4	3	1	1		1		
		5	4	3	1			1	
			4	3	2			1	
3	1	2	1	2	2				1
		3	2	2	1				1
			1	1	1				1
		4	3	1	2				1
			1	3	2				1
			3	2	1				1
			4	2	1	1			
		5	4	2	2	1			
			5	2	1	1			
	2	2	1	1	1		1		
		3	(A)	1	(A)		21		
			6	3	1	1			

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TABLE 2   (Continued)

Phase 1   Gunner Errors

Sight	Group	Subject	Range	Aspect	Speed	Half Stadia	Full Stadia	Out of Range	Outlier
3	2	5	4	1	1			1	
			5	1	1			1	
			5	3	2			1	
4	1	4	2	1	1		1		
			2	1	2		1		
			5	3	2			1	
		5	5	1	1			1	
			1	(B)	(B)				5
	2	3	(A)	1	(A)		22		
5	1	2	5	2	1			1	
			5	3	1			1	
		4	5	3	1			1	
			5	2	2			1	
			5	3	2			1	
			5	3	3			1	
			2	1	2				1
		5	5	3	1			1	
			4	1	1		1		
			1	(B)	(B)				8
	2	1	2	1	2				1
			2	2	2				1
			5	1	1			1	
			4	1	2		1		
		3	(A)	1	(A)		21		
		5	5	1	1			1	
			5	1	2			1	
			5	3	2			1	
	4	1	5	1	2				1
			5	3	2			1	
			2	1	1		1		
			1	2	1				1
		2	4	1	1			1	
			5	1	1			1	
			1	1	1		1		
			2	1	1		1		
		3	1	1	1		1		
			2	1	1		1		
			3	2	2				1
			3	1	1				2

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TABLE 2 (Continued)

Phase 1   Gunner Errors

Sight	Group	Subject	Range	Aspect	Speed	Half Stadia	Full Stadia	Out of Range	Outlier
5	4	4	5	1	1				1
		5	2	1	2		1		
			4	1	2		1		

(A) Gunner number 3 in group 2 positioned all head-on targets in the full stadia.

(B) Gunner number 5 in group 1 used the far target aim-point for most of the near targets (Range 1).

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TABLE 3

Phase II   Gunner Errors

Sight	Group	Subject	Range	Speed	Out of Range	Outlier
1	3	1	2	1		1
			2	2		2
			4	1		1
			4	1	1	
			4	2		1
			5	1	3	
			5	2	2	
			5	3	1	
		2	1	2		1
		3	1	2		2
			4	2		1
			5	1	1	
			5	2	2	
		4	1	(A)		12
			5	3		1
		5	2	2		2
			3	3		2
			4	1		1
			4	2		1
			4	2	1	
			5	1	1	2
			5	2	2	
	4	2	1	(A)		9
			3	1		1
			5	1	2	
			5	2	2	
		3	4	3	1	
			5	1	1	
			5	2	1	
			5	3	1	
		4	2	2		1
			3	3		1
			5	1	1	
		5	4	2		1
			4	3	1	
			5	2	1	
			5	3	1	
2	3	2	5	1		1

Sight	Group	Subject	Range	Speed	Out of Range	Outlier
3	3					
		1	4	2		1
		2	1	(B)		3
		3	4	2		1
		4	1	2		1
		5	1	3	1	
	4	1				
		2	1	(B)		3
			2	(B)		3
			3	(B)		1
		3	1	1		3
			1	2		1
			4	3		1
			4	3		1
		5				
4	3	1	1	2		3
			2	2		1
			3	1		1
		3	4	2		1
			5	2	1	
		4	2	3		1
		5	1	2		1
			5	3		1
			5	3		1

TABLE 3 (Continued)

Phase II   Gunner Errors

Sight	Group	Subject	Range	Speed	Out of Range	Outlier
5	3	1	1	1		2
			1	2		2
		3	1	1		1
			5	1		1
		4	1	1		2
			1	2		2
			3	1		2
		5	4	3		1
	4	1	1	2		1
		3	1	1		2
			2	3		1
			3	1	2	
			3	3		1
			4	1	1	
			4	2	1	
			4	2		1
			5	1	4	
		5	1	2		1

Note: Sight 2 - Group 3 contains only 2 gunners. Data for Group 4 are listed under Phase I Sight 5.

(A)   Gunner used far-target aim point for near target.

(B)   Gunner used boresight cross as aim point for near target.

The ranging method assumed by stadia-sight designers differs from the one actually used by the gunners, causing the sights to underestimate range and superelevation. Army doctrine on the use of length/width-stadia rangefinding sights states that the gunner, when ranging, should touch the ends of the target to the stadia lines, as was done in the experiment. However, the reticle design references the target dimensions to the centers, rather than the edges, of the stadia (Appendix E), and thus assumes that the gunner fits the target there. The resulting superelevation error varies depending on the stadia lines' thickness and slope, for a nominal target size in mils at a given range. The two methods of placing a target in the stadia lines, and the resulting differences in superelevation are depicted in Figure 12 for for half- and full-stadia ranging.

The stadia-line thickness of the four length/width stadia sights used in Phase I varied from 0.3 to 2.63 mils between sights. Table 4 shows the sight superelevation using the two ranging methods for the three target aspects and five ranges used in the experiment. The table shows that the superelevation error is larger for half-stadia versus full-stadia ranging. For sight 2, which has a reduced muzzle velocity (475 versus 1200 fps) and steeper slope at a given range, the error is greatest.

Table 4 was obtained using the vertical measurements of the stadia thickness at a nominal target range, then using the method of least squares to fit functions of the form $Y=AX^B$ to the reticle measurement data from Appendix E, and the true target size, 3.63 meters wide by 6.95 meters long. Superelevation (Y) for placing the target in the centers of the stadia lines was obtained using the target size in mils (X) at a given range in the formula. Then, by subtracting the vertical distance from the center to the edge of the stadia line ($\Delta Y = .5$ times stadia width/cosine (slope of stadia line)), we closely approximated the superelevation for placing the target at the inside edges of the stadia lines (method 1 in Fig. 12) for full-stadia ranging. A similar approach was used for half-stadia ranging, but with half of the stadia width added to the nominal target size in mils.[6]

The reduction in sight superelevation due to the stadia-line thickness is equivalent to having a sight with different characteristics than originally intended. This sight can be regarded as either a sight designed for a higher muzzle velocity, or one with a reduced stadia slope for a given target range. Since the sights have different stadia-line thicknesses, , their characteristics are also different. This is most evident in sight 4's superelevations, which are less than for sights 3 and 5 even if the target is placed in the centers of the stadia lines.

Even after having accounted for this source of bias, reduced superelevations were still evident, with the non-optical sights giving the greatest reduction in superelevation. At first, the reduced superelevations for the non-optical stadia sights were thought to be caused by a focus problem—a target that appeared fuzzy at the edges might cause the gunner to overestimate its width, and thereby underestimate its range. The size of the biases, however, appeared too large to be explained by only this source. The discovery that the sight radius for the stadia lines in the M72 sight is in error by about 5 percent.

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[6]The stadia half-width was not added to the nominal target size for sight 4 since, when the gunners used this sight against head-on targets, they were told to split the stadia centerline with one edge of the target.

Target Placement Assumed by:
1. Army Doctrine
2. Designer
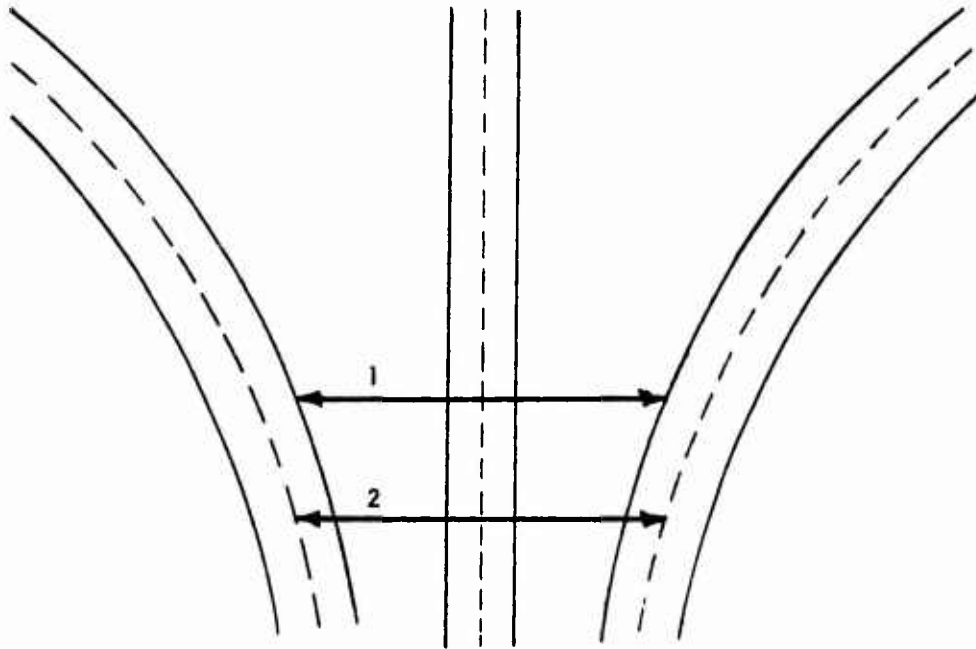
Full Stadia Ranging (Side-on Target)
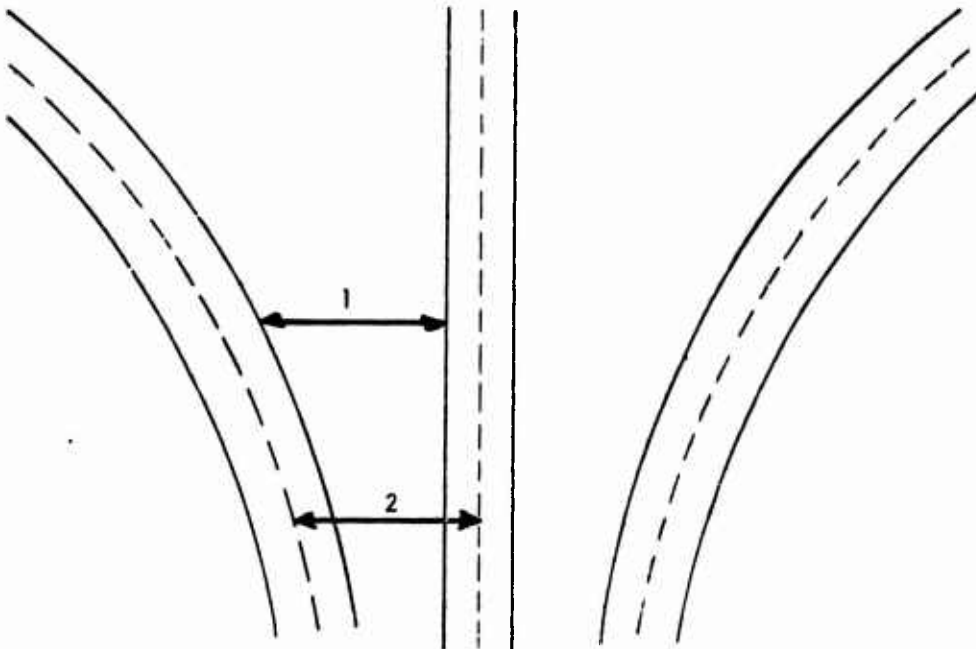
Half Stadia Ranging (Head-on Targets)

Fig. 12. Stadia ranging error due to stadia thickness and ranging methods.

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TABLE 4

Sight Superelevation for Two Stadia-Ranging Methods

Sight Number		2		3		4		5	
Stadia Line Thickness (Mils)		.46		.3		2.63		.48	
Ranging Method		Center	Edge	Center	Edge	Center	Edge	Center	Edge
Aspect (Degrees)	Range (Meters)								
0	130	29.94	29.26	5.06	4.88	5.10	3.75	5.08	4.79
	210	54.57	52.75	9.09	8.82	8.95	7.41	9.14	8.70
	290	81.73	78.03	13.47	13.03	13.08	11.00	13.56	12.86
	370	110.86	104.52	18.13	17.43	17.41	14.37	18.27	17.16
	450	141.64	131.83	23.01	21.97	21.91	17.51	23.21	21.54
62.4	130	27.20	26.85	4.61	4.46	4.66	3.32	4.63	4.38
	210	49.57	48.77	8.27	8.10	8.18	6.70	8.32	8.04
	290	74.24	72.64	12.26	12.04	11.95	10.05	12.34	11.98
	370	100.70	97.95	16.50	16.18	15.91	13.24	16.63	16.11
	450	128.65	124.39	20.95	20.49	20.02	16.23	21.13	20.38
90	130	31.62	31.21	5.34	5.19	5.37	4.01	5.36	5.11
	210	57.63	56.60	9.58	9.40	9.42	7.84	9.64	9.34
	290	86.32	84.23	14.20	13.94	13.76	11.56	14.30	13.88
	370	117.09	113.49	19.12	18.72	18.32	15.04	19.27	18.62
	450	149.59	144.01	24.27	23.67	23.06	18.26	24.48	23.52

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(c) Rangefinding Bias Due to Improper M72 Stadia-Sight Radius

When using the M72, a gunner, especially an experienced one, places his eye far enough behind the sight peep to avoid eye injury during the weapon's recoil. Figure 13 shows the relative position of the front sight reticle, the rear peep in its housing, and the gunner's eye. The peep is not an image-forming device, but merely limits placement of the eye in relation to the front sight reticle and target, to minimize parallax. Nevertheless, the eye's position in relation to the peep changes the size of the front sight reticle which is interposed between the eye and the target.

If a gunner uses an unaided visual-range estimation procedure and, as in Figure 14, sets the appropriate range line on the target, the sight radius of 19.78 inches is correct. But if the gunner ranges to the target using the stadia lines, as in Figure 15, the true sight radius is the distance from the front sight reticle to the gunner's eye—21 inches—rather than the 19.78 inches assumed in designing the stadia lines. This sight-radius error, of about 5 percent, causes the gunner to make an equivalent underestimation of range.

Figure 16 shows the M72 sight's range-estimation biases attributable to the sight-radius error and the stadia-line thickness for half- and full-stadia ranging. Table 5 shows how these biases affect hit probability, as computed by AMSAA, for gunner range estimation 1-sigma errors of 20 and 10 percent of range.

Sight design accounted for only part of the reduced superelevations. Differences between superelevations recorded for the three target aspects, which deviated from those that were predicted (based on the analysis of Appendix A), led to the formulations of some further hypotheses to explain the remaining biases. These hypotheses are discussed in Appendix L.
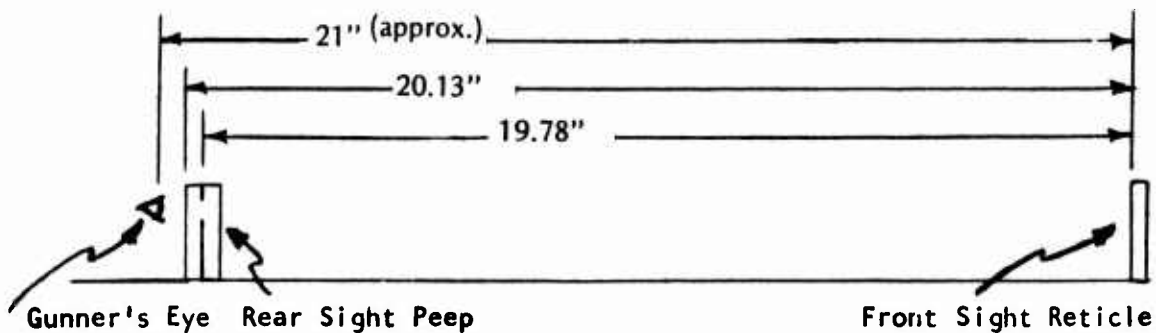
Fig. 13. M72 sight dimensions and approximate positioning of the gunner's eye.
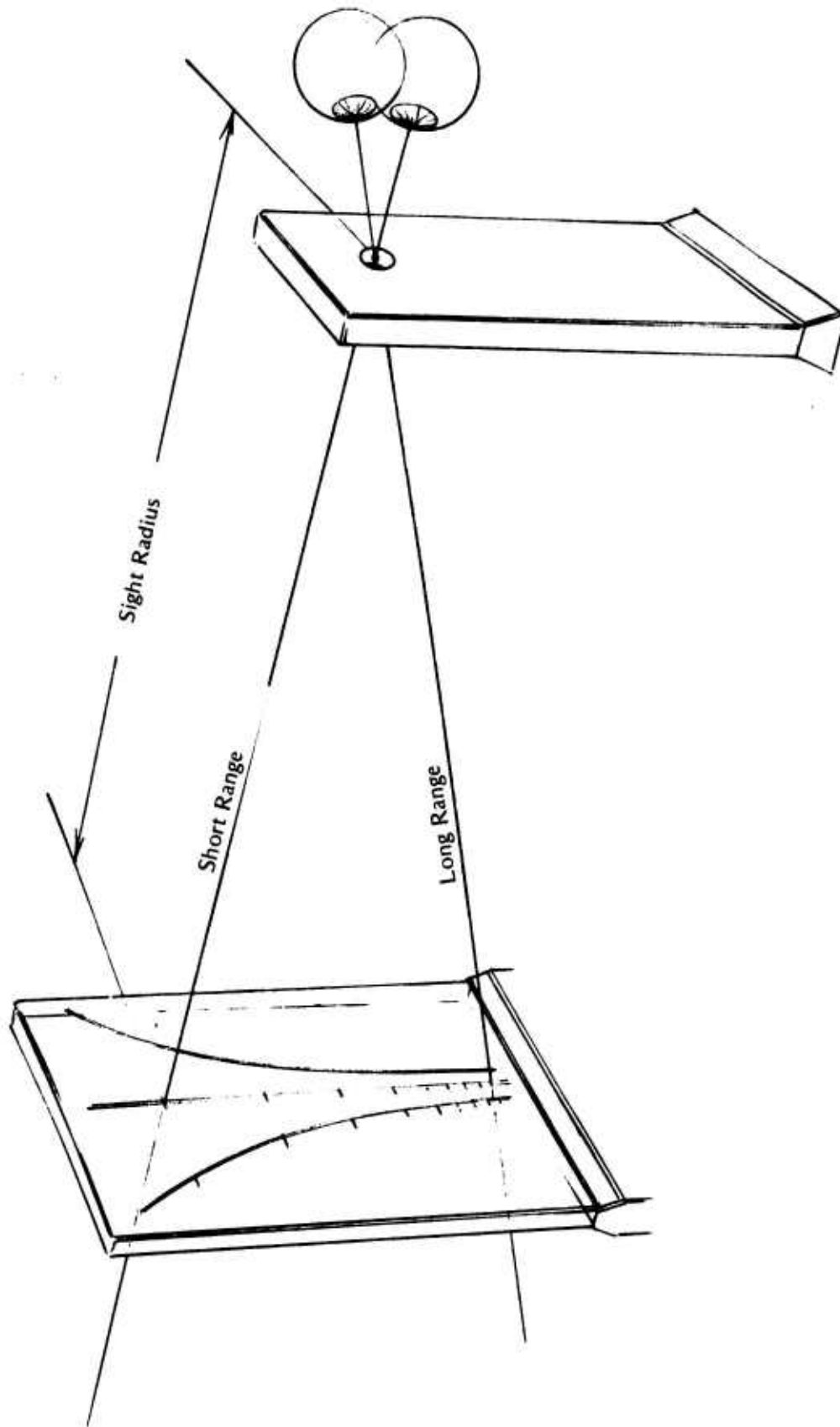
Fig. 14. M72 sight radius for the reticle range markings.
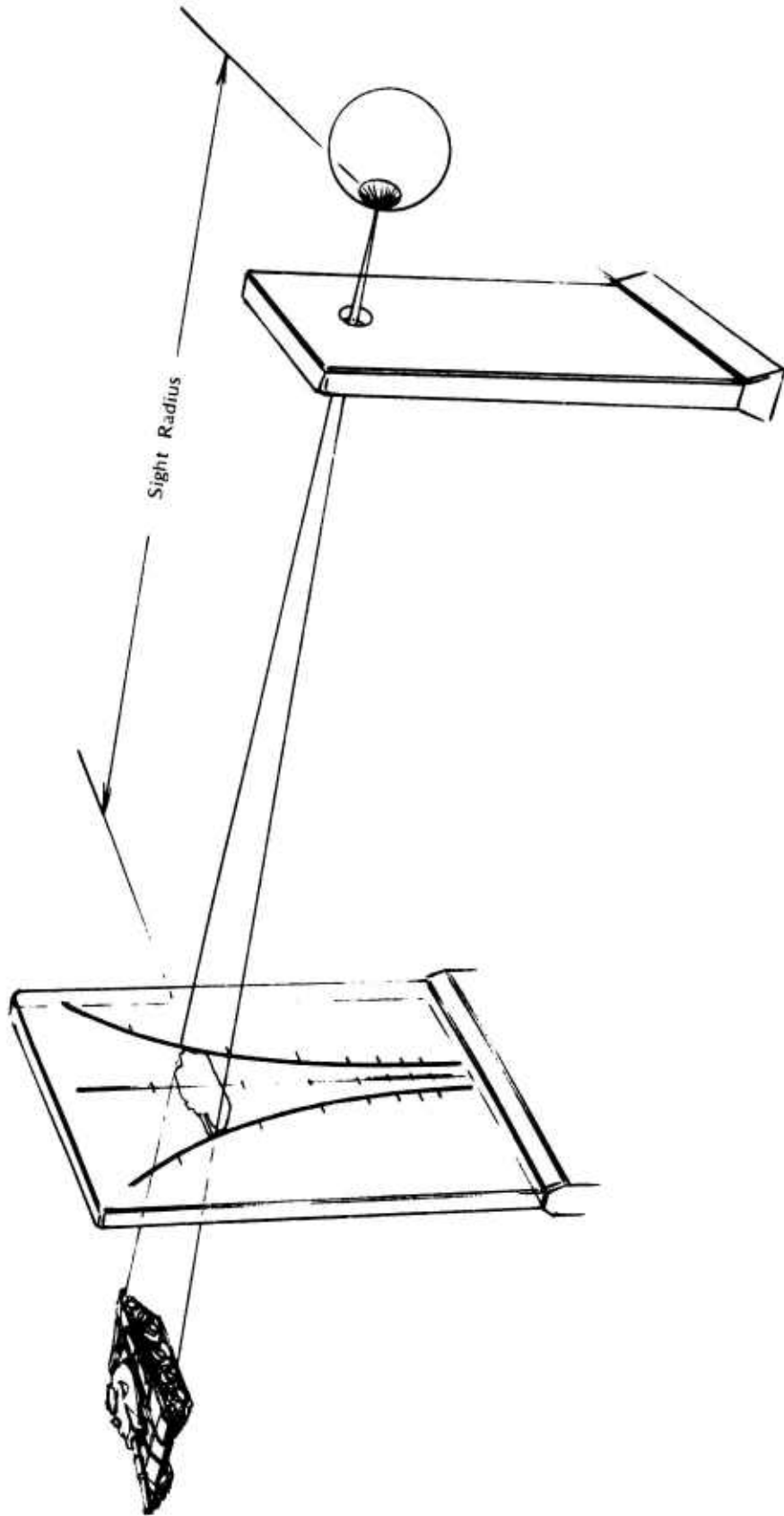
Fig. 15. M72 sight radius for the reticle stadia lines.

Sight Radius
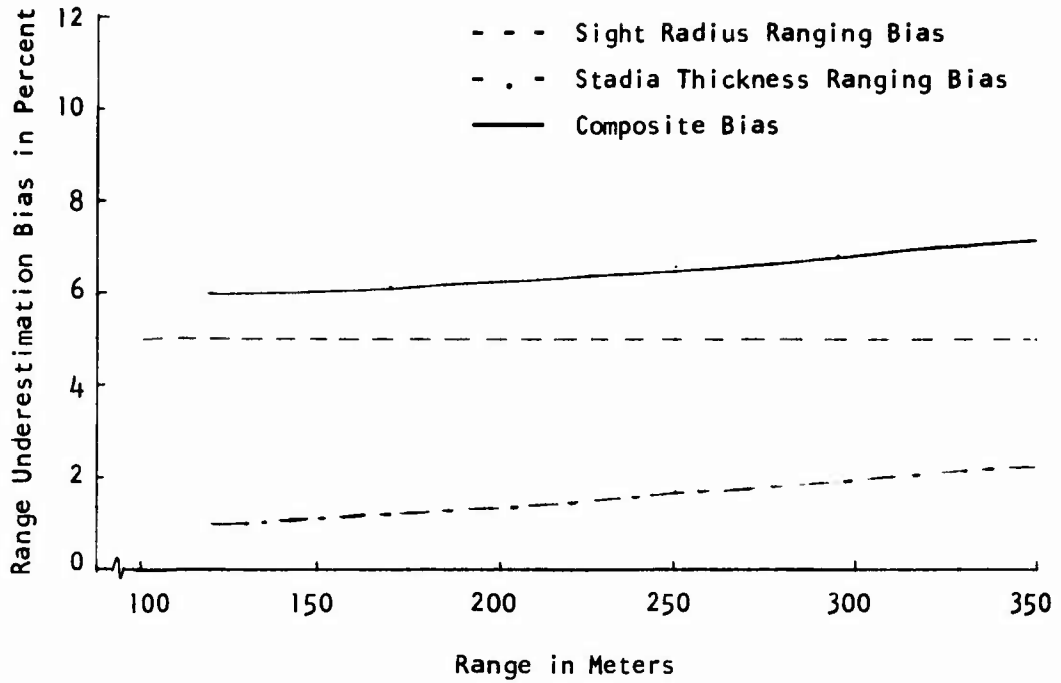
Ranging Bias for Full Stadia Ranging (Side-on Target)
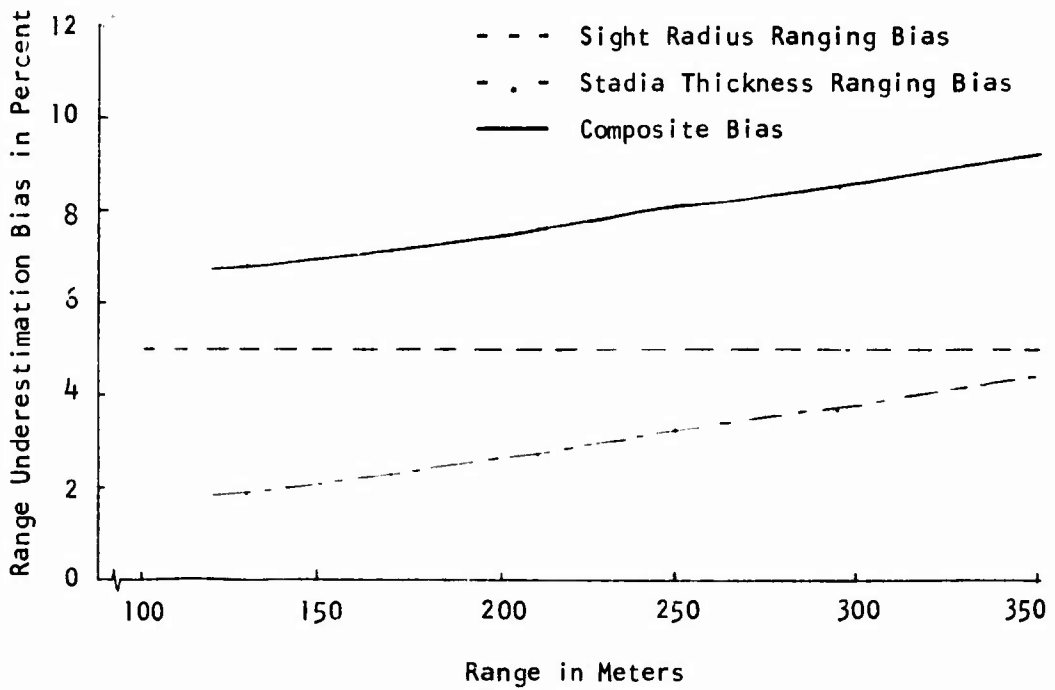
Ranging Bias for Half Stadia Ranging (Head-on Target)

Fig. 16. M72 sight range-underestimation biases for head-on and side-on targets.

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TABLE 5

Effect on Predicted Hit Probability of M72 Sight Range Underestimation Biases.

BIAS	Head-On (7-1/2 ft. Square Target)				Side-On (7-1/2 x 15 ft. Target)			
	0	Stadia Thickness	Sight Radius	Composite	0	Stadia Thickness	Sight Radius	Composite
Range (Meters)	---------- Hit Probability ----------				---------- Hit Probability ----------			
150	.58	.58	.57	.56	.60	.60	.59	.59
200	.27	.27	.27	.26	.34	.34	.33	.27
250	.13	.13	.13	.12	.19	.19	.19	.18
300	.06	.06	.06	.06	.10	.10	.10	.10
350	.03	.03	.03	.03	.06	.06	.05	.05

TABLE 5 (Cont)

Effect on Predicted Hit Probability of M72 Sight Range Underestimation Biases

	Head-On (7-1/2 ft. Square Target)			Side-On (7-1/2 x 15 ft. Target)		
BIAS	0	Stadia Thickness	Sight Radius	Composite	0	Stadia Thickness	Sight Radius	Composite
Range (Meters)	-------- Hit Probability --------			-------- Hit Probability --------		
150	.80	.80	.78	.75	.84	.83	.81	.79
200	.48	.47	.44	.40	.59	.58	.54	.52
250	.23	.22	.21	.18	.35	.35	.32	.30
300	.12	.11	.11	.09	.20	.19	.18	.16
350	.06	.06	.05	.04	.11	.11	.10	.09

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(d) Design Errors in Sights Tested in Phase II

Superelevations for four of the sights tested in Phase II also contained biases. These errors were directly attributable to the design of the sights.

Examination of the reticle-measurement data (Appendix E) provided by the designer, Frankford Arsenal, revealed that the turret stadia sight and the ART sights were designed incorrectly. The turret-stadia design assumed too small a turret, thus shifting the crossover range between QE's, but without seriously affecting the performance analysis of this sight. For the ART sights, the ballistic cams were designed to produce only one-third of the required superelevation; thus it was necessary to use extrapolated data in analyzing the performance of the ART sights. The effects of these errors are discussed fully in the Results section for each of the sights.

Phase I Superelevations

(1) Gunner's Unaided Range-Estimation Ability

The subjects' range-estimation errors in the training exercise, expressed as a percentage of true range, are given in Table 6. As shown, the RMS errors for each group are near the generally accepted value of 21 percent of range (9), and there is only a small mean range-estimation bias of 1 to 2 percent.

In Phase I, when the subjects used the rifle sights, they classified target ranges as near, mid, or far (0-300, 300-400, or 400-500 meters). Table 7 summarizes their judgments by target speed and range. As table 7 shows, the range-classification frequencies for the two groups of subjects are similar; at the three closest target ranges, they are almost identical. Therefore, the percentage of observations in each range class were averaged for the two groups of subjects (Figure 17).

Let us assume that range-estimation error is, as in previous studies, approximately normally distributed about the true range, with a standard deviation of 21 percent of range. We can then compute the probability that a gunner will estimate a range as near, mid, or far, as a function of target range. These predicted values are also shown in Figure 17.

A comparison of the observed and predicted values in Figure 17 shows that the subjects classified an inordinately large percentage of "near" targets as "mid" —this is, the subjects overestimated short target ranges.

The initial predictive-model parameter values—300- and 400-meter crossover ranges between range classifications, and 21 percent range-estimation error—were varied to obtain values that would fit the data better. Crossover ranges of 225[7] and 400 meters, with a range-estimation error between 18 and 21 percent, gave reasonable agreement with the measured frequencies, except at the 450-meter range. At 450 meters, the predicted frequencies were closer to the measurements for the first group of subjects than those for the second group of subjects. Table 8 lists the frequencies predicted from these modified parameter values.

(2) Rifle-Sight Vertical Aiming Error

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[7] This crossover range was extrapolated from the data in Figure 17.

TABLE 6

Gunner's Range-Estimation Errors in the Phase I Training Exercise

True Range in Meters		184	240	303	371	600	Average Over All Ranges
Group	Subject	– – – – Range Estimation Error as a Percent of Range – – – –					
1	1	-24	- 6	- 1	-22	+33	
	2	+25	- 4	-11	-27	-24	
	3	+25	+25	+32	-33	-25	
	4	+20	+ 8	+16	-39	-25	
	5	+ 9	-27	+48	+ 8	-17	
	Mean	+11	- 1	+17	-23	-12	- 1
	RMS	+21	+17	+27	+28	+25	+24
2	1	+17	+19	+ 7	-24	+13	
	2	+17	- 4	+40	+ 1	-14	
	3	-18	-17	- 4	-10	-37	
	4	-27	+25	+32	-19	-33	
	5	+30	-27	+ 7	-15	-17	
	Mean	+ 4	- 1	+16	-14	-18	- 2
	RMS	+22	+20	+24	+16	+25	+22
	Combined Mean	- 4	- 1	+17	-18	-14	- 2
	Combined RMS	+22	+19	+26	+23	+25	+23

TABLE 7

Gunner's Estimate of Target-Range Classification When Using the Rifle Sights (Phase I, Sight I)

Target Range (Meters)			130			210			290			370			450		
Range Class			N	M	F	N	M	F	N	M	F	N	M	F	N	M	F
Group	Subject	Speed	Number of Observations in Each Range Class														
1	1	0	6	0	0	6	0	0	3	4	0	0	4	4	0	1	4
1	1	7	5	1	0	6	0	0	2	4	0	1	4	1	0	2	4
1	2	0	7	0	0	4	1	0	0	3	3	0	4	2	1	1	3
1	2	7	7	0	0	5	1	0	0	6	0	0	1	5	0	0	5
1	3	0	6	0	0	5	0	0	1	5	0	0	6	1	0	1	5
1	3	7	6	0	0	6	0	0	0	6	0	0	5	2	0	1	5
1	4	0	5	0	0	2	3	0	0	5	0	0	6	0	0	2	3
1	4	7	6	0	0	3	3	0	0	7	0	0	5	1	0	4	2
1	5	0	7	0	0	0	5	0	0	6	0	0	7	0	0	1	5
1	5	7	6	0	0	0	9	0	0	6	0	0	6	0	0	0	6
2	1	0	6	0	0	1	4	1	1	6	0	0	5	1	0	2	4
2	1	7	8	0	0	3	3	0	0	6	0	0	4	3	0	0	6
2	2	0	6	0	0	6	0	0	1	6	0	0	5	1	0	2	4
2	2	7	6	0	0	6	0	0	0	5	1	0	4	3	0	0	5
2	3	0	6	0	0	2	4	0	0	6	0	0	2	4	1	0	5
2	3	7	6	0	0	2	4	0	0	5	1	0	4	3	0	0	5
2	4	0	6	0	0	4	2	0	1	5	0	0	4	2	0	2	4
2	4	7	6	0	0	4	1	1	3	3	1	2	2	3	0	1	4
2	5	0	6	0	0	4	2	0	1	6	0	0	6	1	1	0	5
2	5	7	6	0	0	4	2	0	1	5	0	0	3	3	0	0	6
Group I - Percent			98	2	0	63	37	0	10	85	5	2	73	25	2	23	75
Group II - Percent			100	0	0	62	35	3	11	84	5	8	54	38	4	10	86
Average - Percent			99	1	0	62	36	2	10	85	5	5	64	31	3	16	81

50
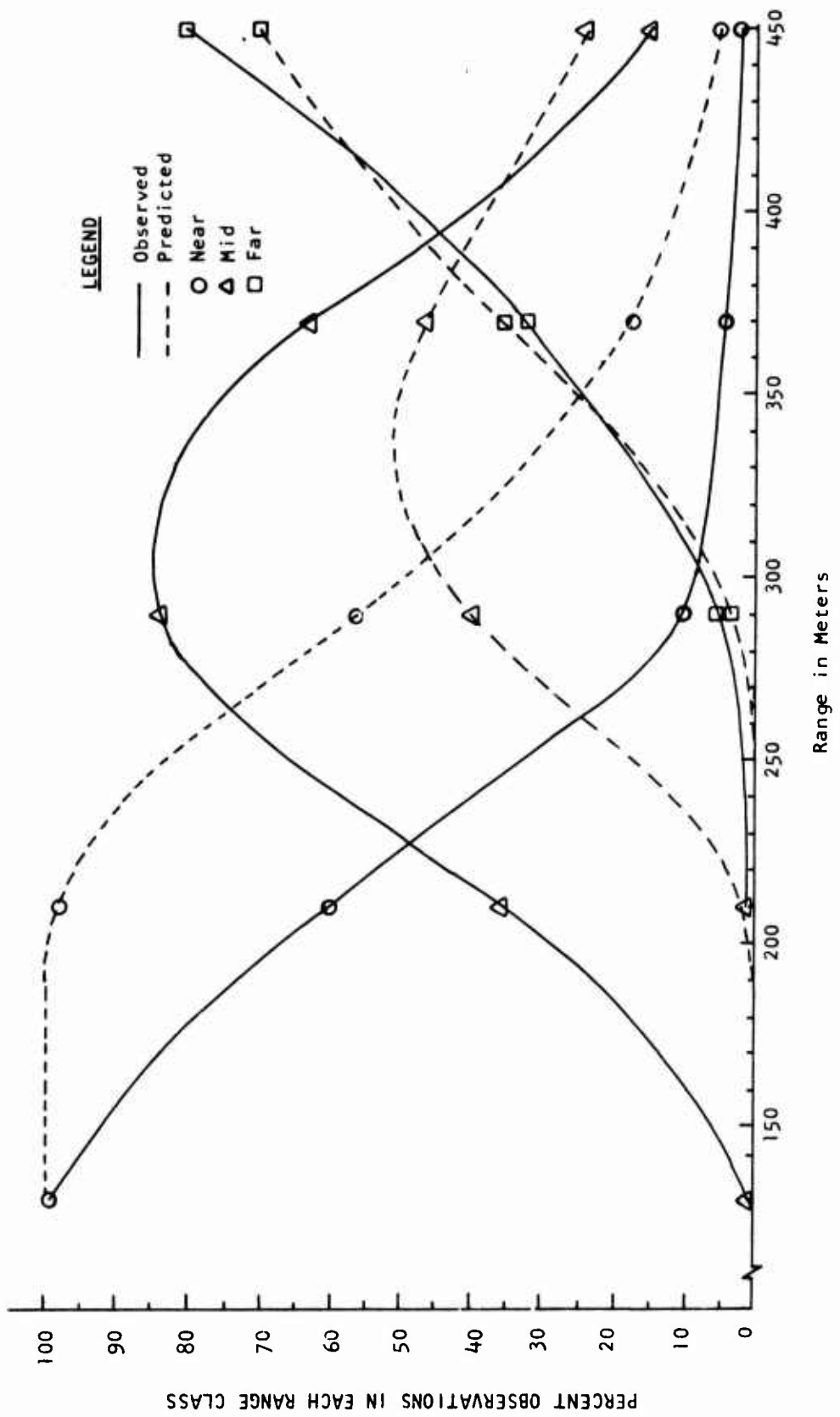
Fig. 17. Observed and predicted frequencies of target-range classification for gunners using the rifle sights (phase I, sight 1).

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TABLE 8

Predicted Percentages of Target-Range Classification for Crossover
Ranges of 225 Meters (near to mid range) and 400 Meters
(mid to far range)

| Actual Range (meters) | Assumed Range-Estimation Error | | | | | |
| | 18 Percent | | | 21 Percent | | |
	Near	Mid	Far	Near	Mid	Far
130	100	0	0	100	0	0
210	65	35	0	63	38	0
290	11	88	2	14	82	4
370	2	66	33	3	62	35
450	0	27	73	1	29	70

Figure 18 shows the variability of rifle-sight aiming errors in mils—vertical standard deviations (SDs)—for the two groups of subjects, by target aspect and at target speeds of 0 and 7 mph. Aiming errors for all target aspects are presented in Figure 19 by group and combined over groups for the three target aspects. These graphs show that (a) aiming error differs between the two groups of subjects: group 1 gunners are more accurate; (b) aiming error increases at faster target speeds; and (c) target aspect does not have any consistent effect on aiming error.

With all target aspects combined for stationary targets at longer ranges, groups 1 and 2 have respective aiming errors of approximate 1.0 mils and 1.4 mils; their average aiming error is 1.2 mils. Group 1's aiming errors are larger for 7-mph targets than for stationary targets; in group 2, there is no difference. For all groups combined, the average aiming errors for the 7- and 14-mph target speeds are 1.3 and 1.5 mils, respectively.

When a target's aim—point is not easy for gunners to identify—i.e., an aim-point one foot below the turret ring—it has been shown (10, 11)[8] that the aiming error for stationary targets is a decreasing function of range or of target size in mils. This effect is apparent here when aiming errors are summed for all targets aspects.

(3) The Effect of Target Aspect on Length/Width Stadia-Sight Range-finding Precision and Accuracy.

In this analysis, an "ideal" gunner is one who (1) does not make errors in selecting half- or full-stadia ranging, (2) correctly brackets the target image in the stadia, (3) has no cant angle between the stadia and the target, and (4) uses an infinitesimally thin stadia line.

When the target vehicle is head-on to the gunner (aspect equals zero degrees), the gunner uses half of the stadia for ranging (Figure 1). As the vehicle is turned from head-on, the apparent width is used for ranging until the apparent width and length are equal. At this aspect angle, the gunner switches to full-stadia ranging, using the end points of the target.

As the vehicle turns, the target dimension that is fitted in the stadia also changes. The percentage change in apparent target size causes corresponding changes in measured range. The change in target size, and the corresponding effect on the measured range, are shown in Figure 20 for a target with a length-to-width ratio of 2 to 1, at aspect angles from 0 to 90 degrees. For 90 to 180 degrees, the curve is a mirror image of the first one, and this entire curve is repeated between 180 to 360 degrees. This analysis, which is explained in detail in Appendix A, shows that the measured range can be in error by more than plus-or-minus 10 percent of the true target range. The average underestimation of the true range is 4 percent, and the average overestimation of the true range is 9.6 percent. The RMS error is 7.4 percent of range.

If the target has a reduced length-to-width ratio, designing the stadia to fit its averaged length and width (as was done for the sight reticles used in the experiment) would reduce the range-finding error due to target aspect; for a circular target, there would be no error. Results of the analysis, using the M60 tank with a 1.91-to-1 ratio, show the maximum range-estimation errors are near plus and minus 10 percent, with an average range-finding underestimation, overestimation, and RMS of 3.9, 5.9 and 6.3 percent of range, respectively.

These errrors define the upper limits of range-finding accuracy for length/width stadia sights. Adding the gunner's errors to the system will reduce both the precision and accuracy of range-finding. There will be further degradation from using the stadia against targets that differ from the one for which the stadia was designed.

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[8] Aiming errors in mils computed from hit probabilities in References 12 and 13 also show this effect.
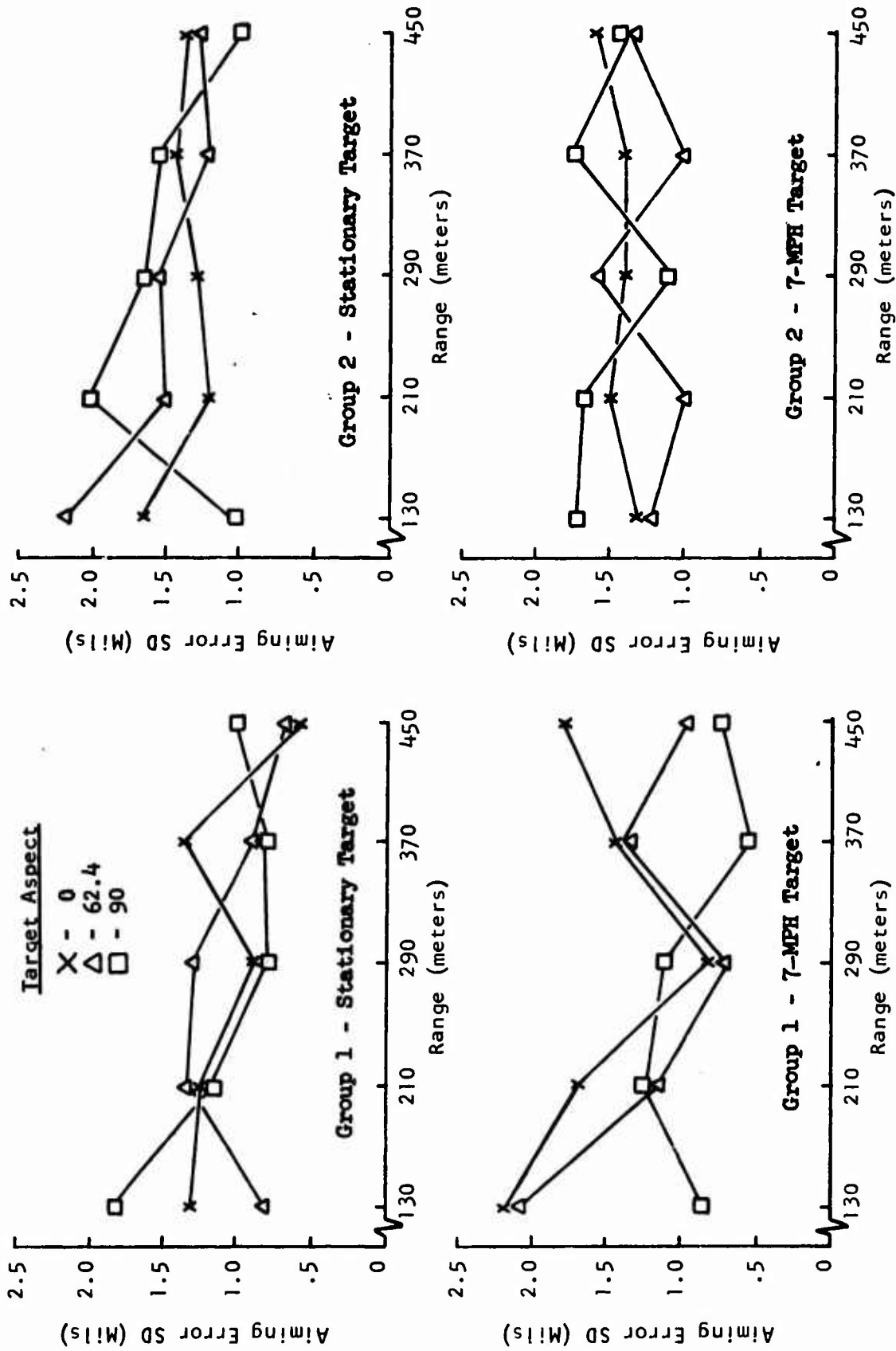
Fig. 18. Rifle-sight aiming error–standard deviations for two groups of subjects, with target speeds of 0 and 7 mph, and three target aspects.

54
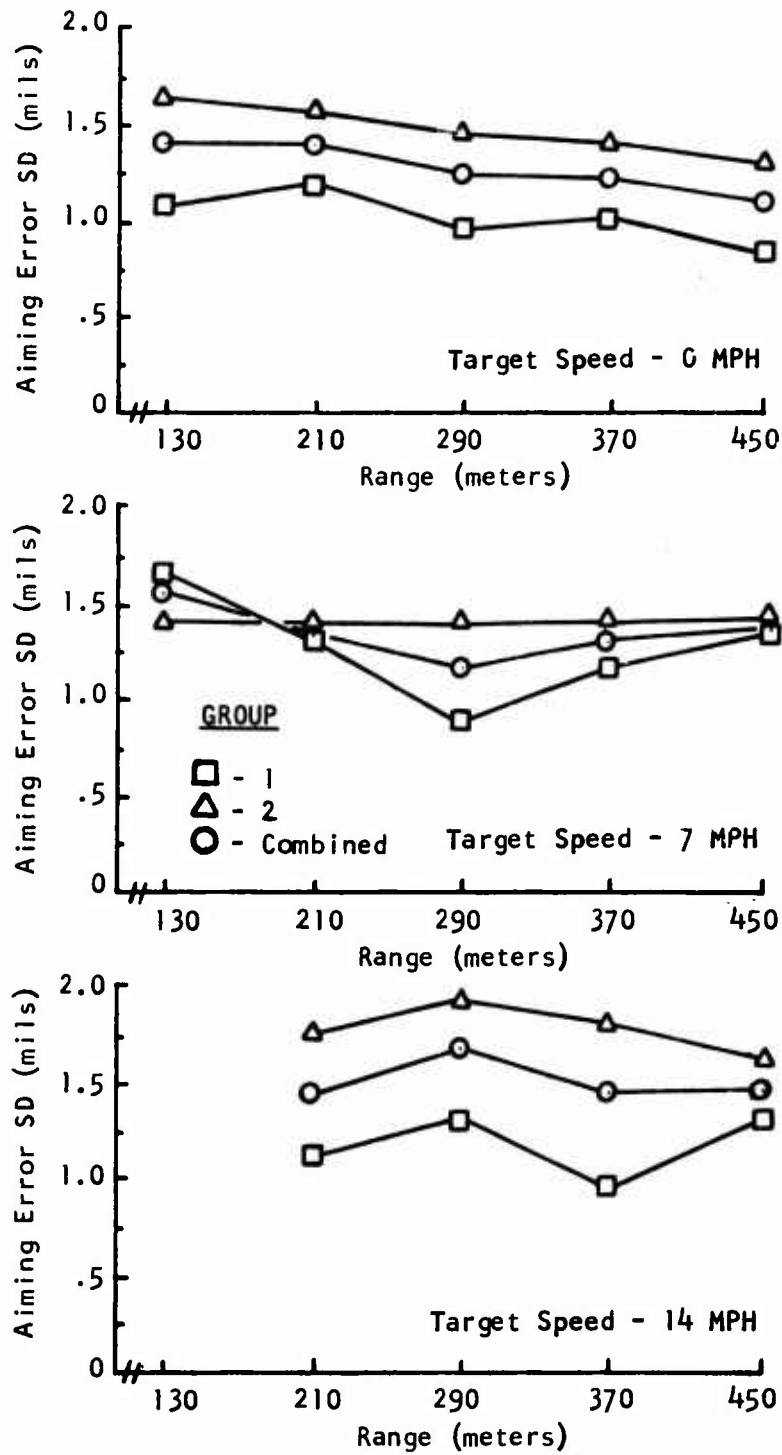
Fig. 19. Rifle-sight aiming error--standard deviations for all target
speeds, with data summed over target aspect.

55
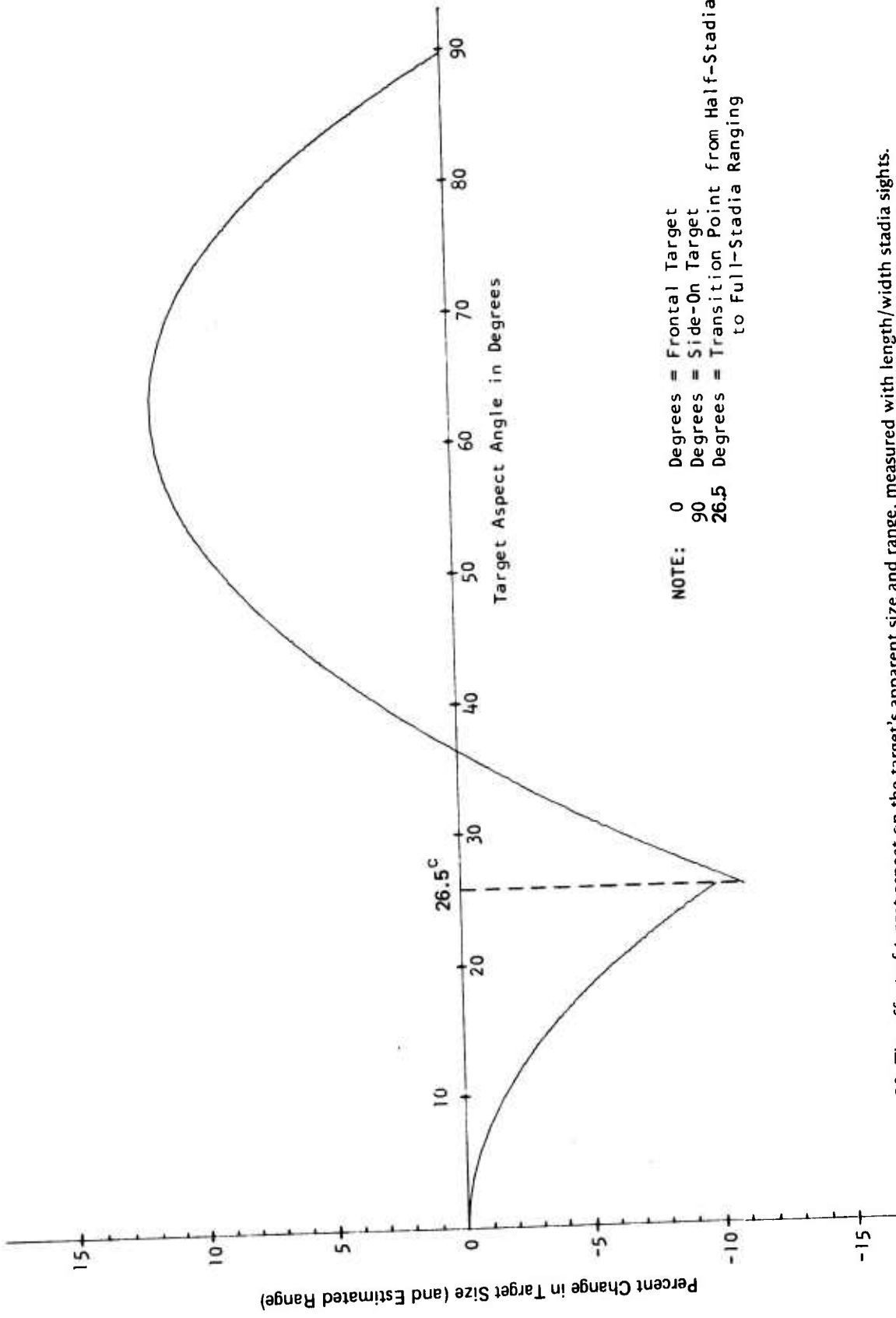
Fig. 20. The effect of target aspect on the target's apparent size and range, measured with length/width stadia sights. (Target's actual length is half its width; stadia reticle designed for same exact ratio.)

NOTE:
  0   Degrees = Frontal Target
  90 Degrees = Side-On Target
  26.5 Degrees = Transition Point from Half-Stadia to Full-Stadia Ranging

Target Aspect Angle in Degrees

Percent Change in Target Size (and Estimated Range)

(4) Sight Superelevations

(a) General

Sight-superelevation means and SDs, tabulated by target range, speed and aspect, are shown in Appendix G, Tables 1G through 6G. These data are summarized graphically for target speeds of 0 and 7 mph in Figures 21 through 38, and for target speeds of 14 mph in Figures 39 through 41. The differences between the predicted superelevations (Table 4) and measured superelevations (QE difference) are also shown in Figures 21 through 38. Since Table 4 does not account for the sight-radius error for the simple stadia sights, the QE difference for the M72 and modified M72 sights should increase with range.

Figures 21 through 24 and Figure 38 do not show any data for the M72 sight at the 130-meter target range; this is because the gunners judged the targets to be too close to use the stadia, and used the zero-range aim-point, which was outside the cameras' field of view. At the 450-meter range, the stadia lines are almost parallel, so it becomes difficult for gunners to judge whether the target is in or out of range for the stadia; therefore, the gunners considered almost all head-on targets to be in range, and most of the other targets to be out of range. Here the errors were smaller than at shorter ranges, probably because the gunners placed the targets at maximum range in the stadia. Had the stadia been extended to a greater range, the errors might have been much larger.

As shown in Figure 3, the minimum and maximum ranges for which there were stadia lines differed among the three-power, unity-power, and modified-M72 sights (respective minimum ranges are 110, 125, and 175 meters). As a result the three sights give different superelevations at 130 meters (Appendix G). When using the modified M72 sight at 130 meters, all the gunners judged (correctly) that targets were too close. With the three-power sight and the unity-power sight, only some targets were misjudged as too close. Since the gunners were instructed to fire using a zero-range aim-point for targets that were too close, these misjudgments inflated the superelevation SD s for ranges near the sights' minima.

As with the rifle sights, there are differences between the two groups of subjects, and group 1 gunners were more accurate.

(b) Superelevation Standard Deviations

As shown in Figures 21 through 40, the three-power optical sight is the most precise (lowest SD) for all but the 14-mph test conditions (where there are no differences). The non-optical sights are the least precise, and the M72 sight had the lowest precision. The performance of the non-optical sights was apparently degraded because the stadia lines—plated metal, rather than etched and filled lines—were difficult to see. Group 4 used an improved reticle for the modified M72 sight without showing any discernible improvement in performance.

The superelevation SD for all sights was larger for moving targets than for stationary targets, regardless of aspect. At the 14-mph target speed (Figures 39 through 41), the SDs were large enough to mask any differences between the 1200-fps weapon sights—except in group 2 where, at some ranges, the superelevation SDs for the unity-power sight were the largest. It should be remembered that the subjects did not apply sight lead to the moving targets; applying lead would increase the SDs for non-head-on moving targets.

The superelevation SDs for all sights were larger with half-stadia ranging (head-on targets) than with full-stadia ranging. This was probably because the gunner had to bracket a smaller target within the stadia lines, then shift the aim-point after ranging.

57
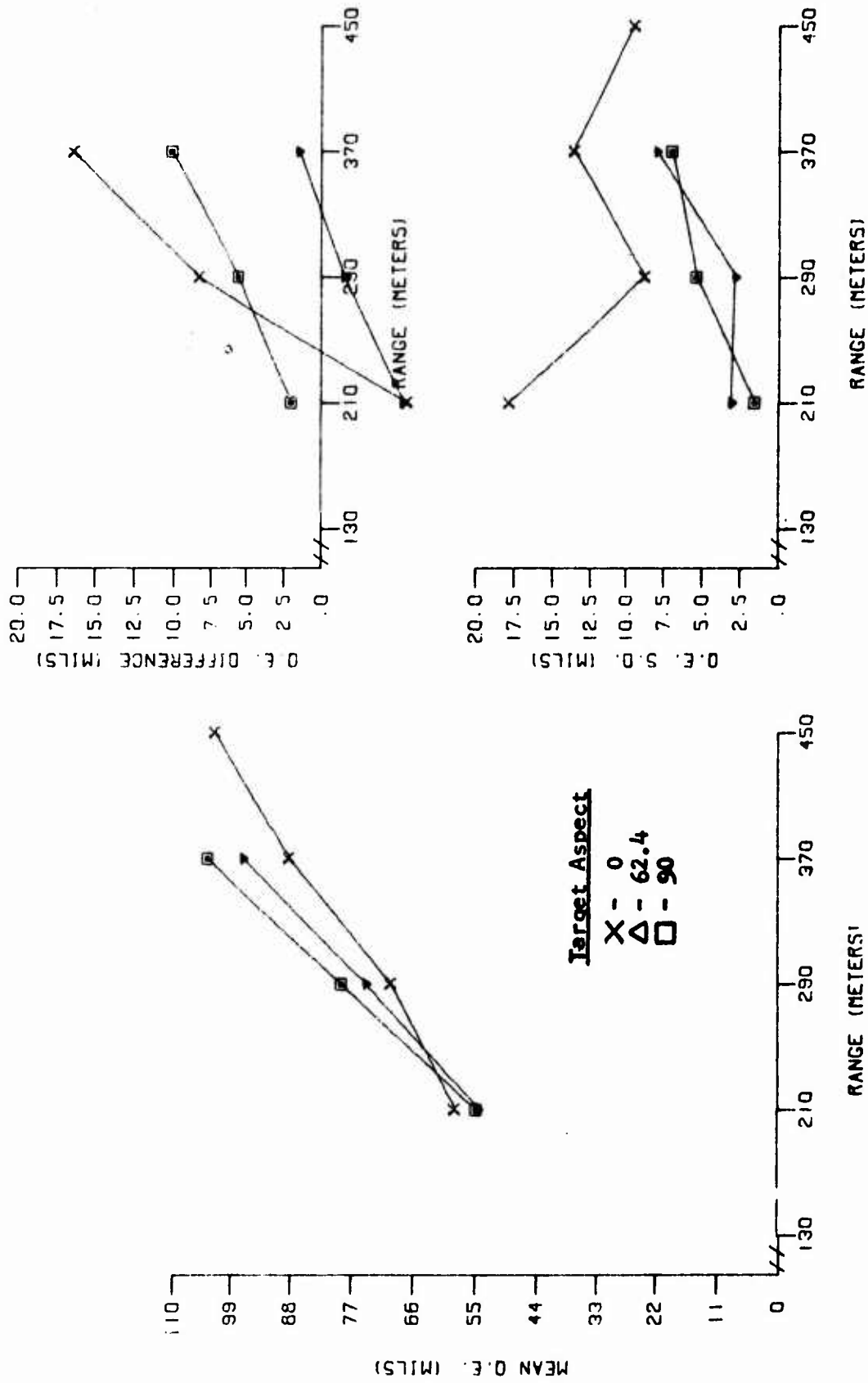
Fig. 21. M72 sight-superelevation data for three target aspects stationary targets, group 1.

58
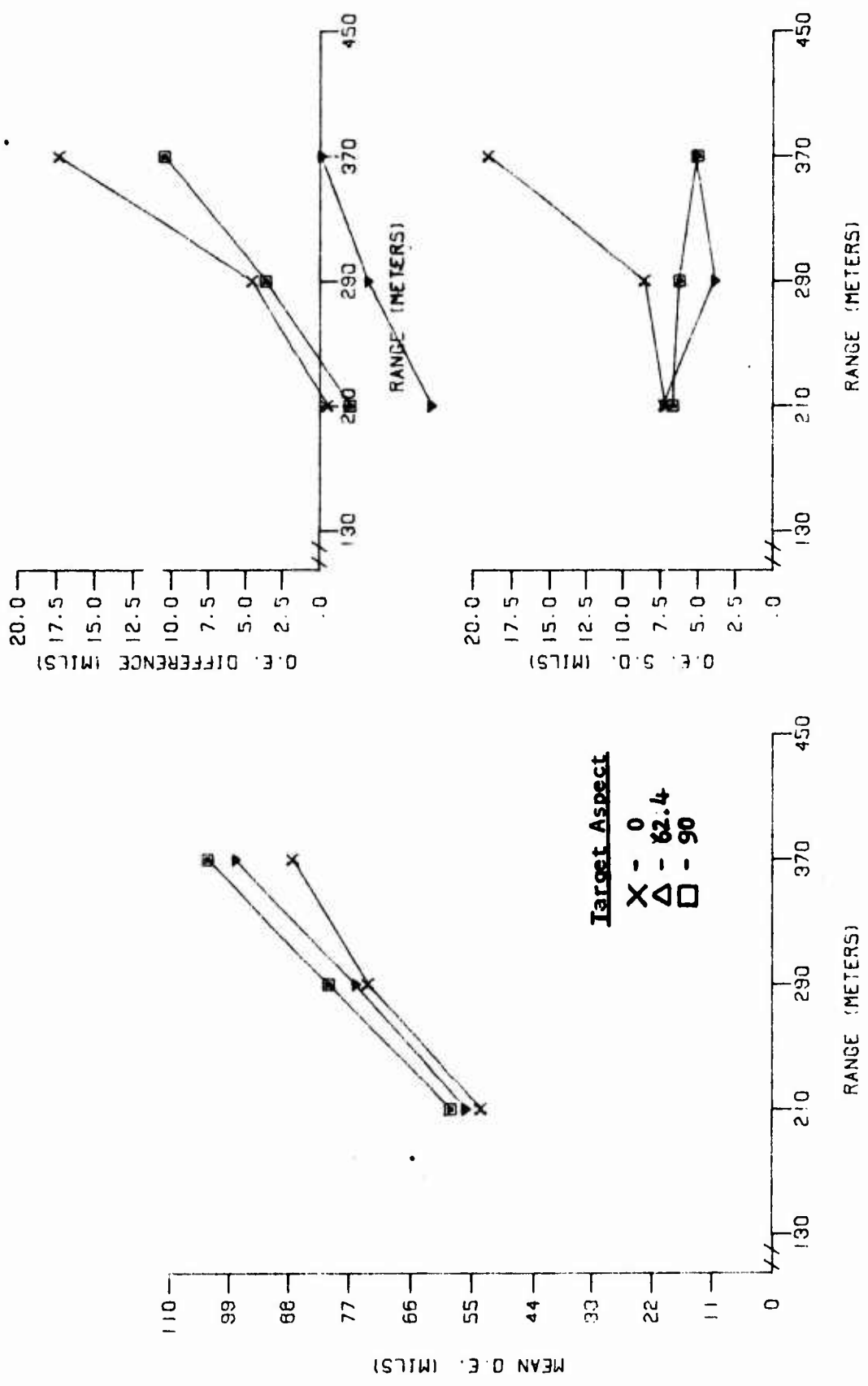
Fig. 22. M72 sight superelevation data for three target aspects stationary targets, group 2.

59
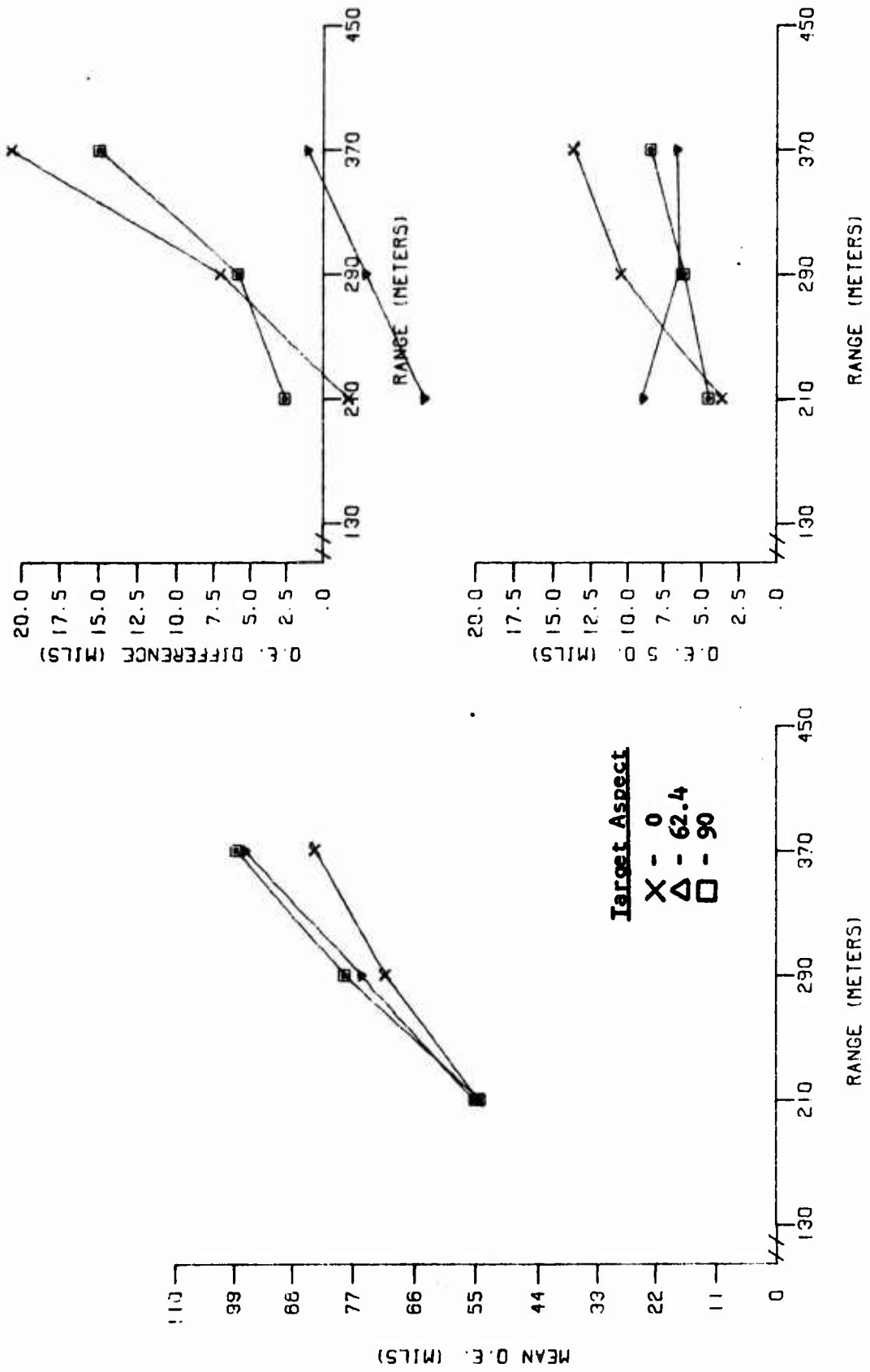
Fig. 23. M72 sight superelevation data for three target aspects 7-mph targets, group 1.
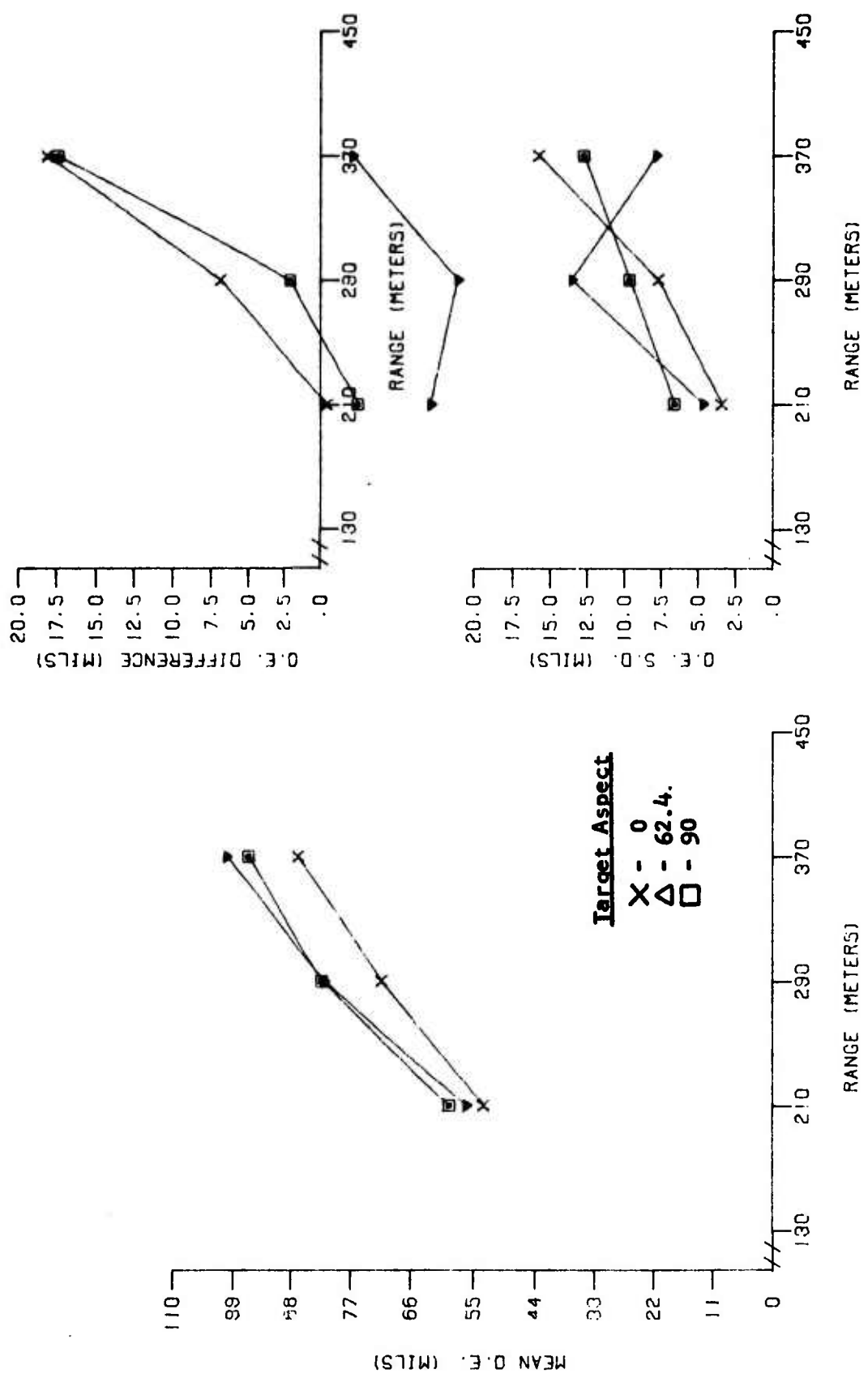
Fig. 24. M72 sight superelevation data for three target aspects 7-mph, group 2.

61
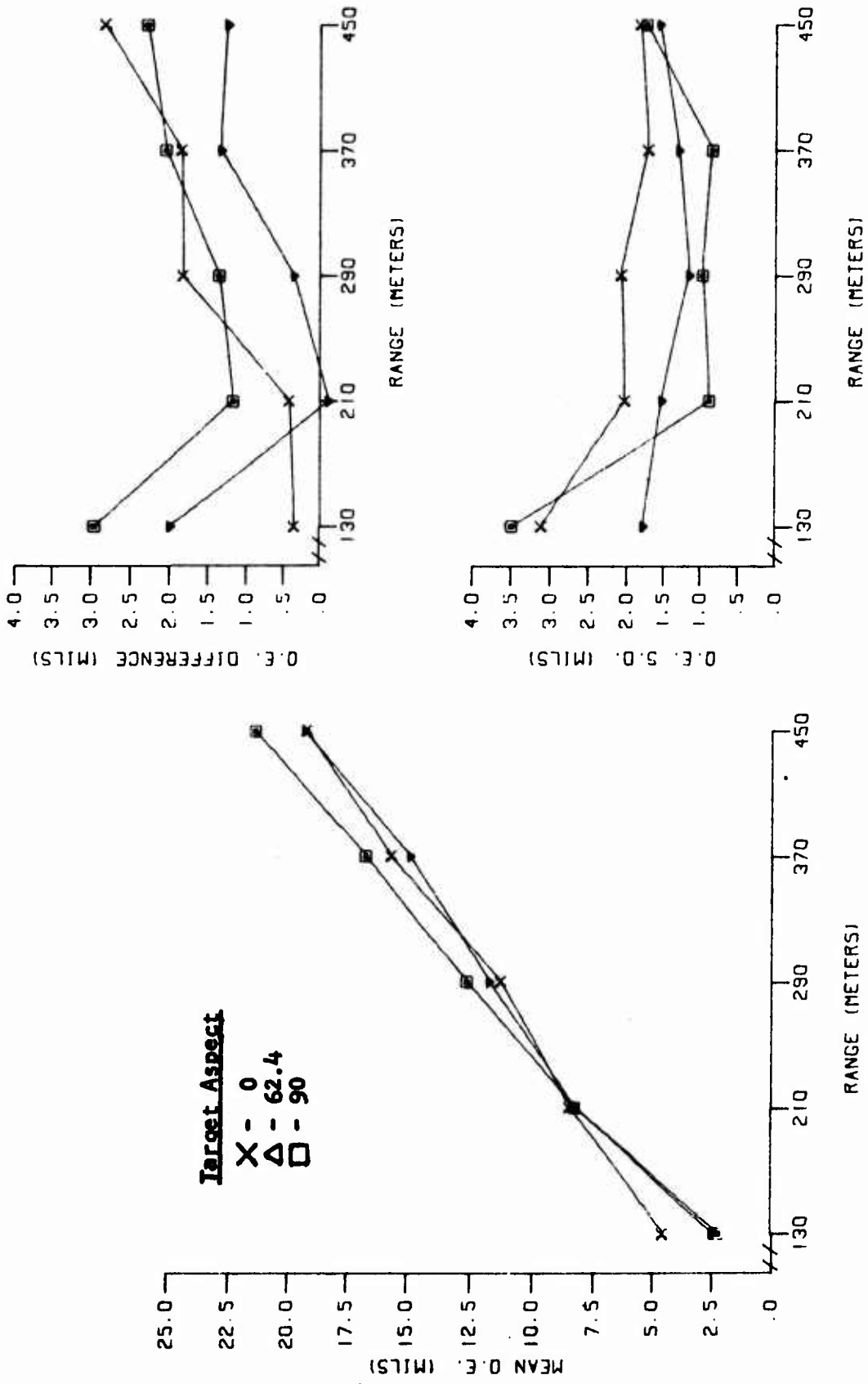
Fig. 25. Advanced LAW 3X sight superelevation data for three target aspects stationary targets, group 1.
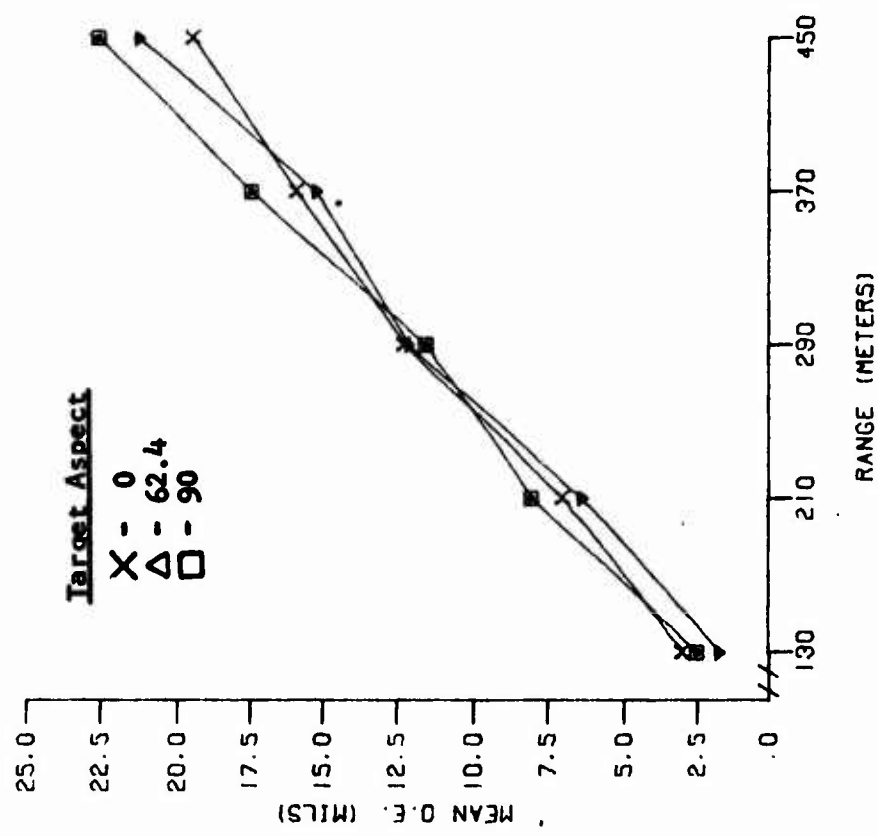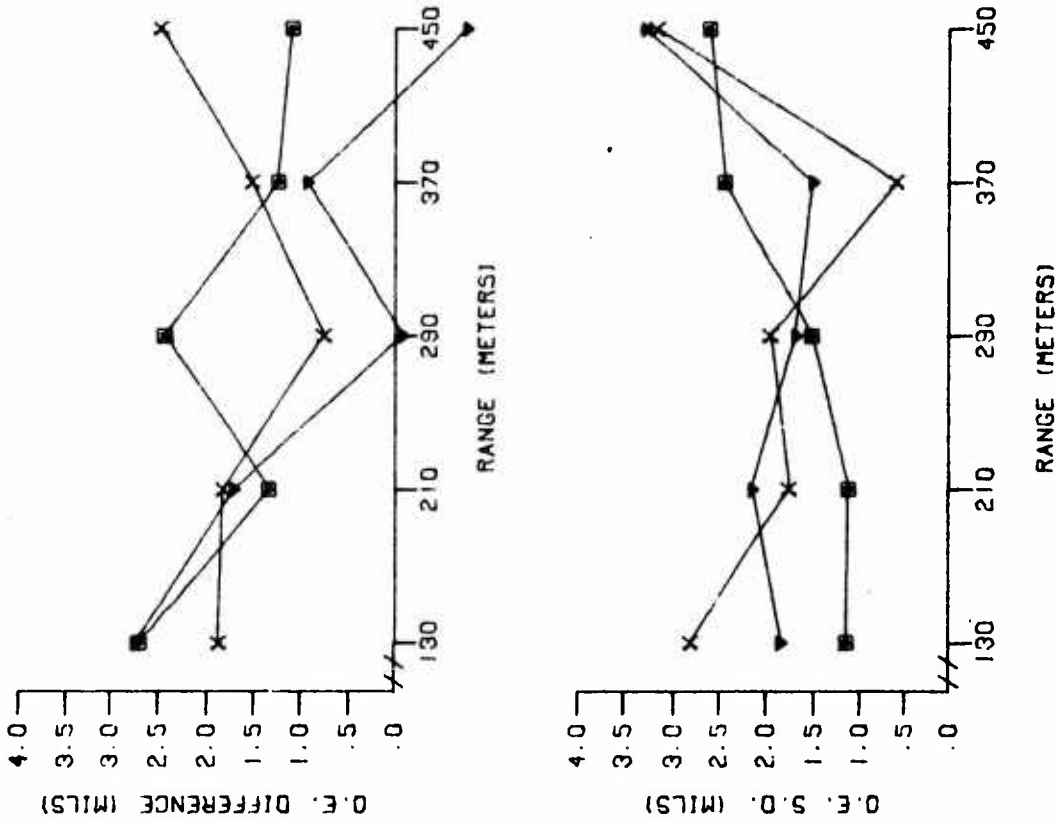
Fig. 26. Advanced LAW 3X sight superelevation data for three target aspects stationary targets, group 2.
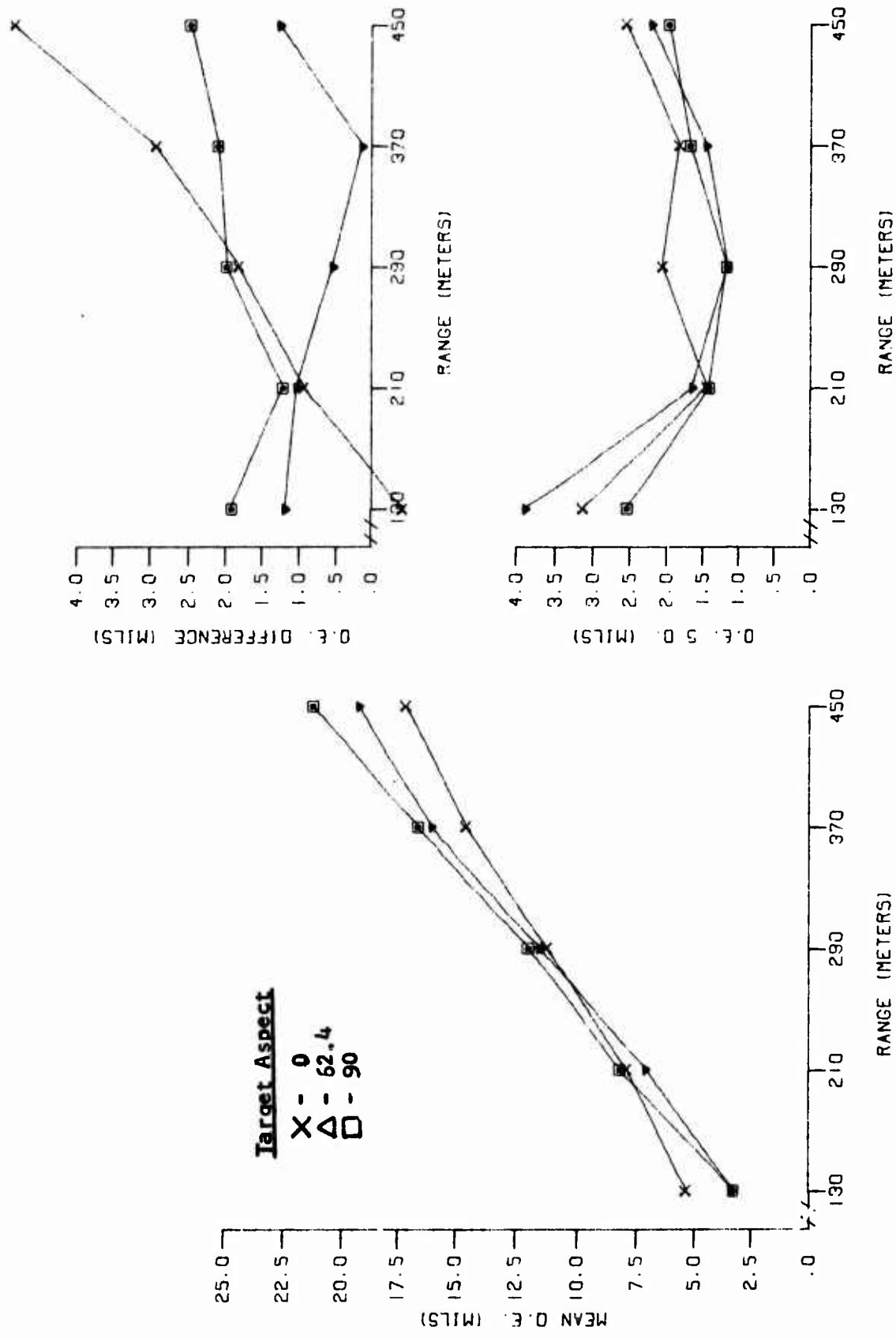
Fig. 27. Advanced LAW 3X sight superelevation data for three targets aspects 7-mph targets, group 1.

64
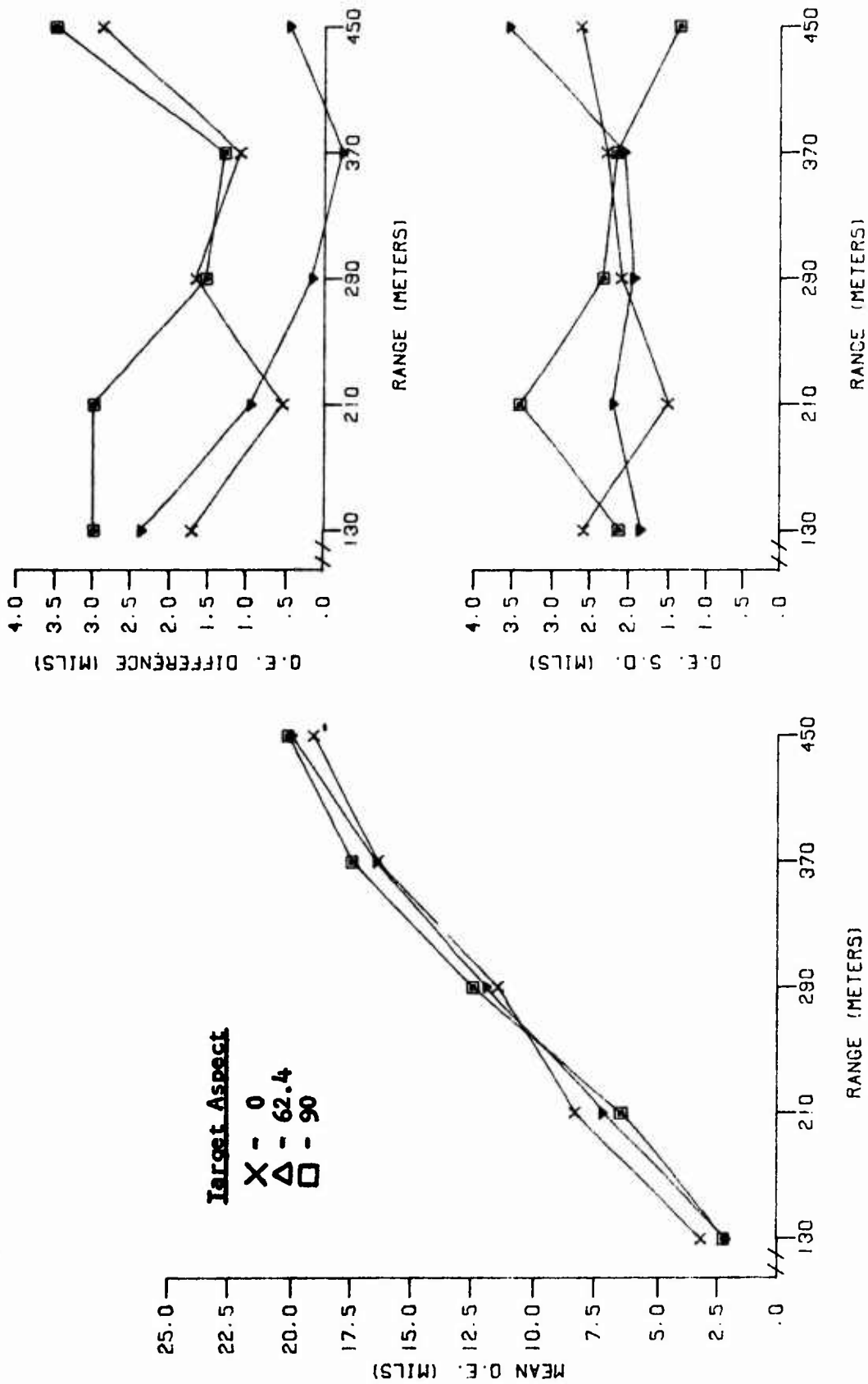
Fig. 28. Advanced LAW 3X sight superelevation data for three target aspects 7-mph targets, group 2.

65
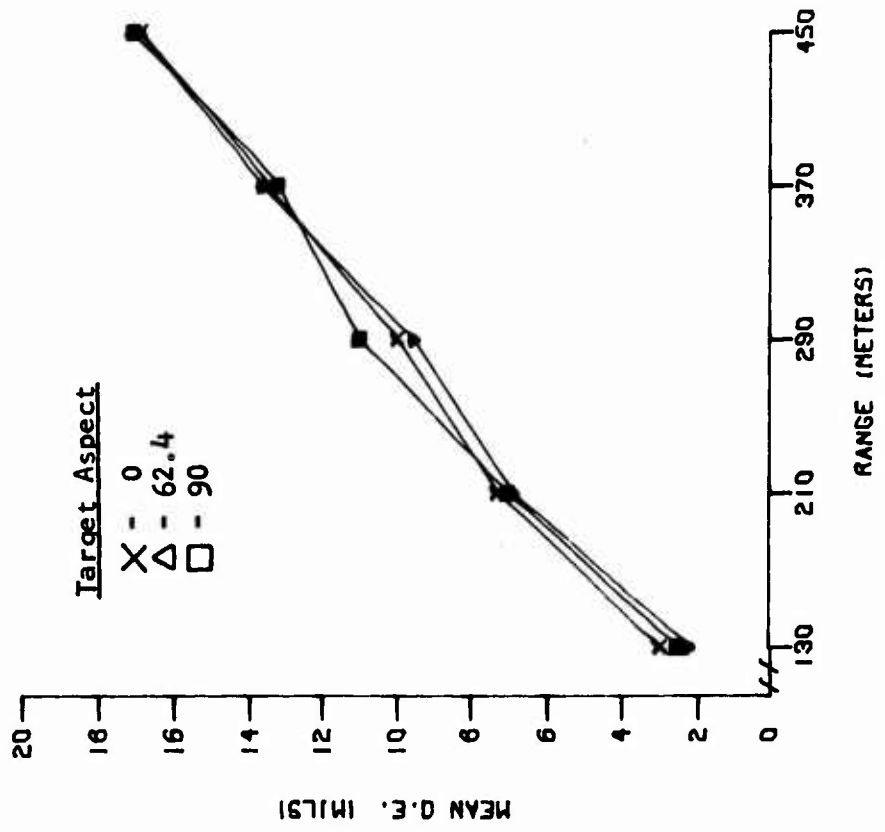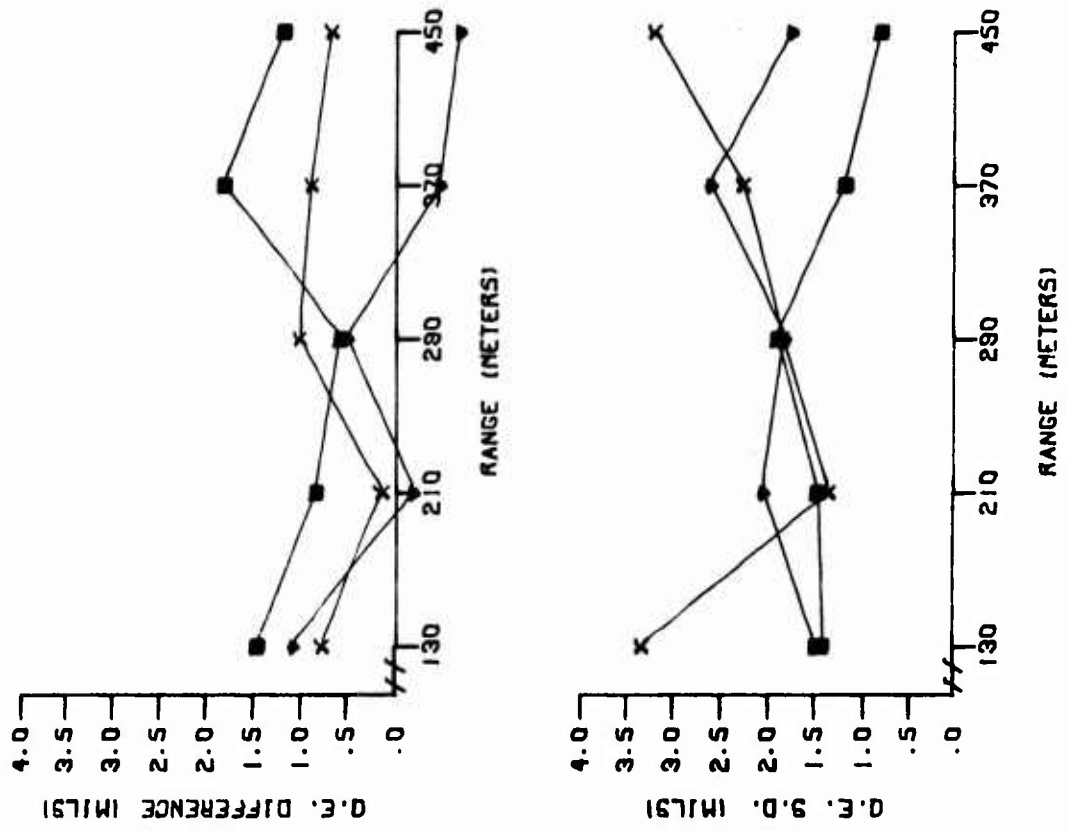
Fig. 29. Reflecting 1X sight superelevation data for three target aspects stationary targets, group 1.
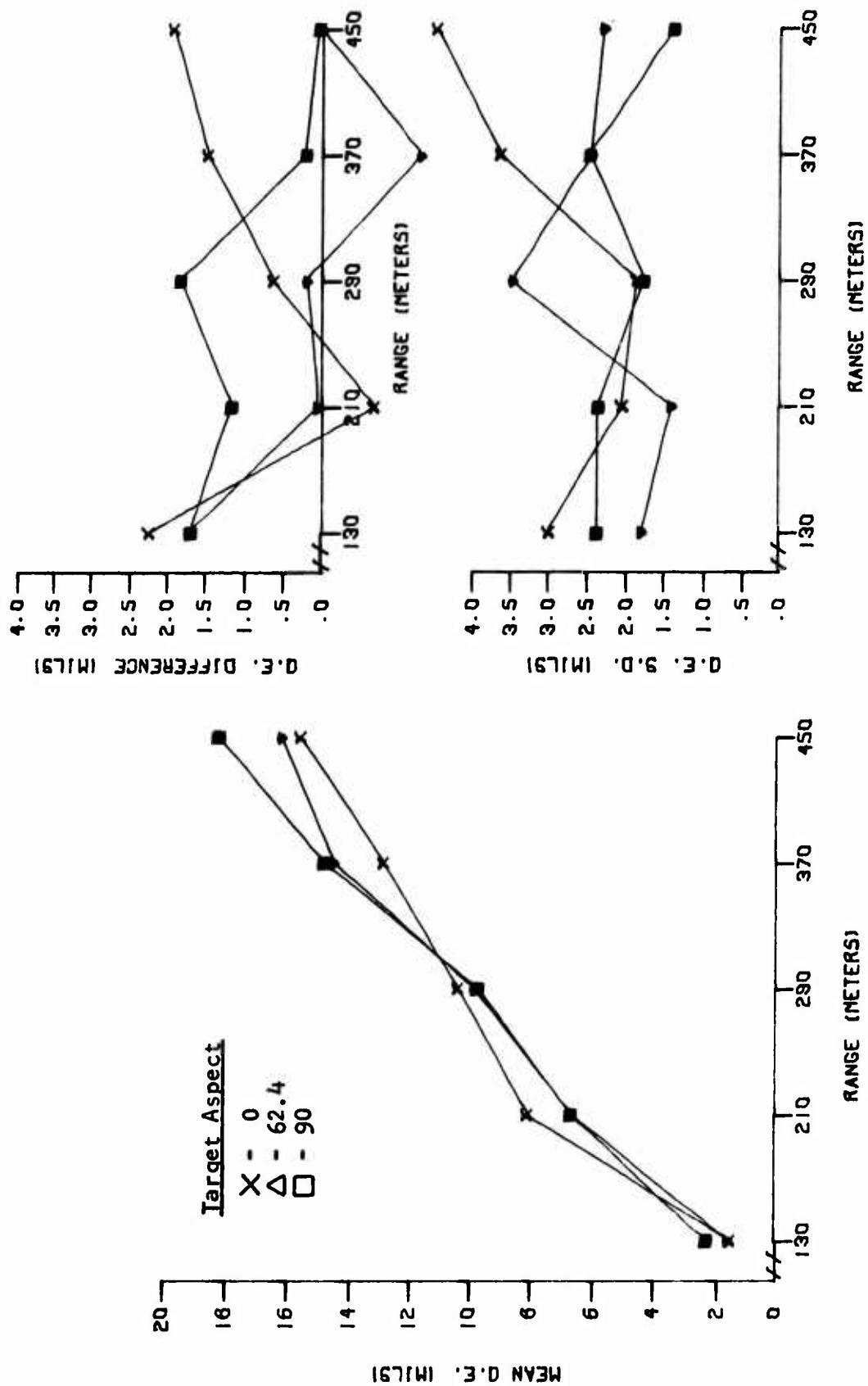
Fig. 30. Reflecting 1X sight superelevation data for three target aspects stationary targets, group 2.
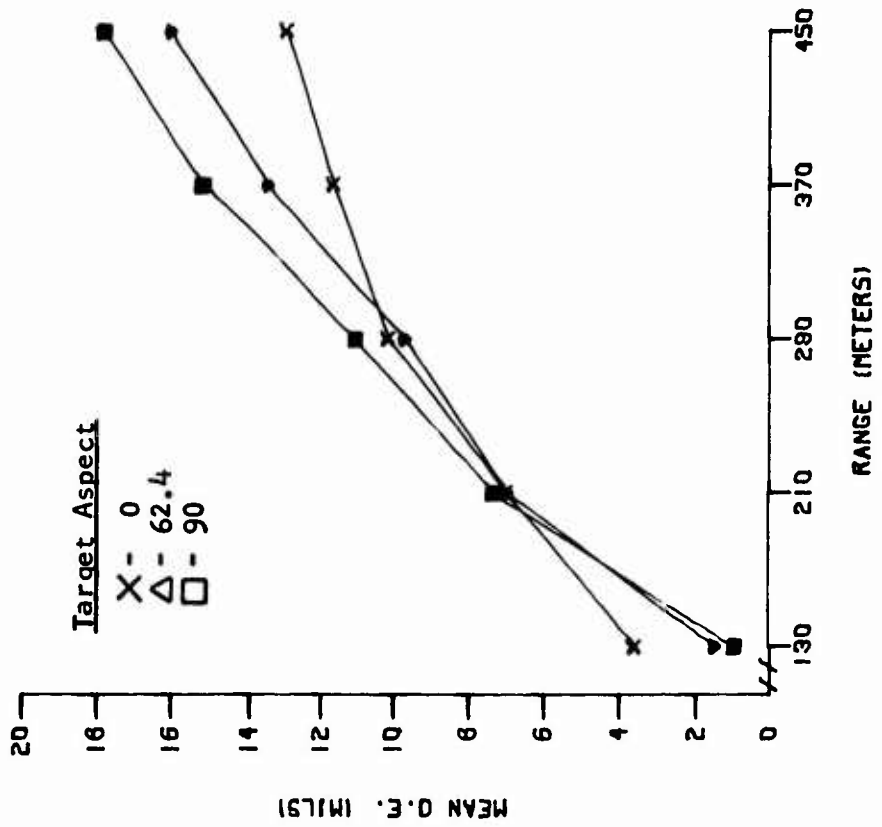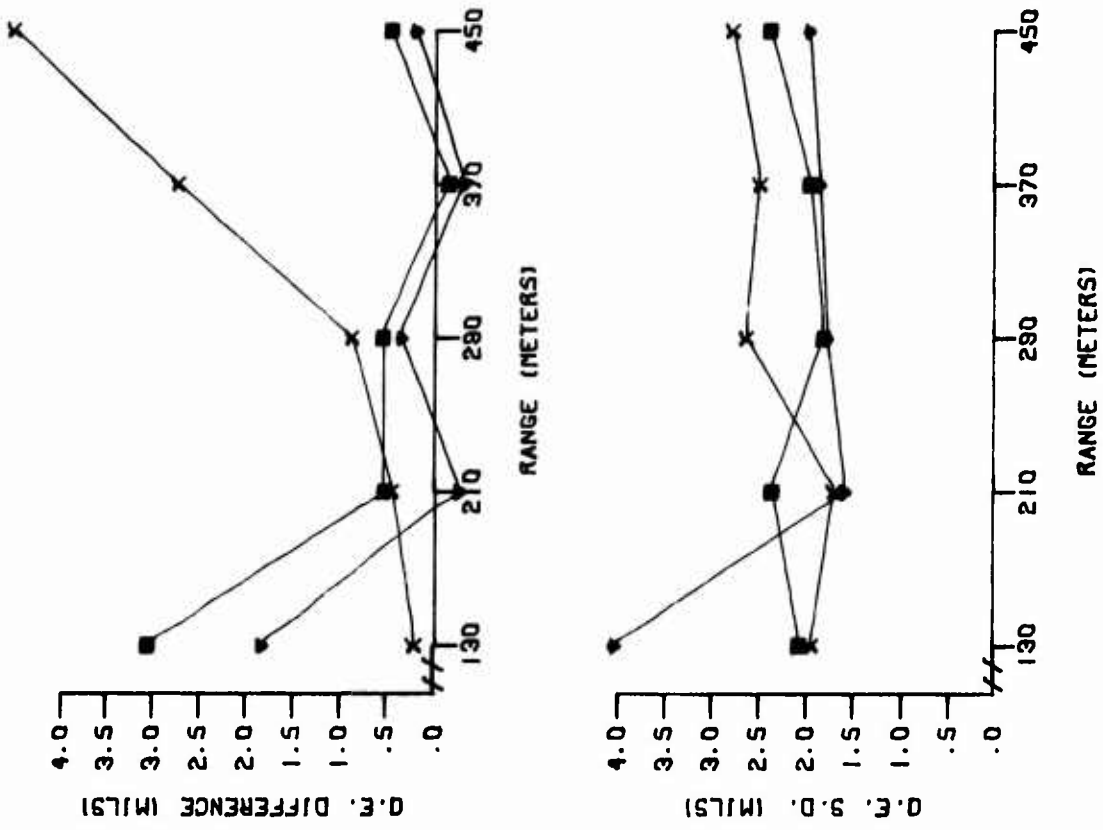
Fig. 31. Reflecting 1X sight superelevation data for three target aspects 7-mph, group 1.

68
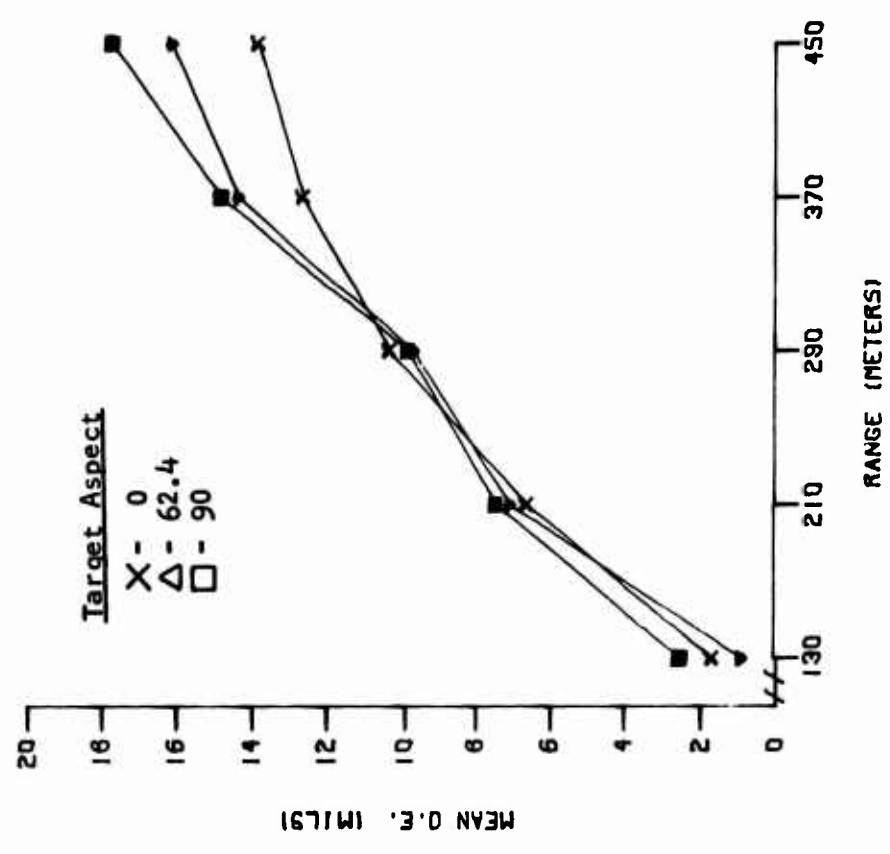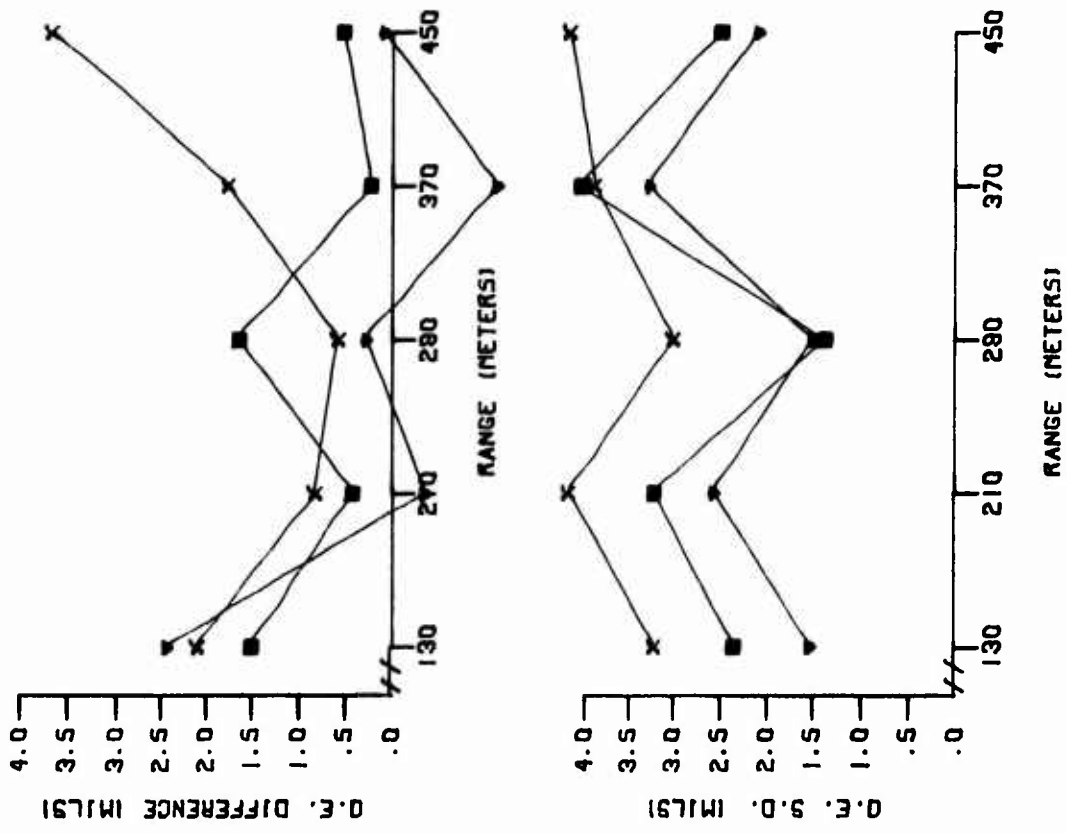
Fig. 32. Reflecting 1X sight superelevation data for three target aspects 7-mph targets, group 2.

69
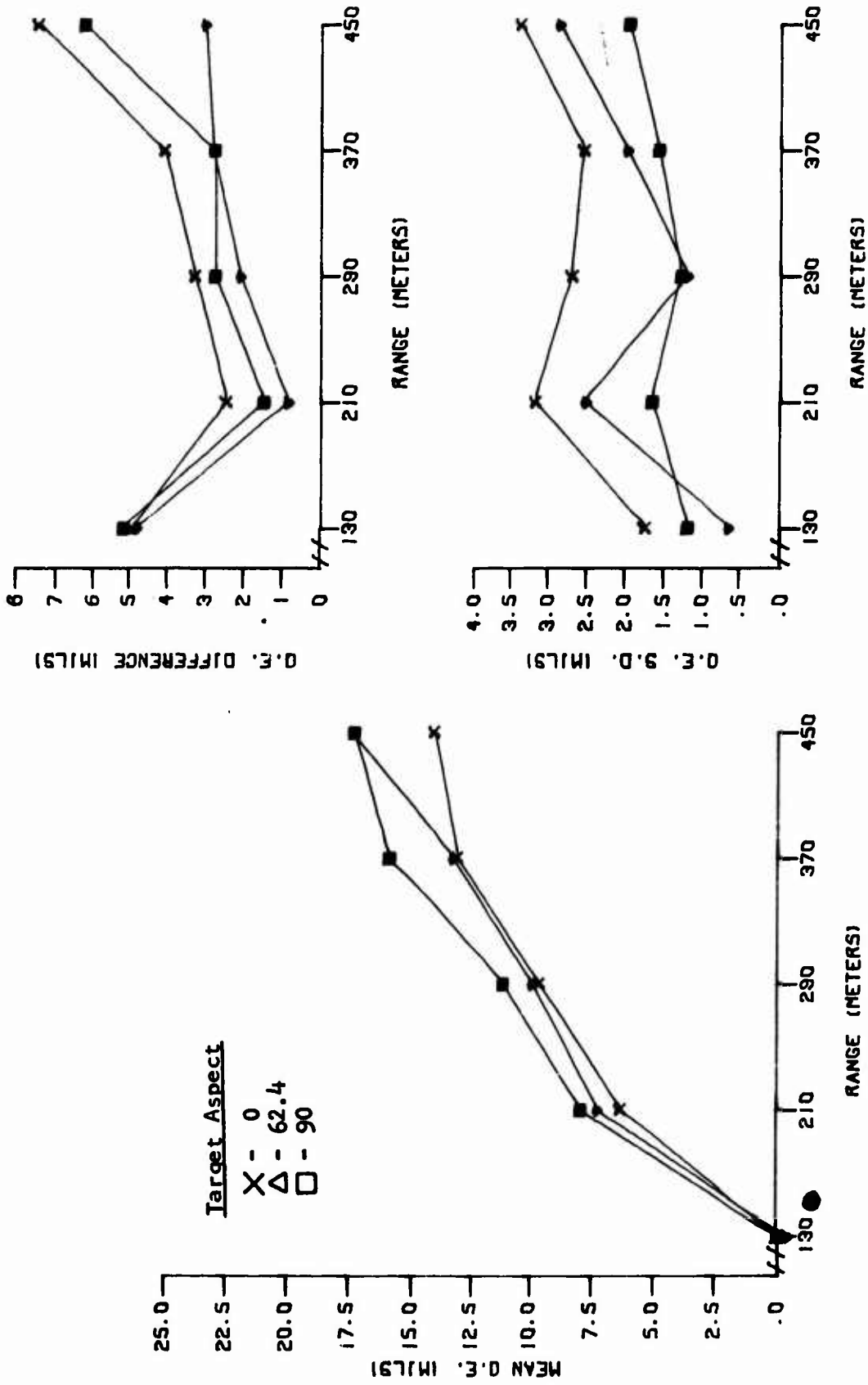
Fig. 33. Modified M72 sight superelevation data for three target aspects stationary targets, group 1.
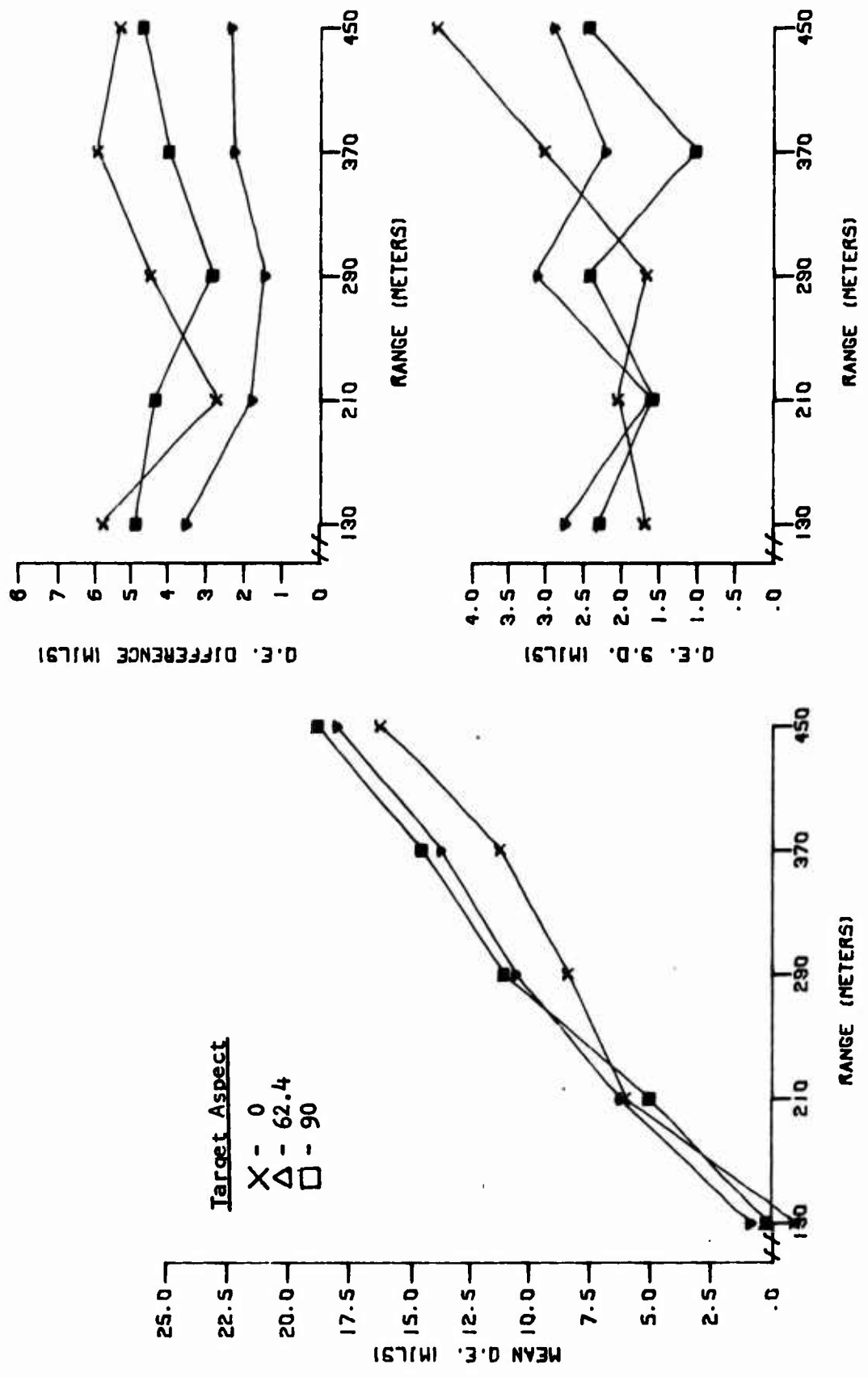
Fig. 34. Modified M72 sight superelevation data for three target aspects stationary targets, group 2.

71
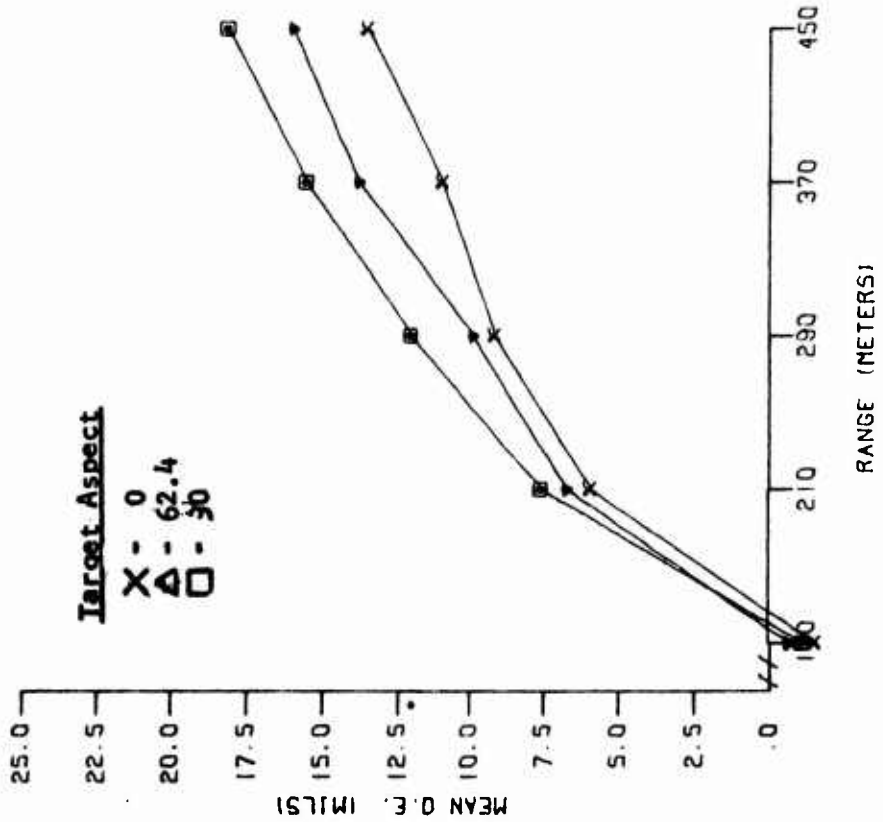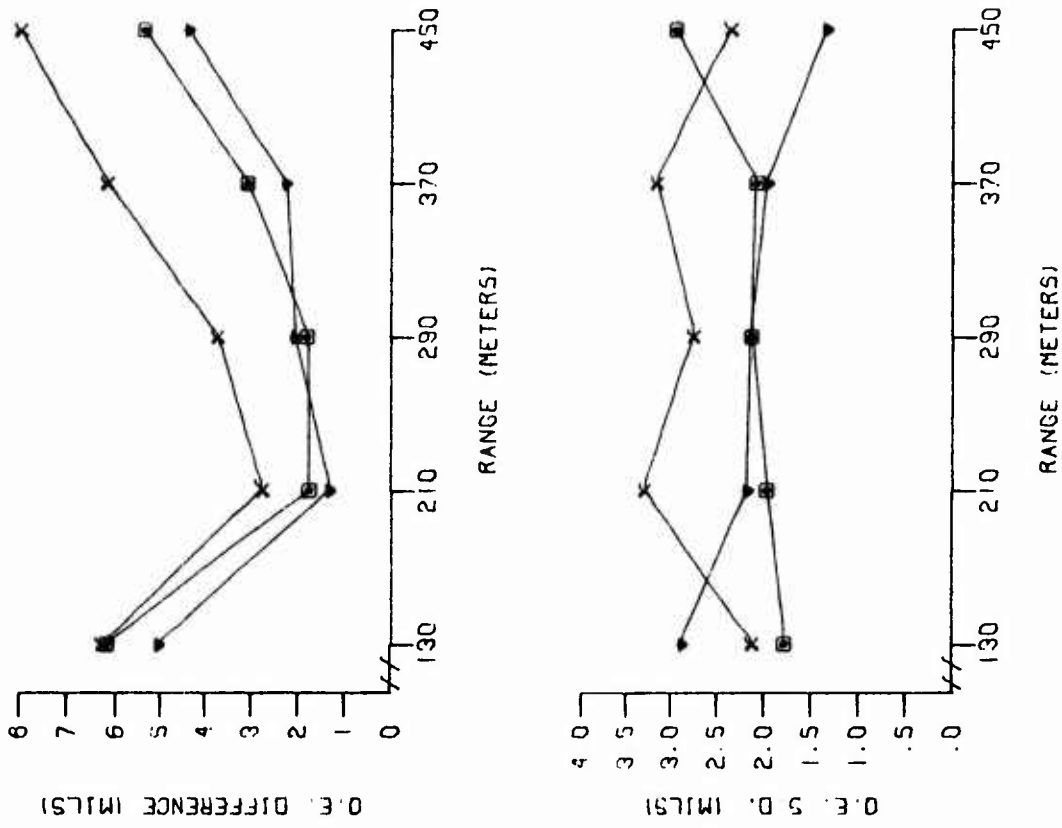
Fig. 35. Modified M72 sight superelevation data for three target aspects 7-mph targets, group 1.

72
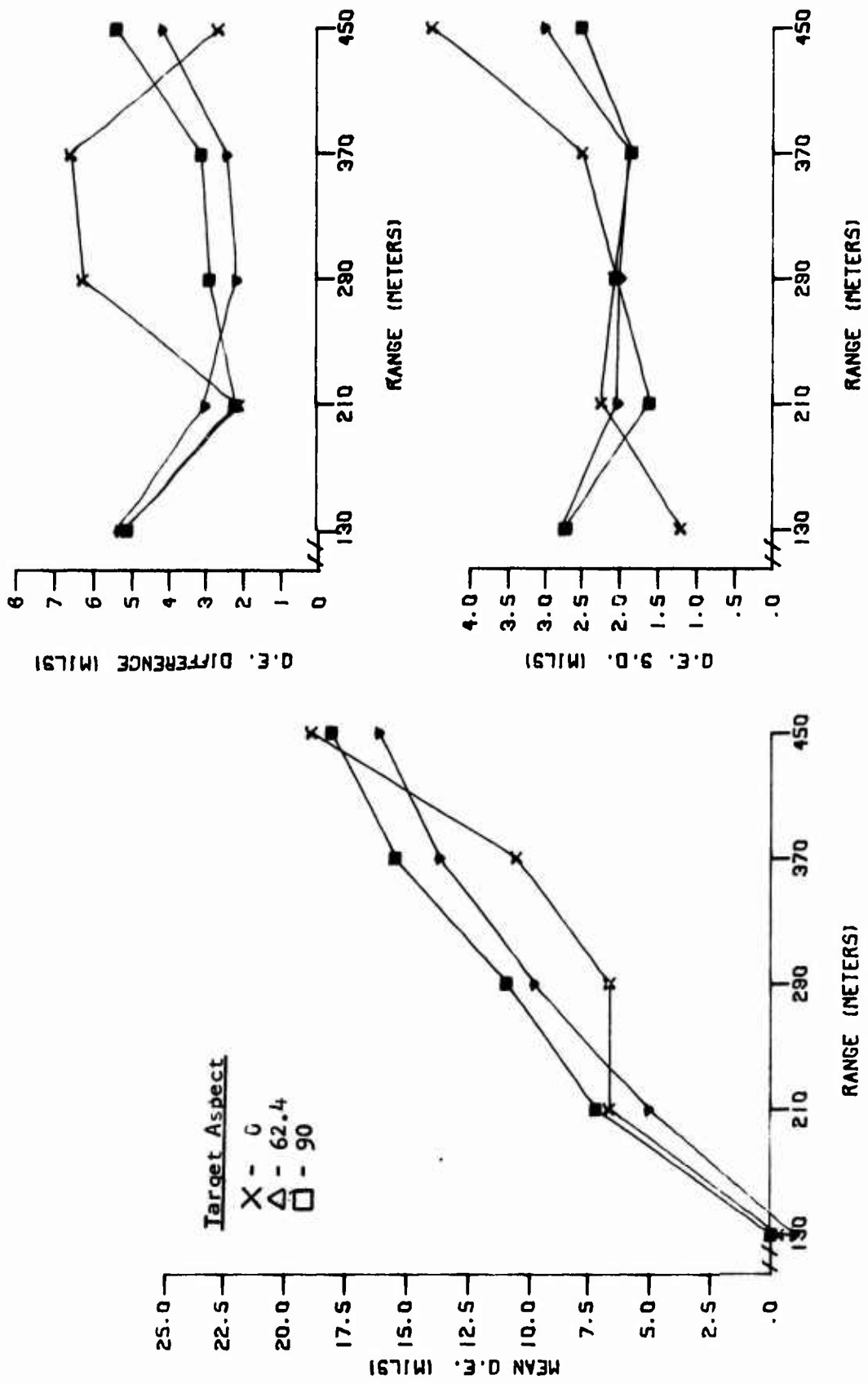
Fig. 36. Modified M72 sight superelevation data for three target aspects 7-mph targets, group 2.

73
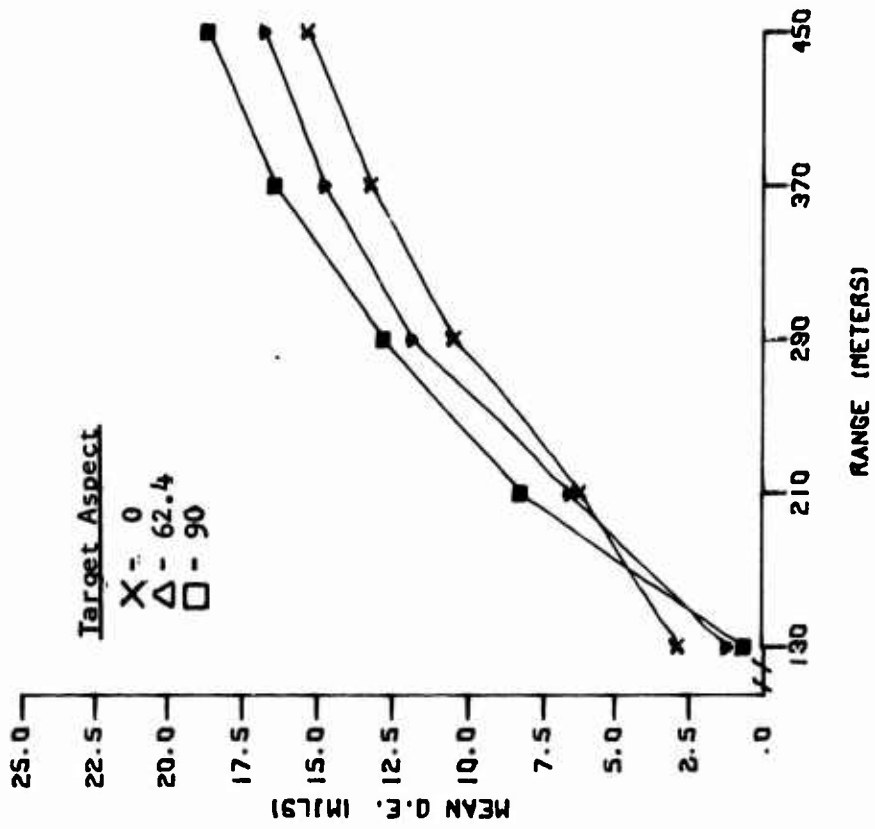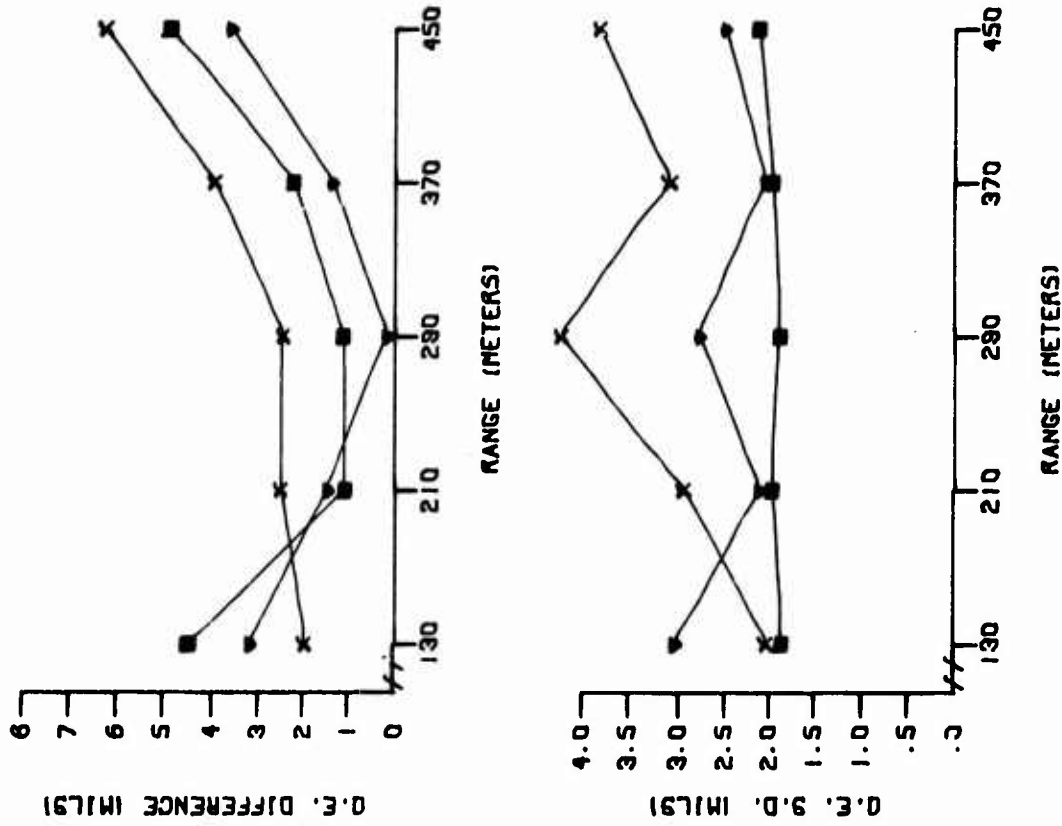
Fig. 37. Modified M72 sight superelevation data for three target aspects stationary targets, group 4.

74
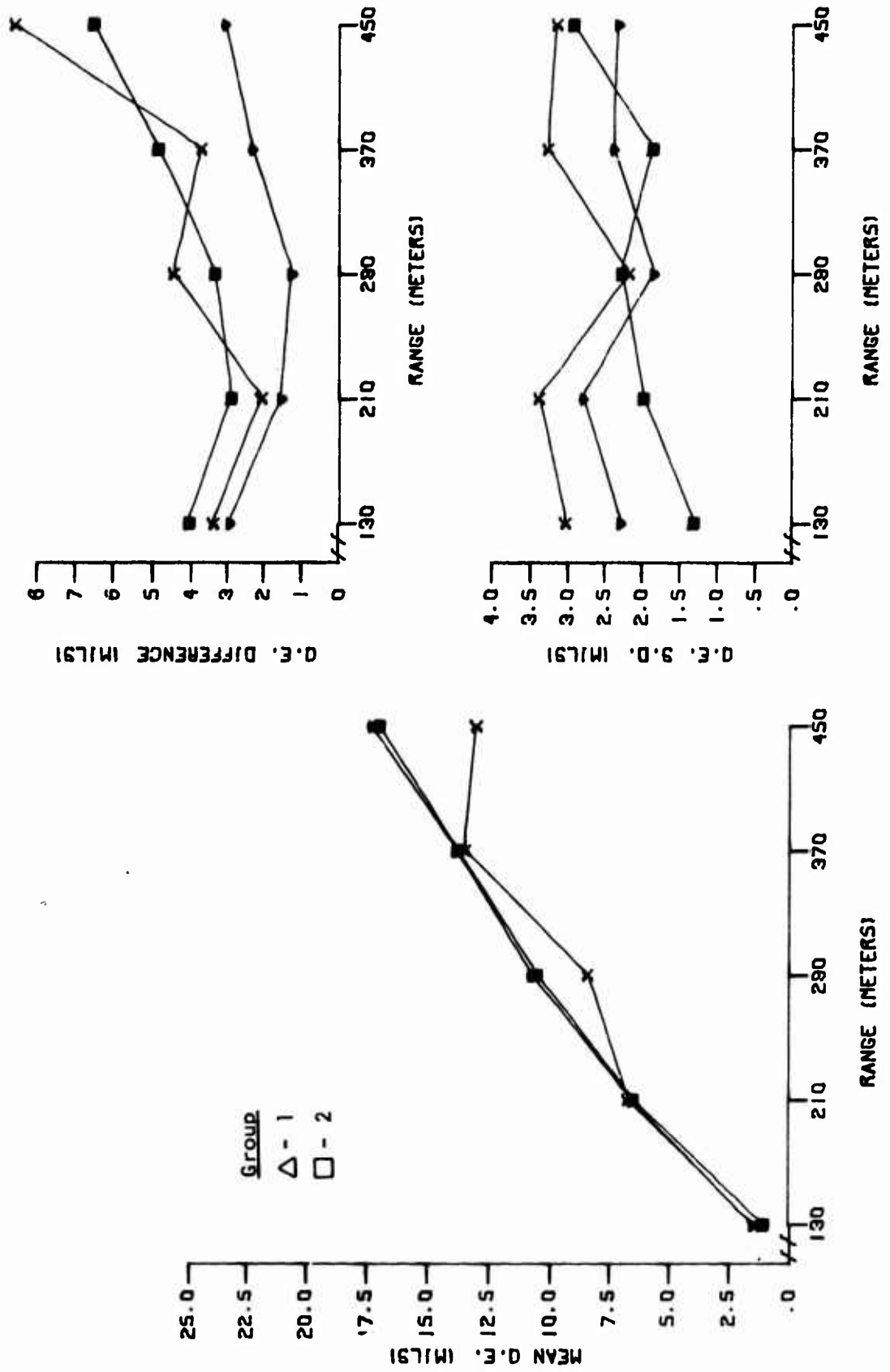
Fig. 38. Modified M72 sight superelevation data for three target aspects 7-mph targets, group 4.

75
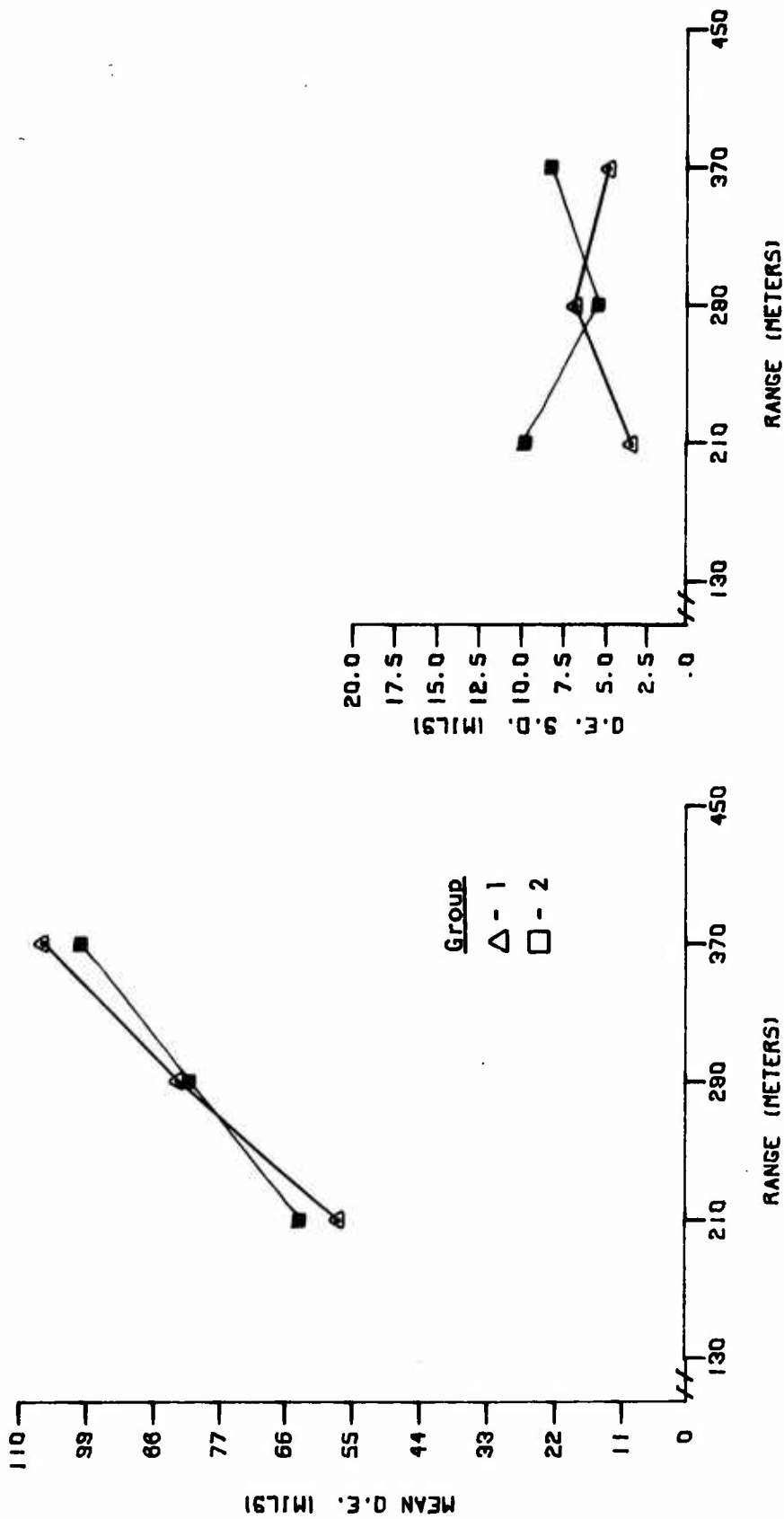
Fig. 39. M72 sight superelevation data for 14-mph targets, groups 1 and 2.
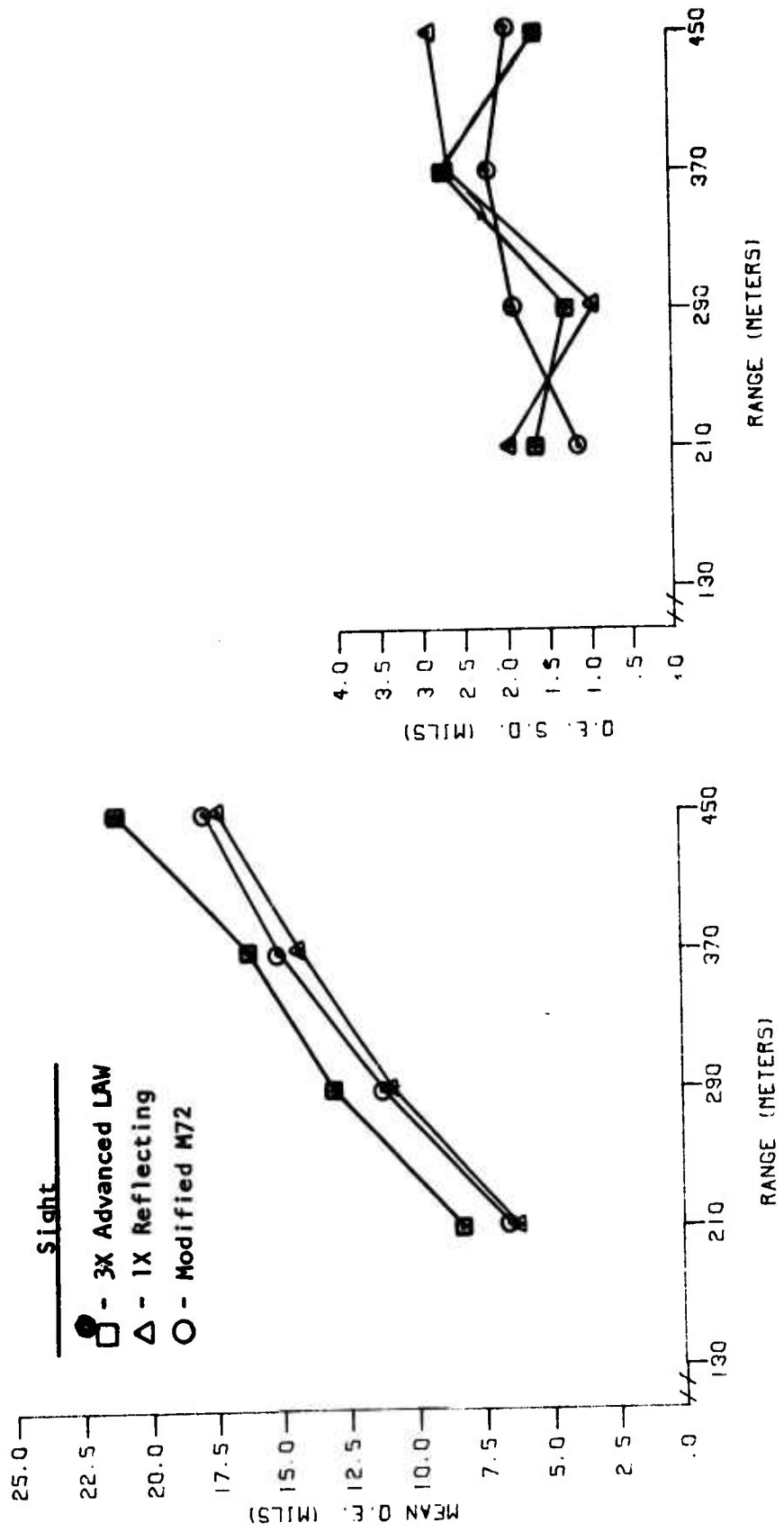
Fig. 40. Superelevation data for the 1200-fps conventional length/width stadia sights, 14-mph targets, group 1.

77
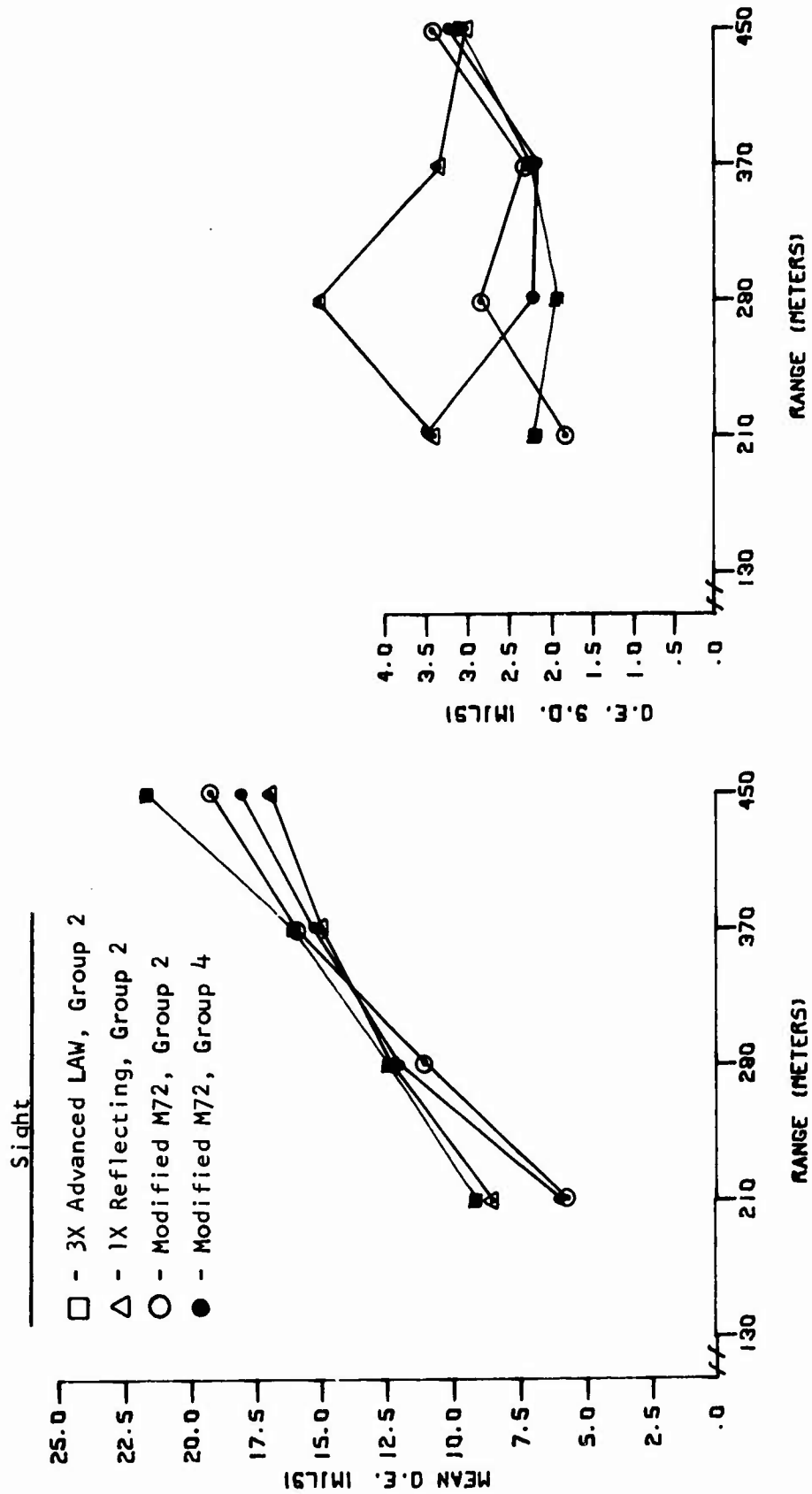
Fig. 41. Superelevation data for the 1200-fps conventional length/width stadia sights, 14-mph targets, groups 2 and 4.

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Comparing the superelevation SDs for the two non-optical sights shows that increasing the weapon's muzzle velocity improves performance. Superelevation SDs for the M72 sight (designed for a 475-fps muzzle velocity) can be compared with those for the modified M72 sight (designed for a 1200-fps muzzle velocity) only at ranges of 210, 290, and 370 meters, where there are data for both sights. The SDs for the M72 sight are about four times greater than those for the modified M72 sight, evidently because the M72's stadia lines have a greater slope.

The stadia lines' slope depends on target range, as well as the muzzle velocity for which the sight is designed. As target range increases, the stadia lines slope more steeply, becoming almost parallel (depending on muzzle velocity) at distant ranges. This increasing slope causes the superelevation SD to increase with longer target ranges (beyond the minimum range of the stadia). For the 1200-fps weapon sights, the data fluctuate, but the relationship between superelevation SD and range is discernible for target ranges between 210 and 450 meters. With these sights, the SDs did not increase substantially at the longer target ranges. This finding indicated that at the test ranges, the stadia slopes were not steep enough to degrade precision in measuring ranges.

(c) Superelevation Means

The mean superelevations in Figures 21 through 40 show that with sights designed for a 1200-fps muzzle velocity, the 3X (three-power) sight gives the highest superelevation, and the 1X (unity) sight gives the lowest.

The differences in mean superelevation arising from target aspect increase directly with range (or nominal mean superelevation), with side-on targets producing the highest superelevations, and head-on targets producing the lowest.

For the head-on aspect, mean superelevation is lower with moving targets than with stationary targets; however, the other target aspects do not show similar relationships. Table 4 shows the rank order of sights by superelevation. Superelevation was predicted to be lowest for 62.4-degree-aspect targets, but it proved lowest for head-on (zero-degree) targets.

Graphs of QE differences in Figures 21 through 38 show that, except for some target conditions, mean superelevations were lower than predicted for all sights. These graphs further show that the reduction in superelevation is:

1. Directly related to range (or target size in mils) for each target aspect.

2. Inversely related to nominal target size (since the 62.4-degree target aspect produces the smallest reduction, and the zero-degree target aspect the largest).

3. Greater for moving than for stationary targets, in the head-on target aspect.

4. Greatest with the M72 sight (except for the 62.4-degree target aspect at ranges less than 370 meters, where the superelevation is higher than predicted).

5. For the 1200-fps weapon sights, least for the 1X (except for head-on targets), and greatest for the modified M72 sight with any target aspect.

Whereas increased superelevation SD implies reduced hit probability, the implication of a superelevation bias is not as straightforward. If a weapon is imprecise, superelevation bias may not substantially affect its hit probability (e.g., the reduced superelevation caused by the M72's 5-percent sight radius). But with a more precise weapon, superelevation bias that varies as a function of target aspect, range, or speed will limit the weapon's maximum effective range.

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Phase II Superelevations

(1) General

Superelevation means and SDs for all of the sights tested in Phase II are presented in Appendix G (Tables 7G through 12G). The data for sights 1 and 3 are shown graphically in Figures 42 through 47. The data for sight 2 in group 4 (the M72 sight with a new, modified reticle) is contained in the Phase I results. All data for the ART sights are summarized in Table 14, because there was a gross error in the design of the sights.

Much of the data for the height-stadia and man-silhouette stadia ART sights was lost. Midway in the testing of group 3, it was found that the ART height-stadia sight was not securely fastened to the weapon; the other ART sights were checked and found to be securely fastened. These sights were subjected to a great deal of handling, as well as some force when the gunners adjusted them. The loose sight, if grabbed and forced up or down, would shift slightly, but enough to invalidate the data for the first three of the five gunners in group 3. Since this sight was replaced with the modified M72 sight with the new reticle in the testing of group 4, there were valid data for only two gunners.

When the superelevation data for the man-silhouette stadia sight were computed, the subjects in group 4 showed large biases in superelevation. Since the sight mounting had been continually checked, and found to be secure, the source of these biases remains unknown. Therefore, data are presented only for group 3.

(2) ART Sights

The ART sights, as planned, were to be equipped with ballistic cams designed to match the trajectory characteristics of a 1200-fps muzzle-velocity weapon. However, the sights that were actually supplied[9] and tested, had ballistic cams designed for trajectory characteristics that both differed from the planned characteristics[10] and varied from one sight to another. Because of the errors in the design of these sights, the performance data for them must be interpreted especially cautiously. Although the measured superelevation SD s are small, the mean superelevations are approximately one-third of those measured for the 1200-fps weapon sights tested in Phase I.

The superelevation SD s for an ART sight are a function of the slope of the superelevation range characteristic designed into the ballistic cam. Obviously, if there is no change in superelevation for different ranges (infinite muzzle velocity, or circular cam), the SD s merely represent the aiming error with a variable-power optical sight. To estimate the ART sights' performance with a cam designed for a 1200-fps muzzle-velocity weapon, it was first necessary to derive a functional relationship between superelevation SD and ballistic cam design.

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[9]Frankford Arsenal fitted the ART sights with reticles and forwarded them to HEL during the Phase-I portion of the experiment. However, the sight-reticle measurements shown in Appendix E were not received until the end of the experiment.

[10]These discrepancies become evident in comparing the reticle measurements for the ART sights with those for the sights used in Phase I of the experiment.
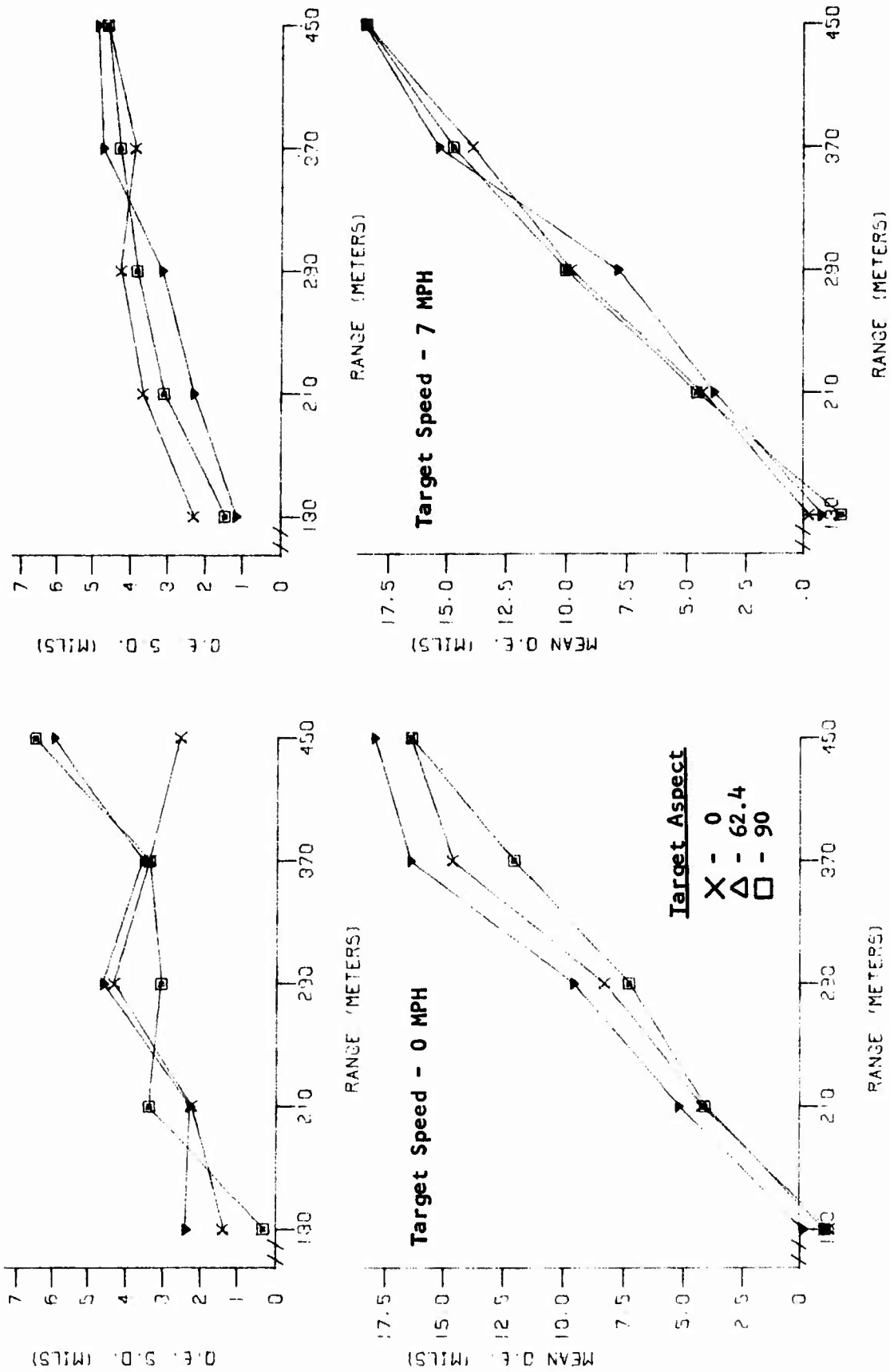
Fig. 42. RPG-7 sight superelevation data for three target aspects, stationary and 7-mph targets, group 3.
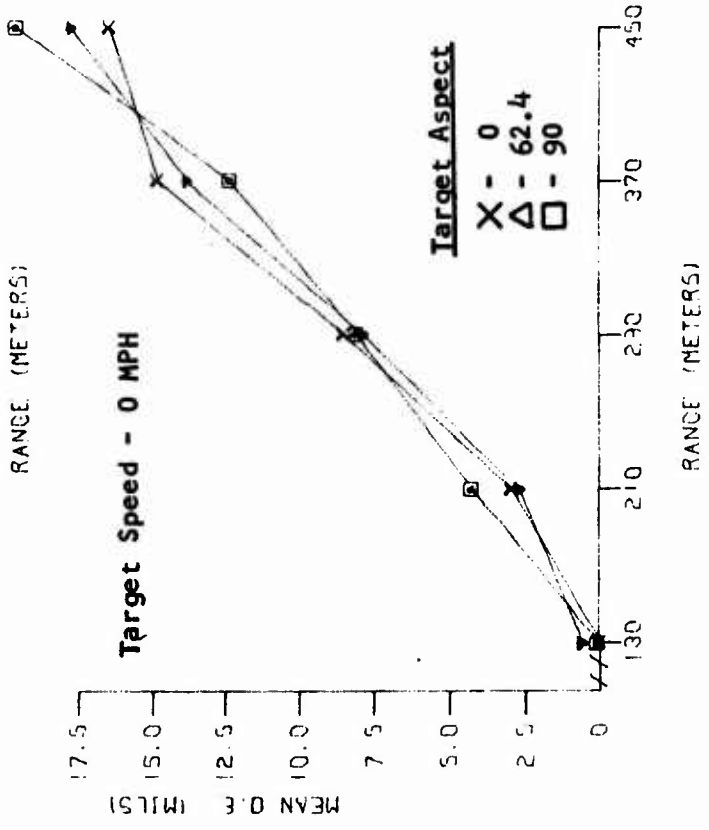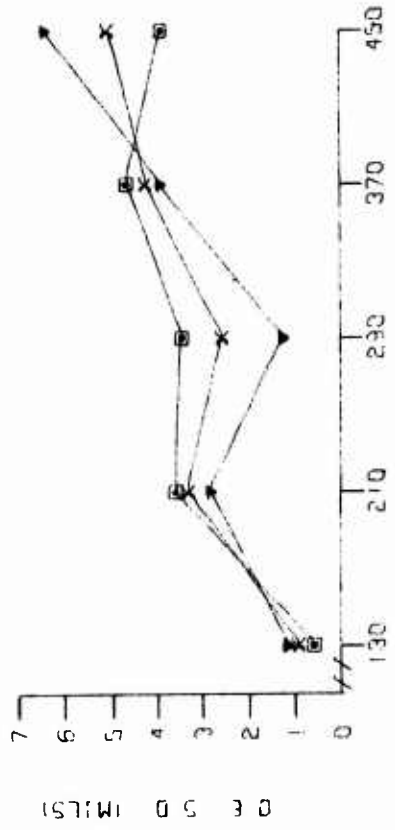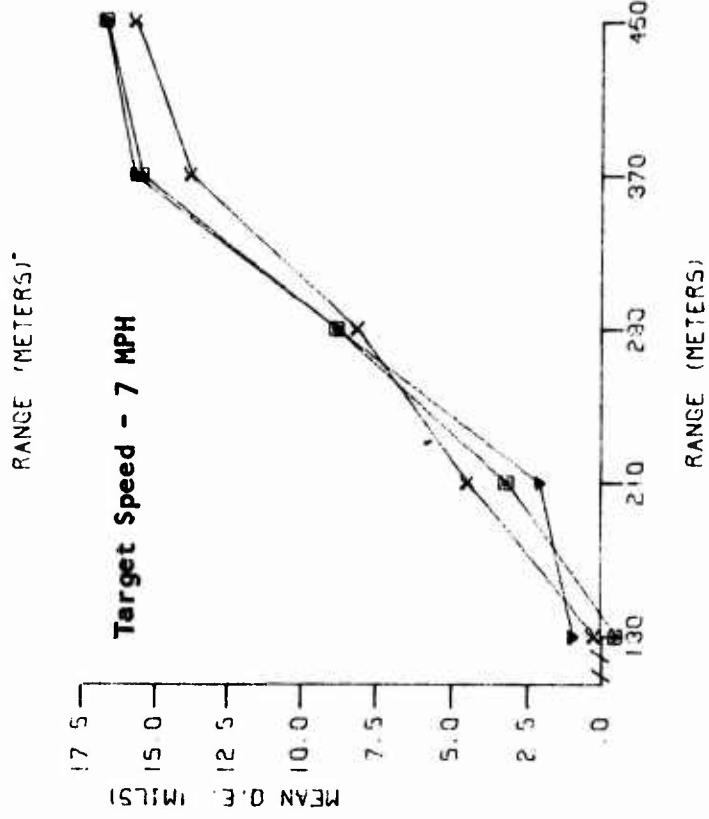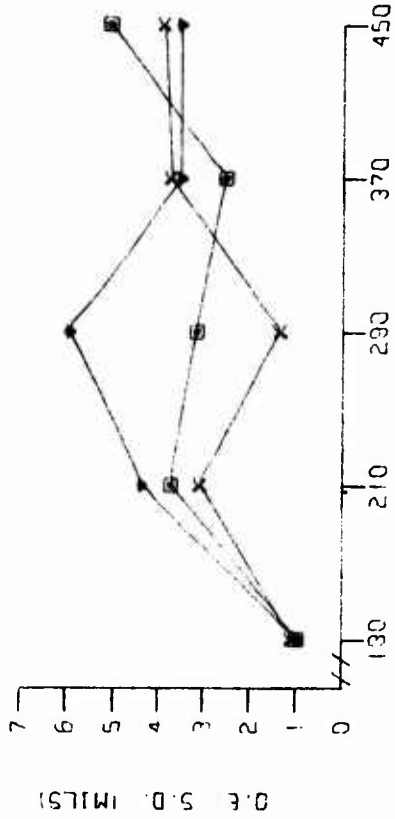
Fig. 43. RPG-7 sight superelevation data for three target aspects, stationary and 7-mph targets - group 4.

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Fig. 44. Fixed QE turret stadia-sight—mean superelevation and aiming error SD for two aimingpoints, stationary and 7-mph targets - group 3.

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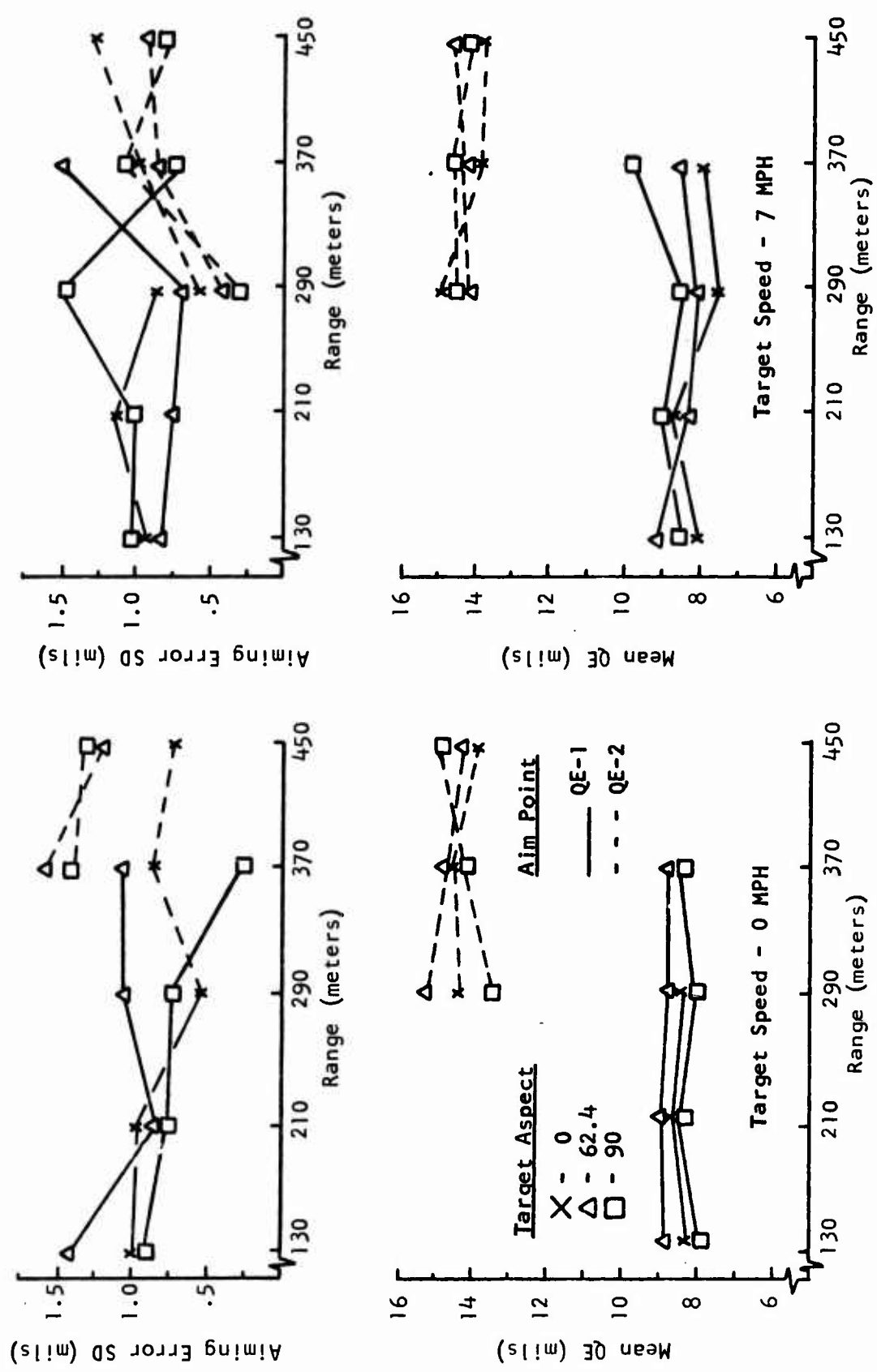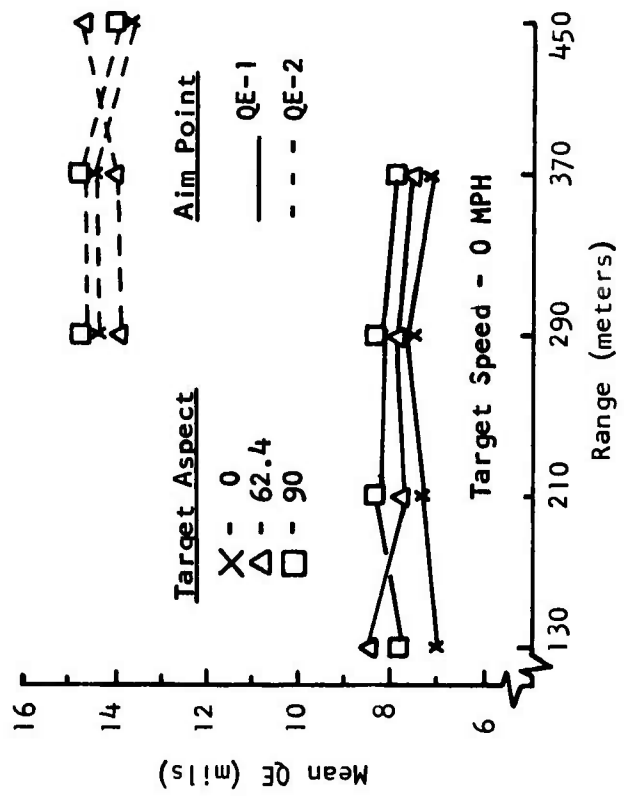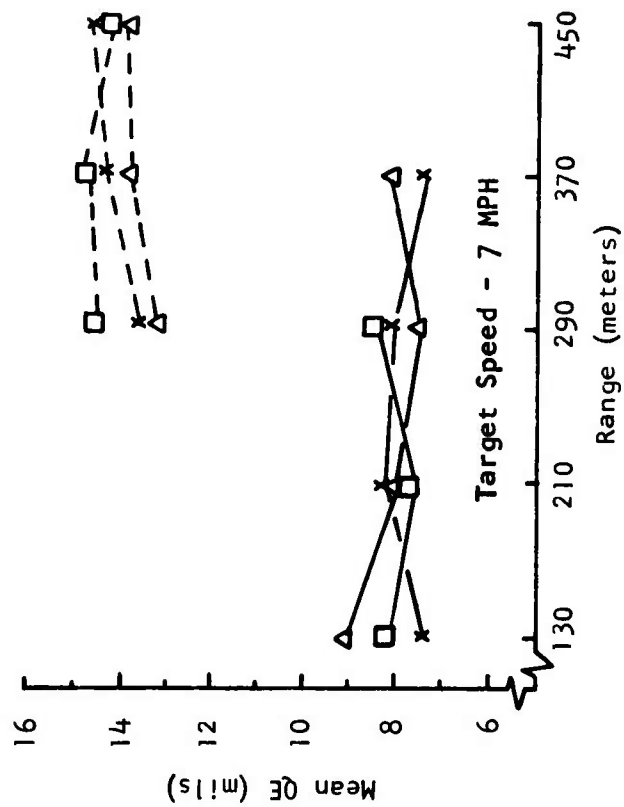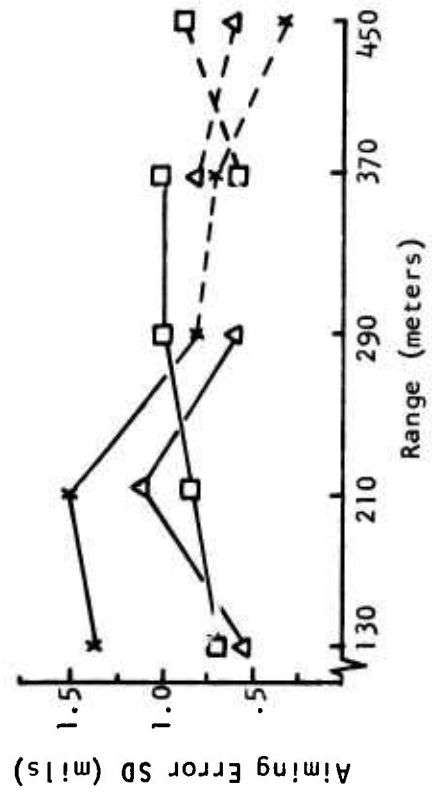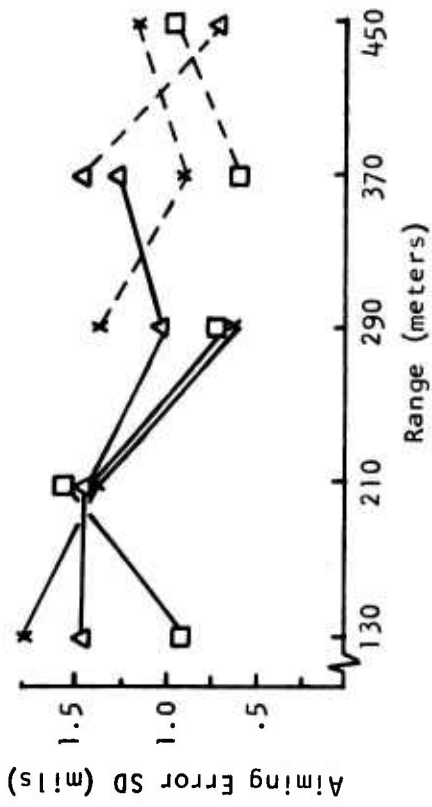
Fig. 45. Fixed QE turret stadia-sight—mean superelevation and aiming error SD for two aimingpoints, stationary and 7-mph targets - group 4.

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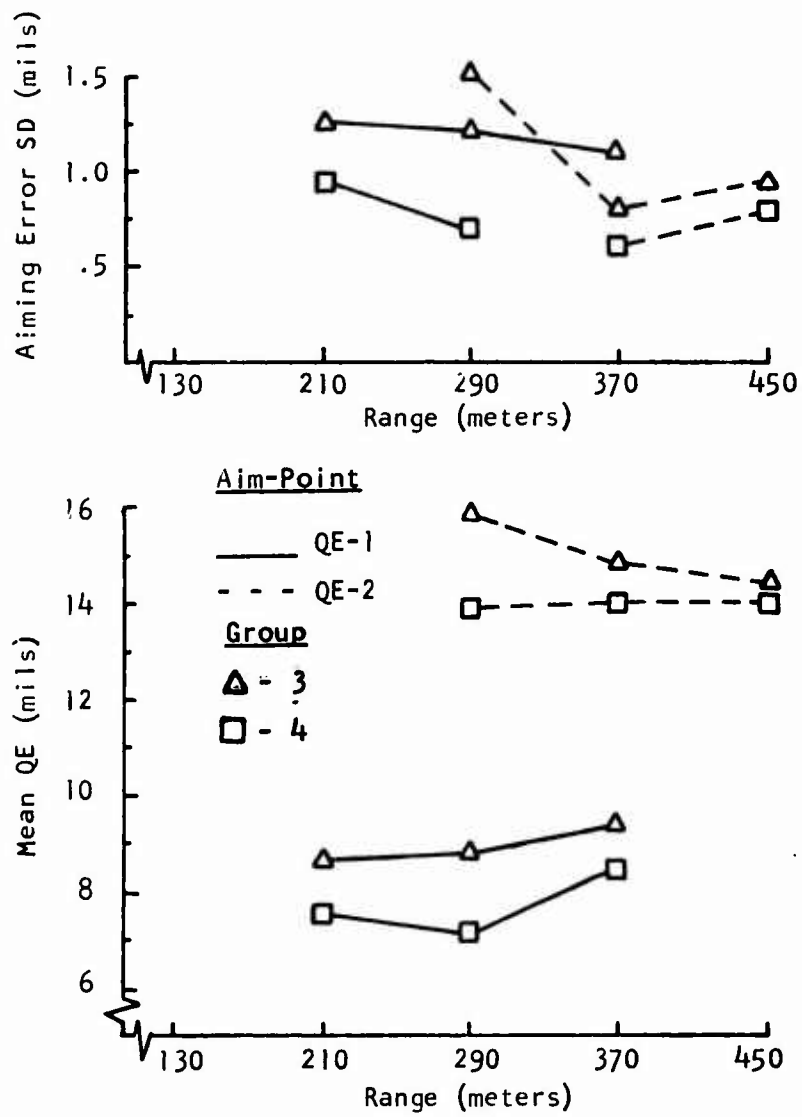
Fig. 46. Fixed QE turret stadia-sight—mean superelevation and aiming error
SD for two aimingpoints and 14-mph targets - groups 3 and 4.
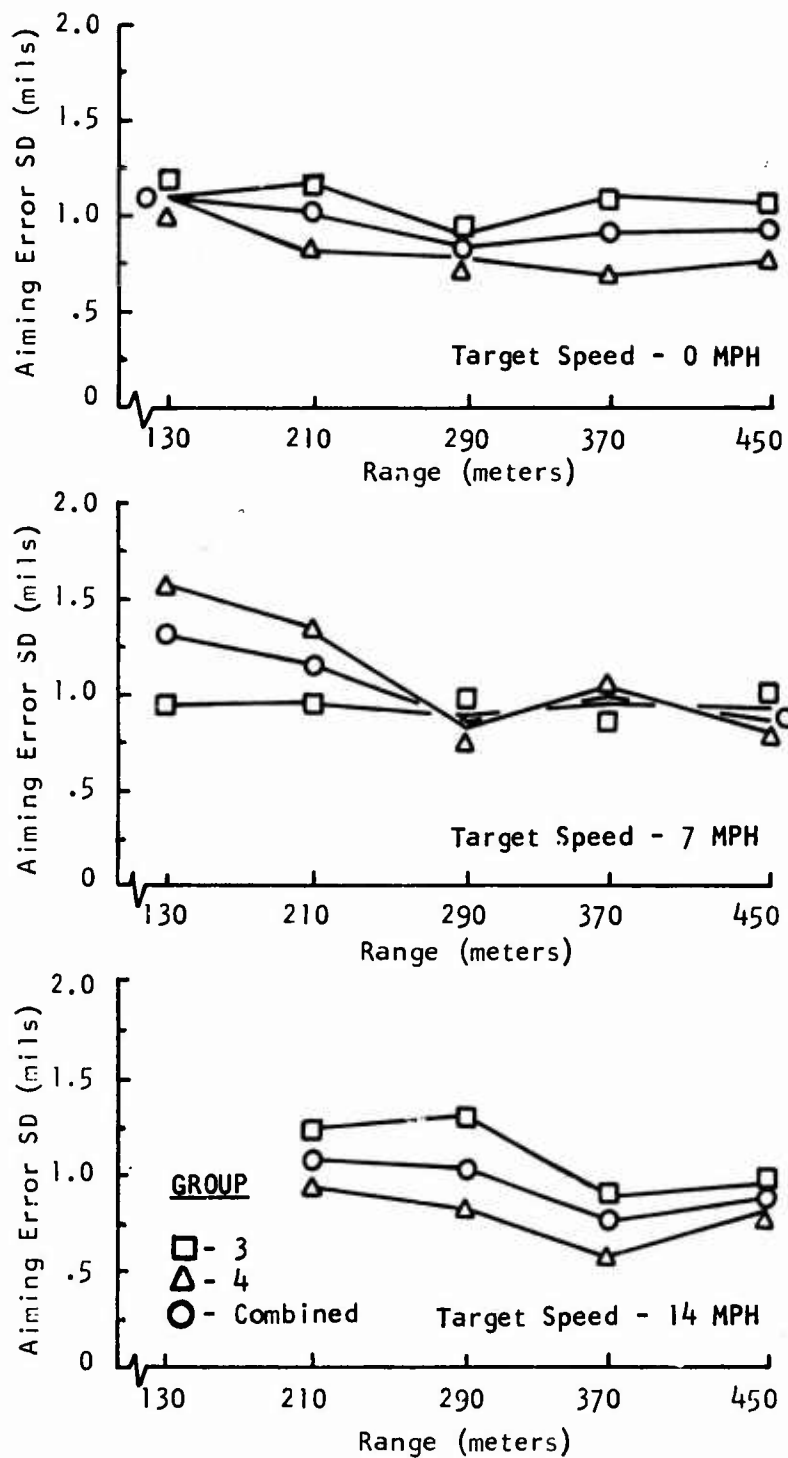
Fig. 47. 3X sight—aming error standard deviations for all target speeds, will all target aspects combined.

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When ranging with an ART sight, the gunner turns a ring to adjust the sight's magnification, bracketing the target within the reticle lines. In performing this task, he incurs a ranging error which arises from three sources: (1) resolving power - the gunner's ability to judge when the target just touches the stadia lines; (2) holding error - the gunner's ability to hold the weapon perfectly still (the reticle is moving in relation to the target, causing an error in bracketing the target); and (3) precision of adjustment - the gunner's precision in adjusting the setting of the adjustment ring. The combination of these errors is reflected in an angular error, $\Delta\theta$, with respect to the correct setting, θ, on the adjustment ring and its attached ballistic cam. This angular error, $\Delta\theta$, is independent of the ballistic cam's superelevation/range characteristic. However, the angular error produces a superelevation error, $\underline{S}$, which is a function of the slope of the superelevation/range characteristic designed into the cam at the angular setting, θ, and, for a linear function in the region of interest, this superelevation error is

$$S_1 = \Delta\theta \left[\frac{d \text{ (superelevation)}}{d\theta} \right]$$

The angles $\Delta\theta$ and $d\theta$ also cause incremental changes in the target's apparent size in mils and, for a stadiametric range-finder, these changes are proportional to range, or,

$$S_1 = \Delta R * K \left[\frac{d \text{ (superelevation)}}{dR} \right]$$

where $\underline{K}$ is a constant of proportionality, and $\underline{R}$ is the nominal range at the setting θ on the adjustment ring.

If the sight's cam were replaced with one designed for a slope $\underline{M}$ times greater, the superelevation error would be

$$S_2 = M*S_1$$

However, S_1 does not account for the total superelevation error at trigger operation.

When the gunner has finished ranging, he aims and fires with an aiming error[11], (ϵ) that is independent of superelevation, yet increases the total superelevation error. Thus the superelevation error at trigger operation is

$$S_1' = S_1 + \epsilon \text{, and}$$

$$S_2' = M(S_1 - \epsilon) + \epsilon.$$

It follows that the relationship between superelevation SDs for two ballistic cam designs will be

$$\sigma_2 = \left[M^2 (\sigma_1^2 - \sigma_\epsilon^2) + \sigma_\epsilon^2 \right]^{1/2}$$

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[11] The aiming error (as it is usually defined) combines both the gunner's aiming precision with the sight, and his holding error.

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where σ_1 = the measured superelevation SD for the original ballistic cam,

σ_2 = the predicted superelevation SD for a cam designed with a slope $\underline{M}$ times greater than the original one, and

σ_ϵ = the aiming error (SD).

Table 9 shows the slope inverse in meters per mil (approximate) for the three ART sights and the 1200-fps muzzle-velocity weapon. The sights have diverse slope characteristics, and at a reference range of 290 meters the slope ratio, $\underline{M}$, is the largest for the man-silhouette reticle. As a first approximation, let us assume that the slopes for each sight are linear at about 290 meters, and the aiming error SD is 0.6 mils[12]. The above formula may be used to predict superelevation SDs for a cam designed to the 1200-fps weapon's ballistic characteristics.

Averaging measured sight-superelevation SDs for all groups and target aspects at the reference 290-meter range, Table 10 shows the predicted superelevation SDs for the correct cam design. The measured SDs are near those of the most precise sight in Phase I (sight 3), but the predicted SDs are larger than those of the least precise 1200-fps weapon sight in Phase I (sight 5).

(3) RPG-7 Sight

The mean superelevations for the RPG-7 sight, as shown in Figures 41 and 42, are referred to the 200-meter range line on the sight (where the boresight readings were taken). Using this reference point with a target smaller than the one for which the sight was designed[13], the measured superelevations more nearly approximate those of the 1200-fps length/width stadia sights tested in Phase I.

At the closest target range, 130 meters, the subjects judged the target as too close for the stadia, so they fired using the 200-meter range line in the sight. Therefore, SDs at this range measure the gunners' errors aiming at a large target with a 2.5-power optical sight.

The SDs generally increase with longer target ranges. Variability is larger than with the length/width stadia sights tested in Phase I, so large, in fact—4 to 5 mils at the far target ranges—that it tends to mask any difference between stationary and moving targets.

---

[12]Aiming errors measured with the 3X sight (discussed subsequently) average about 0.9 mils for stationary targets. It is sometimes assumed that increasing the magnification decreases aiming error. This was assumed to be true, and our analysis accepts this assumption, and the calculations are based on the lower aiming error, 0.6 mils, which is near the gunner's holding error for the firing position. However, if one assumes that 0.9 mils is a better estimate of the gunner's aiming error, then the lowest and highest predicted SDs in Table 10 will be reduced by 0.2 to 0.4 mils, respectively.

[13]The sight, of Soviet origin, is designed for the height of an M60 tank. In Phase II of the experiment, the M60 tank turret was replaced with the mockup Soviet tank turret, reducing the target height to 2.6 meters.

TABLE 9

Superelevation Versus Range-Slope Characteristics for 1200-fps Trajectory Data and the ART Sights

Target Range	Slope^{-1} (Meters/Mil)			Ratio (M)
	200	290	450	290
1200-fps Trajectory Data	19.9	18.1	15.4	
Length/Width Stadia	30	35	28	1.9
Height Stadia	41	38	28	2.1
Man-Silhouette Stadia	68	44	28	2.4

TABLE 10

Measured and Predicted Superelevation SD's for the ART Sights— 290-Meter Reference Range, with Aiming Error SD of 0.6 Mils

	Superelevation SD			
	Measured		Predicted for 1200-fps Muzzle Velocity	
Target Speed (mph)	0	7	0	7
Length/Width Stadia	1.5	1.6	2.7	2.8
Height Stadia	1.8	1.8	3.6	3.6
Man-Silhouette Stadia	1.5	1.6	3.4	3.7

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Since the stadia are based on the target's height, target aspect should not influence superelevation appreciably. While there are some differences between superelevations measured at differing target aspects, they are not consistent between groups, ranges, or speeds, and thus appear inconclusive.

(4) Fixed-QE Turret Stadia Sight

(a) Data Reduction and Outlying Data Points

When using this sight, the gunners aimed at the target with one of the sight reticle's three aim-points and, after firing, marked their scoresheets to indicate which aim-point they had selected. Two of the aim-points (here called QE-1 and QE-2) were for targets considered within range for the stadia lines in the sight reticle; the third aim-point was for targets beyond the range of the stadia.

Measurements of the gunners' sight superelevations were first sorted by the aim-points the gunners had recorded on their scoresheets. The superelevations were than correlated with the true aim-point superelevations obtained from reticle-measurement data (Appendix E). During this analysis, some points appeared to belong to the superelevation category for one QE, although the subject had specified that he used the other. Therefore, criteria were established to remove any questionable data from further analysis.

Reticle measurements show the true superelevation for QE-1 and QE-2 to be 8.4 and 14.3 mils, respectively. These values and approximate three-standard-deviation bounds for the QE s were used to classify a data point as: (1) QE-1, if between 5 and 11.3 mils; (2) QE-2, if between 11.3, and 17.3 mils; or (3) out of range, if greater than 17.3 mils. A data point was then classified as an "outlier" if: (1) the data point was beyond the lower bound of superelevation; (2) QE-1 was used at the 130-meter range; (3) QE-2 was used at the 450-meter range; or (4) the QE was different from the one the gunner had specified on his scoresheet.

Table 11 lists the 23 data points that were classified as outliers and eliminated from all subsequent computations. The number of data points in each of the four categories of outliers were: 1, one; 2, none; 3, two; and 4, twenty. In category 4, nine were specified as QE-1 by the gunners but classified as QE-2; and 11 were specified as QE-2 by the gunners, but classified as QE-1. It is quite probable that most of the data in the fourth outlier category represent occasions when the gunners marked their scoresheets incorrectly. The direction of the superelevation errors—low for far target ranges, and high for near target ranges—supports this contention, as does the analysis that follows. Since the true source of error cannot be determined, it seems more conservative to eliminate these outlying data, rather than risk the possibility of their biasing data known to be valid.

(b) Range-Estimation Ability with a Turret Stadia

The gunners' selection of an aim-point in the sight depended on the relationship of the turret width to the separations of the two stadia (or judgment gates): i.e., if the target was smaller than the judgment-gate separation, the gunner elevated the sight to the next higher aim-point. The turret width for head-on targets was 2.57 meters, and for the other aspects it was 2.84 meters.[14] For these turret sizes and the separations of the judgment gates—7.75 and 5.75 mils,

_____ _____

[14]The reason for the difference in size between the two aspects is the T62 tank turret is slightly egg-shaped, but not as much as a T55 tank.

TABLE 11

Outlying Data Points For the Fixed—QE Turret Stadia Sight

Group	Subject	Range	Aspect	Speed	QE-1 Superelevation in Mils	QE-2 Superelevation in Mils
3	1	1	2	1	13.4	
		1	1	1	14.4	
		1	2	2	13.8	
		1	3	2	16.4	
		1	2	2	3.3	
		1	2	1	12.0	
		5	2	2		9.1
	3	4	2	2		9.8
		5	3	2		8.8
	4	4	3	1		8.6
		1	2	2	11.8	
4	1	5	1	1		7.3
	2	5	2	1		7.8
		5	3	1		8.6
		5	1	1		7.3
	3	1	3	2	11.6	
		1	3	2	11.3	
		2	1	2		8.9
		3	3	2		9.0
		5	3	2	7.6	
	4	5	3	2	8.8	
	5	1	3	2	11.7	
		5	2	1		7.6

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TABLE 12

Frequency of Occurrence for Each Aimpoint with the Fixed-QE Turret Stadia Sight

			Range (meters)								
			130	210		290		370		450	Out of
		Aimpoint:	QE-1	QE-1	QE-2	QE-1	QE-2	QE-1	QE-2	QE-2	Range
Group	Speed	Aspect				Number of Observations					
3	1	1	10	11	0	5	5	0	7	4	3
		2	8	10	0	11	2	5	8	4	3
		3	9	10	0	9	2	3	6	8	2
	2	1	9	11	1	5	3	1	9	5	5
		2	6	8	1	8	2	3	8	6	2
		3	8	10	0	6	1	4	7	7	2
	3	3	-	9	0	8	2	3	6	4	3
4	1	1	8	10	0	5	5	2	10	7	4
		2	7	9	0	7	2	2	5	7	3
		3	8	10	0	8	2	4	7	9	1
	2	1	9	9	0	7	4	2	9	5	5
		2	10	9	0	8	4	3	7	9	4
		3	7	8	0	10	4	1	6	7	5
	3	3	-	9	1	7	3	2	6	8	4
						Percent Observations					
3 & 4	1	1	100	100	0	50	50	11	89	61	39
		2 & 3	100	100	0	81	19	35	65	76	27
	2	1	100	95	5	63	37	14	86	50	50
		2 & 3	100	97	3	74	26	28	72	69	31
	3	3	100	94	6	75	25	29	71	63	37
3 & 4	1&2	1	100	98	2	56	44	13	87	55	45
	1&2&3	2&3	100	98	2	77	23	31	69	70	30

including the 0.25-mil stadia-line thickness—the aimpoint crossover range [15] from QE-1 to QE-2, and from QE-2 to out of range were, respectively, 332 and 447 meters for head-on targets, and 366 and 494 meters for the other target aspects. These crossover ranges were greater than the nominal ranges originally intended.[16]

Table 12 lists the number of times the two groups of subjects selected each aimpoint, as a function of target range, by levels of target speed and by aspects. The table shows that the aimpoint-selection frequency does not differ consistently, either between subject groups or between target aspects of 62.4 and 90 degrees (aspects 2 and 3, respectively) at each target speed. Therefore, the data were summed over subject groups for head-on and non-head-on targets, and the percentage of observations at each aimpoint was computed (middle section of Table 12).

By hand-fitting smooth curves to graphs of the percentage of observations at each combination of aimpoint and range, the approximate mean crossover range between QE-1 and QE-2 (the range at which there is equal likelihood of selecting either aimpoint) was interpolated. The mean crossover range between QE-2 and the out-of-range aimpoint could not be found by this method, since the out-of-range aimpoint was used at only one range. The mean crossover range between QE-1 and QE-2 was: (1) 290 meters for head-on, stationary targets; (2) 310 meters for head-on moving targets; (3) 340 meters for non-head-on, stationary targets; and (4) 330 meters for non-head-on moving targets. Because the turret was egg-shaped, the mean crossover ranges (as well as frequency of observations) were greater for non-head-on targets than for head-on targets. However, whereas target movement apparently increased the crossover range for head-on targets, it actually reduced the crossover range for non-head-on targets. Also, the percentage of out-of-range targets at the 450-meter range indicated that, regardless of aspect, target motion decreased the mean crossover range between QE-2 and the out-of-range aimpoint.

Chi-square tests (fourfold contingency table) were applied to the aimpoint frequency count (Table 12) at the 290-meter target range for head-on and non-head-on targets, and for stationary and moving targets. The results of the tests showed the differences between target aspects were highly significant ($p < .01$), but that differences between target speeds were not significant ($p > .10$). These results indicated that the crossover ranges were affected by target aspects, but not by target speeds. Hence, the data were further summed over target speeds, and the percentage of observations at each aimpoint was recomputed (lower portion of Table 12).

This sight was similar to the rifle sight tested in Phase I—three range brackets and corresponding QEs—except that the gunners used a stadia to measure target-range increments. To determine whether if offered any improvement over unaided-gunner range estimation, the predictive model for range classification used with the rifle sights in Phase I was applied to the data in Table 12. The model's parameter values (crossover ranges and standard deviations) were varied to obtain a reasonable fit to the actual aimpoint-selection frequencies. The model produced frequencies corresponding to the data, except at the longer target ranges, with the following parameter values: a crossover range from QE-1 and QE-2 within 10 meters of the one previously determined from the data, a 260-meter increment to the crossover range between QE-2 and the out-of-range aimpoint, and a range-estimation standard deviation between 18 and 21 percent of range.

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[15]Crossover range is where turret size in mils equals stadia-line separation.

[16]After completion of the experiment, FA provided sight-measurement data which revealed a difference between the nominal turret size intended for the experiment (2.8 meters) and the actual turret size designed into the sight reticle (2.30 meters). This difference increased the intended crossover ranges by 14.6 percent over the desired 300 and 400 meters.

Table 13 lists the model's predicted aimpoint-selection frequencies for head-on and non-head-on targets. Table 13 shows a low frequency of usage for both QE-1 at the 450-meter range, and for the out-of-range aimpoint at the 370-meter range, which did not occur in Table 12. For the former, retaining outlying data points in category 4 at the 450-meter range would have increased the frequency for QE-1 to 5 percent at this range, and correspondingly reduced the frequency for QE-2. For the latter, increasing the predicted crossover range between QE-2 and the out-of-range aimpoint would give a better fit to the data at the 370-meter range, but a poorer fit at the 450-meter range.

Since values of range-estimation standard deviation larger or smaller than those used in the model provide poorer fits to the data, the range-estimation standard deviation attributable to this sight must be between 18 to 21 percent of range.

These results show that:

-Adding stadia judgment gates based on a T62 turret for the sight's nominal crossover ranges does not substantially improve range estimation over unaided visual-range estimation (21 percent of range).

-Aimpoint crossover ranges for head-on and non-head-on targets differ by about ten percent, evidently because varying the target's aspect changes its apparent turret size.

-The actual aimpoint crossover range is closer than the nominal crossover range.

(c) Mean Superelevation and Aiming Error SD

Mean superelevations and aiming errors (SDs) at each QE (reticle aimpoint) are plotted in Figures 44 and 45 for 0- and 7-mph target speeds, and in Figure 46 for the 14-mph target speed. Mean and SDs are shown only for samples larger than 2 (see Table 12 for sample sizes).

Figures 44 and 45 show no consistent differences in mean superelevation attributable to target aspects or ranges within aspects. However, the figures do show that group 4 gave lower superelevations than group 3 did. This difference is most evident for 14-mph target speeds (Figure 46).

In comparison to the reticle measurements for each aimpoint, the mean superelevations over all target speeds, ranges, and aspects for QE-1 and QE-2 were, respectively: (1) 0.2 and 0.3 mils higher for group 3, and (2) 0.6 and 0.3 mils lower for group 4. Of these, only the 0.6-mil difference is statistically significant.[17] With group 4, there was greater reduction in superelevation at the closer ranges (where QE-1 was used) than at the longer ranges (where QE-2 was used). This indicates that the subjects in group 4 were aiming lower than 1 foot below the turret ring.

As with the rifle sight tested in Phase I, this sight's aiming errors should not be greatly affected by target aspect. In addition, there is no reason to believe that the aiming errors with respect to either the QE-1 or the QE-2 aimpoint should be different. The aiming errors shown in

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[17] t-tested; $p < .05$

TABLE 13

Predicted Percent of Aimpoint Selection with the Fixed-QE Turret Sight

Aspect	Range (meters)	Standard Deviation (Percent of Range)					
		18			21		
		QE-1	QE-2	Out of Range	QE-1	QE-2	Out of Range
1	210	98	2	0	99	1	0
	290	57	43	0	58	42	0
	370	18	69	12	15	77	9
	450	7	49	46	3	52	45
2 & 3	210	100	0	0	100	0	0
	290	83	17	0	79	21	0
	370	33	65	2	35	60	5
	450	9	64	27	12	58	30

Notes: 1. Crossover ranges from QE-1 to QE-2 and from QE-2 to Out of Range are: (1) for Aspect 1, 300 and 460 meters, respectively; and (2) for Aspects 2 & 3, 340 and 500 meters, respectively.

2. The predictive model assumes (1) that the range-estimation errors are normally distributed about the true target range, and (2) that the range-estimation standard deviation is a fixed percentage of true target range.

Figures 44 through 46 are consistent with these expectations. Therefore, the data were combined for all target aspects, and the aiming errors for each aimpoint were recomputed. At target ranges where there were data for both aimpoints, the aiming errors were pooled[18] to obtain a more reliable estimate of the aiming error. The average aiming error was also computed for each of the two groups of subjects.[19] These pooled data are presented in Figure 47.

Figure 47 shows that increasing the target range increased aiming error similarly for both groups of subjects, although group 4 had less aiming error at the longer target ranges. The average aiming error for the two groups was approximately 0.9 mils at the longer target ranges.

Azimuth Standard Deviations for Phase I and Phase II

Azimuth errors were measured in reference to the midpoint between the target's horizontal extremes (in the data film), except at the 130-meter target range. At this range, one or both of the target's end-points were sometimes outside of the camera's field of view, so the target center was estimated from known points on the tank turret. At the 450-meter target range, the target end-points were difficult to discern because there was so little color contrast between target and terrain. Therefore, the data at these ranges are not considered reliable.

Table 14 summarizes the azimuth SDs for all sights at a reference 290-meter range, as obtained by linear interpolation from the azimuth data in Appendix G. The table shows five relationships:

-Azimuth SD is less for head-on targets than for side-on targets.

-For side-on targets, azimuth SD increases with faster speeds.

-For head-on targets, azimuth SD has no consistent relationship to speed.

-In each test phase, and for most test conditions, the 3X sight (sight 3) gave a smaller azimuth SD thus any other sight. (However, unreliable data based on only two subjects suggested a lower SD for the height-stadia ART sight, which has a reduced superelevation).

-With head-on targets, the azimuth SDs for the rifle sight (Phase I, sight 1) and the 3X fixed-QE sight (Phase II, sight 3) are approximately the same as their respective vertical aiming error SDs ; with side-on targets, however, azimuth errors vary more than the vertical aiming errors.

$$[18]S = \left[\frac{(N_1 - 1) S_1^2 + (N_2 - 1) S_2^2}{N_1 + N_2 - 2} \right]^{1/2}$$

$$[19]S = \left[\frac{S_1^2 + S_2^2}{2} \right]^{1/2}$$

TABLE 14

Summary of Azimuth SD's (mils) for All Sights at a Reference 290-Meter Range

			ASPECTS				
			Head-On		Side-On		
		Speed (mph)	0mph	7mph	0mph	7mph	14mph
Phase	Sight	Group					
I	1	1	.9	1.0	1.6	2.1	1.7
		2	1.8	1.3	2.1	2.9	2.3
	2	1	1.2	1.4	1.8	1.9	2.6
		2	1.4	1.3	1.2	2.2	2.0
	3	1	.8	.9	1.2	1.9	2.2
		2	1.2	1.1	1.5	2.2	2.1
	4	1	1.2	1.3	1.4	2.1	1.6
		2	2.5	1.5	1.4	1.9	2.3
	5	1	1.3	1.4	1.4	2.4	2.4
		2	1.6	1.2	1.7	2.5	1.6
		4	1.5	1.5	1.8	2.2	2.4
II	1	3	1.7	.1.2	1.6	2.6	2.8
		4	1.1	1.0	2.0	1.7	2.3
	2	3	.6	1.0	1.8	2.3	2.8
	3	3	.8	1.6	2.0	2.0	3.5
		4	1.3	1.2	2.3	2.5	3.5
	4	3	1.1	1.4	1.9	3.4	3.5
		4	1.5	1.6	2.2	2.5	3.2
	5	3	1.2	1.9	2.0	2.7	2.9
		4	1.9	1.9	1.5	2.7	3.3

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Time to Fire

a. Data Reduction

Time-to-fire data were obtained from films taken from behind the subjects, by counting the number of frames between the fire command and the appearance of the trigger-actuated indicator light on the rear of each weapon. Firing-time means and SDs and cumulative probabilities of firing as a function of time, were calculated for the independent variables of interest, using special computer programs (3). These results are shown in Figures 48 through 50 for Phase I, and in Figures 51 through 57 for Phase II.

In computing firing-time means and SDs , times less than 1 second or greater than 30 seconds[20] were discarded as invalid outlying observations.

b. Phase I

Mean firing times ranged from 4 seconds to 6.4 seconds over the various test conditions. Figures 48 through 50 analyze the test conditions' effects.

Figures 48 and 49 show that the gunners took more time to aim at stationary targets than at moving targets. Figure 49 also shows that firing times increased with range, and decreased as the target-aspect angle increased (0 degrees = head-on). A further breakdown for the five sights (Figures 49 and 50) shows that the modified M72 (sight 5) gave the fastest firing times, and the 3-power sight (sight 3) gave the slowest. Their means differed by about 0.6 seconds.

c. Phase II

Each group's firing times for Phase II are reported separately, since one sight (sight 2) was changed between the two groups. Group 3's mean firing times ranged from 3.8 seconds to over 14 seconds, and for group 4 they ranged from 3.7 seconds to just under 10 seconds.

Figures 51 and 52 show probability of firing versus time for each sight, illustrating the large differences between sights. A breakdown of mean times to fire by test conditions (Figures 53 through 57) points up these differences between the sights, as well as the differences between the two groups.

Mean firing times increased with range for both groups, but Group 3 showed longer times and sharper increases than Group 4.

Mean firing times were much greater for the ART sights than for the sights used in Phase I. The subjects fired using the modified M72 sight with the new reticle in about half the time they took with the ART sight. The man-silhouette ART sight required the greatest time of all, while the modified M72 and fixed-QE stadia sight required the least time.

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[20] Times as large as this were observed with the ART sights.
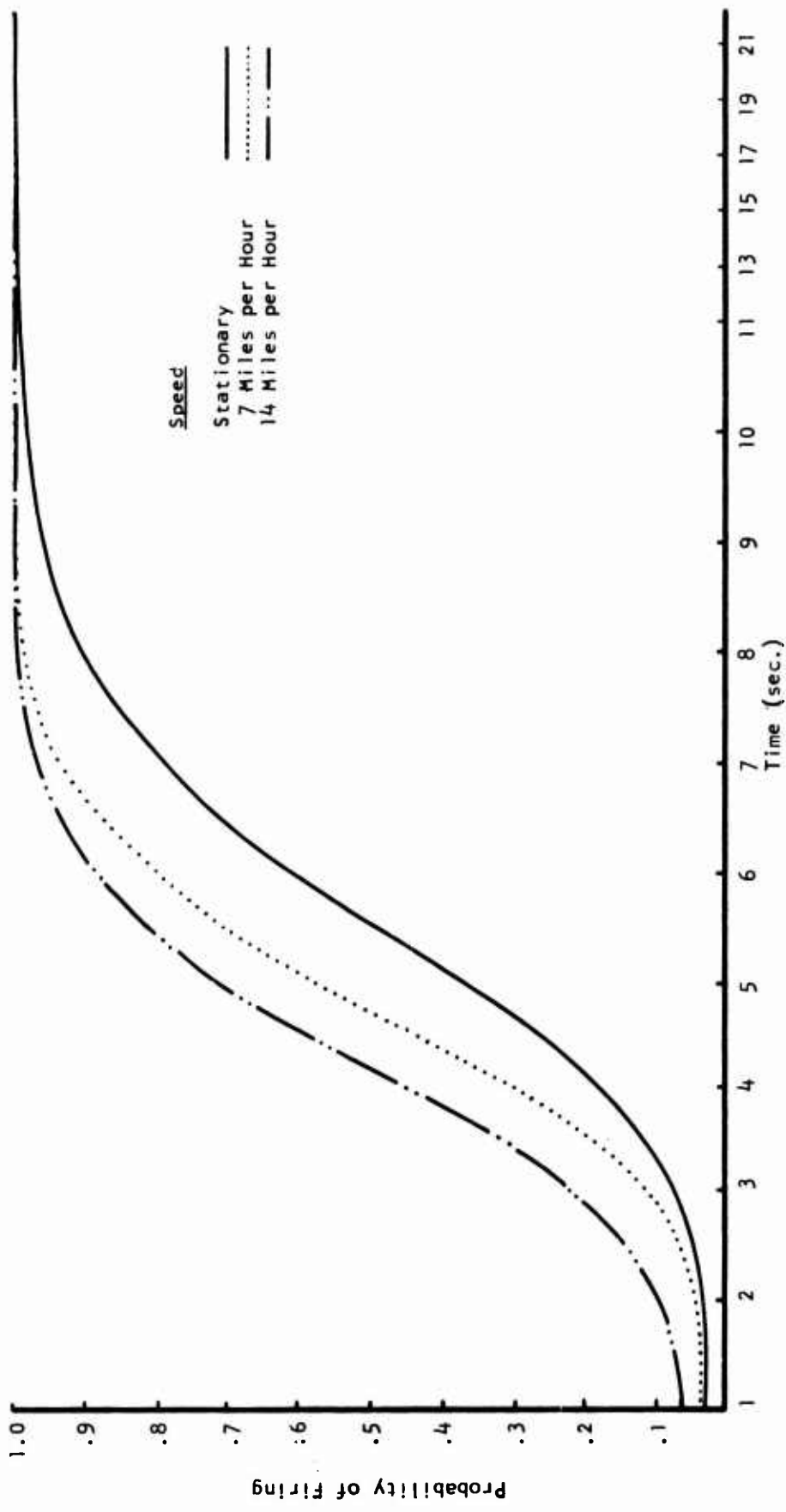
Fig. 48. Phase I – Probability of firing by time for three target speeds.

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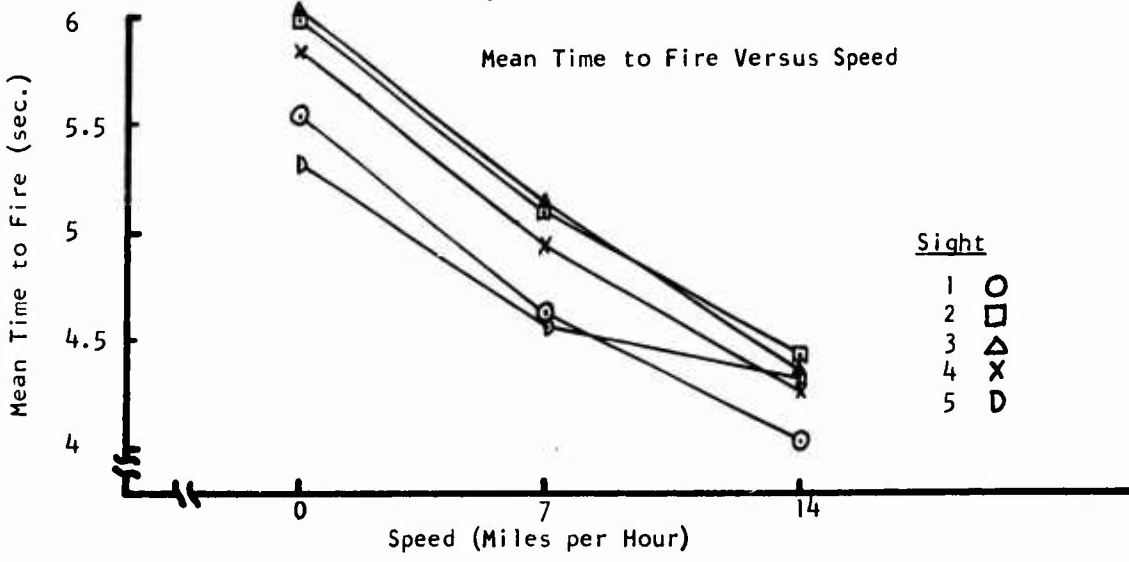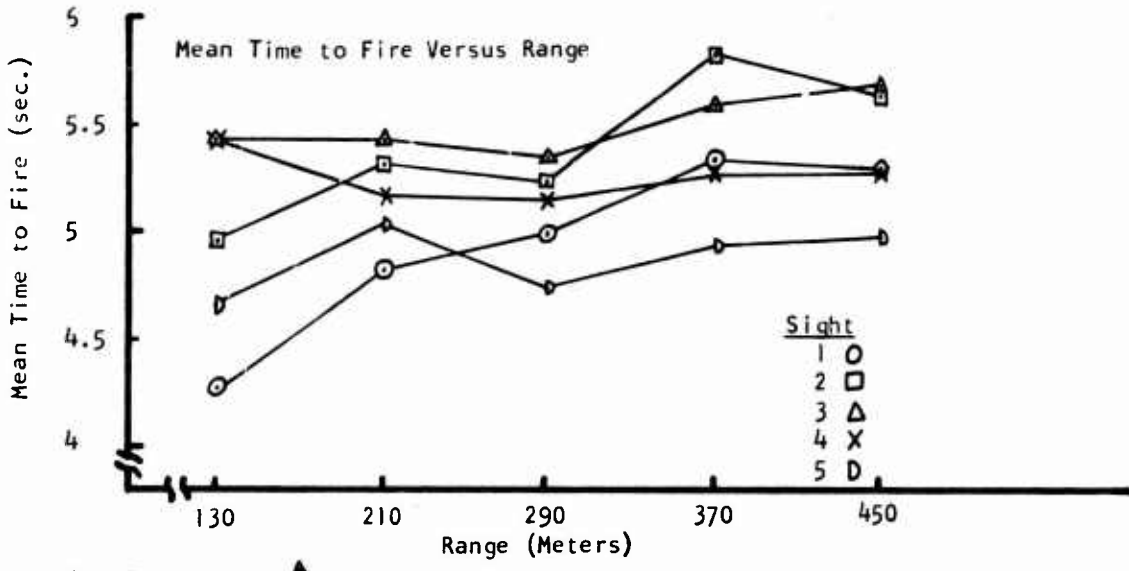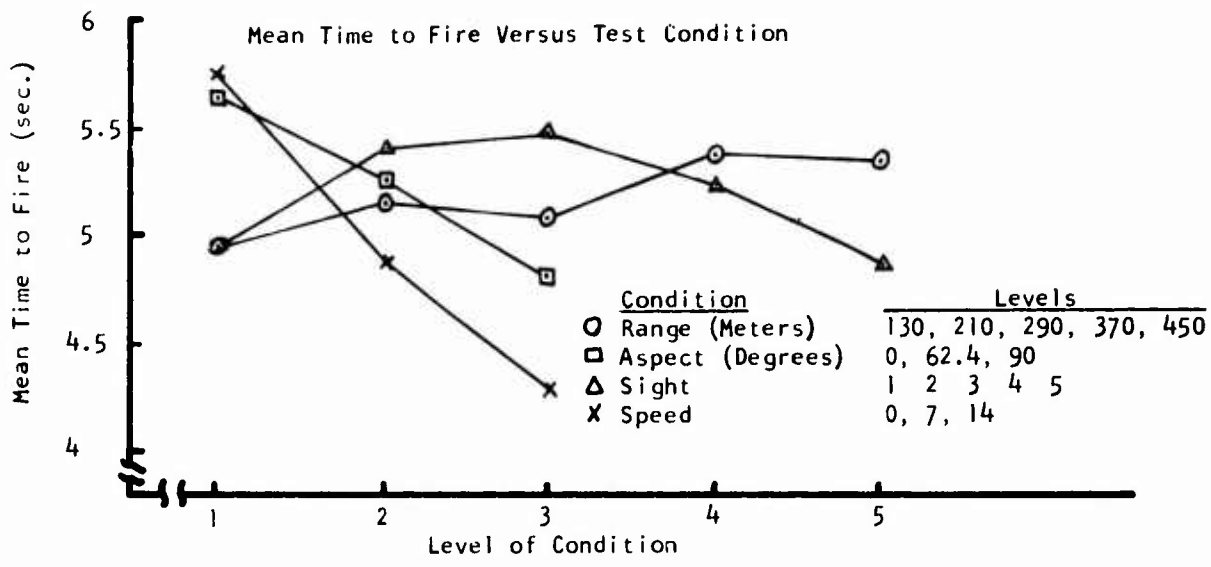
Fig. 49. Phase I — Mean time to fire.
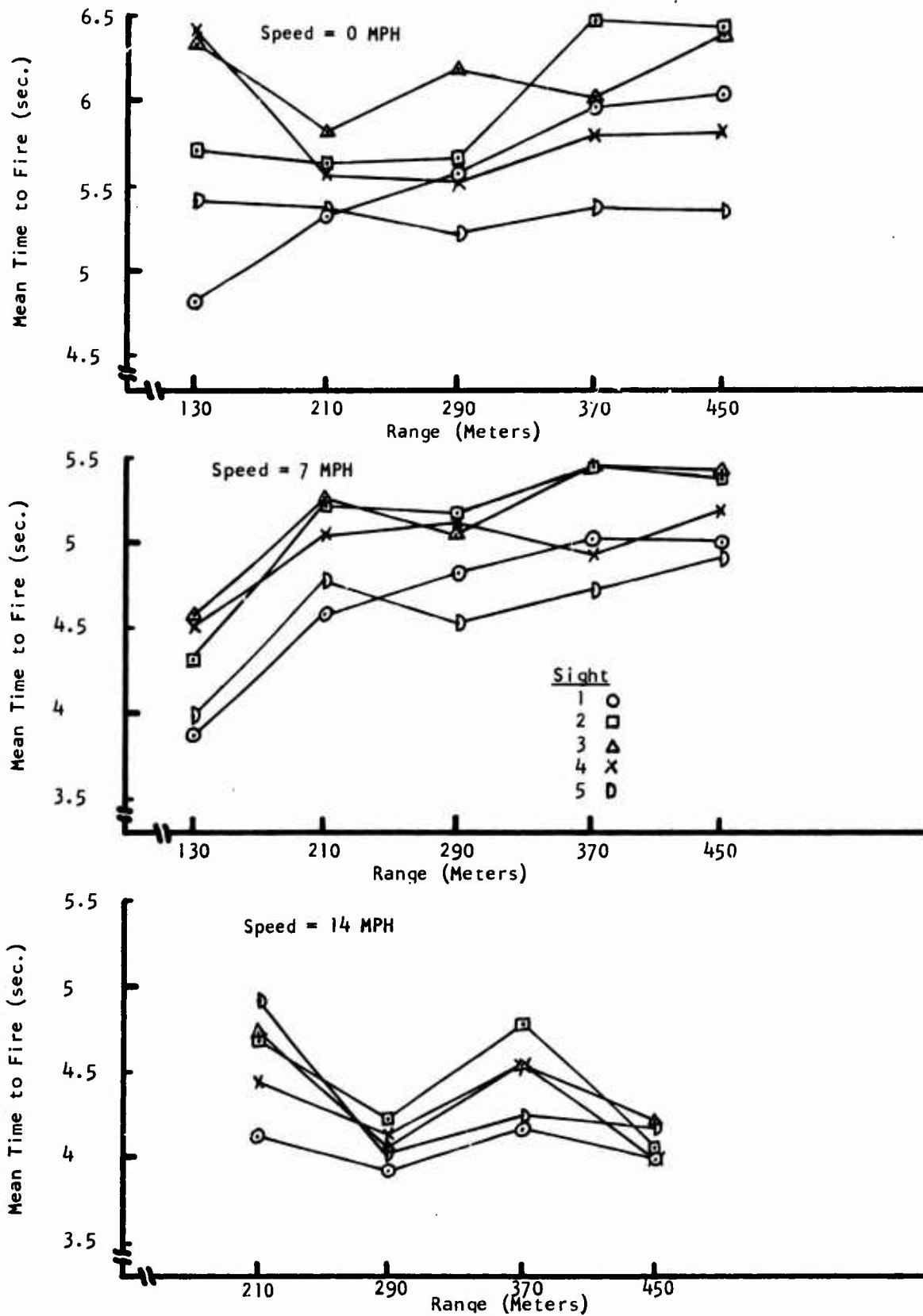
Fig. 50. Phase I — Mean time to fire versus range, for five sights at three target speeds.
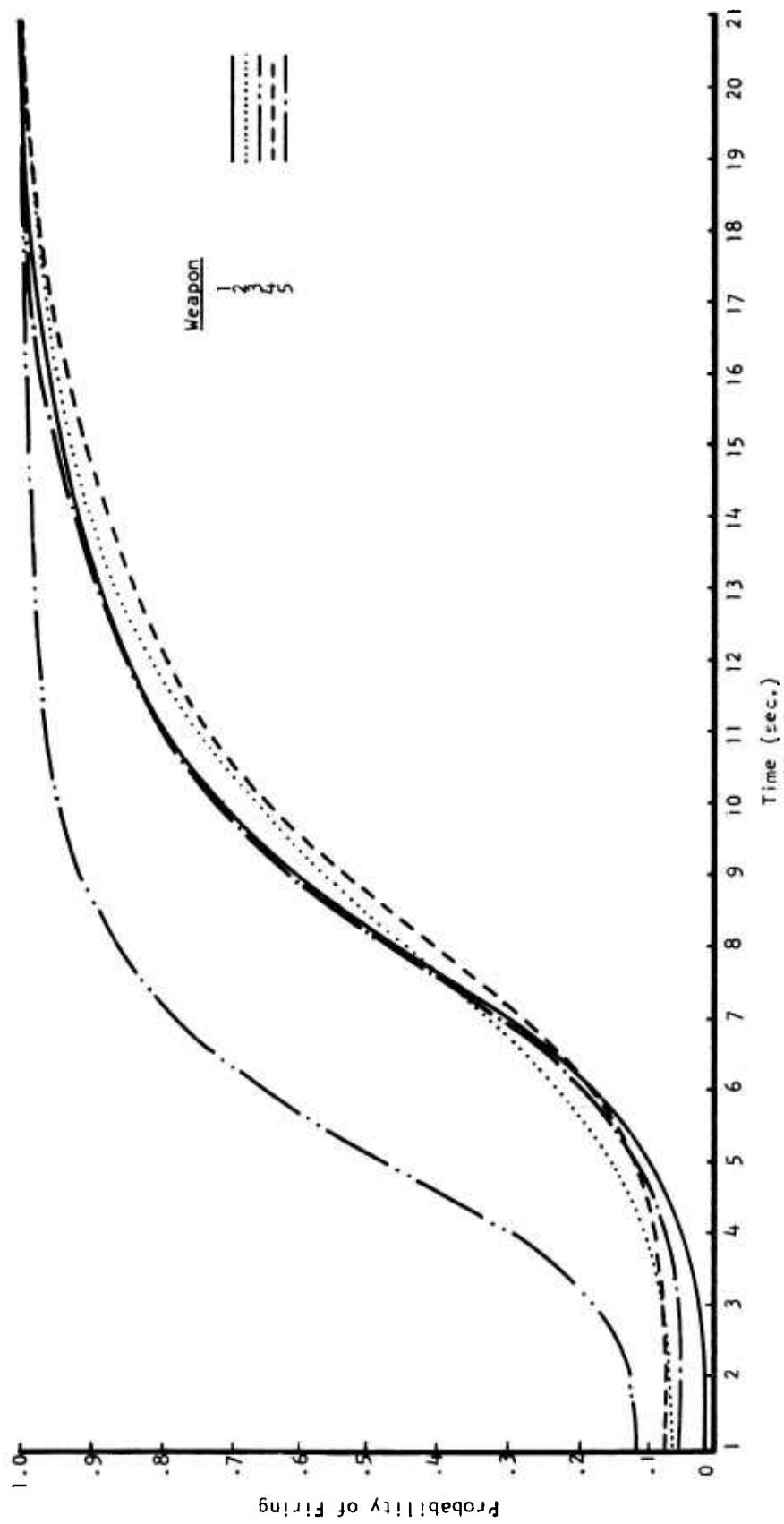
Fig. 51. Phase II, Group 3 — Probability of firing versus time for five sights.
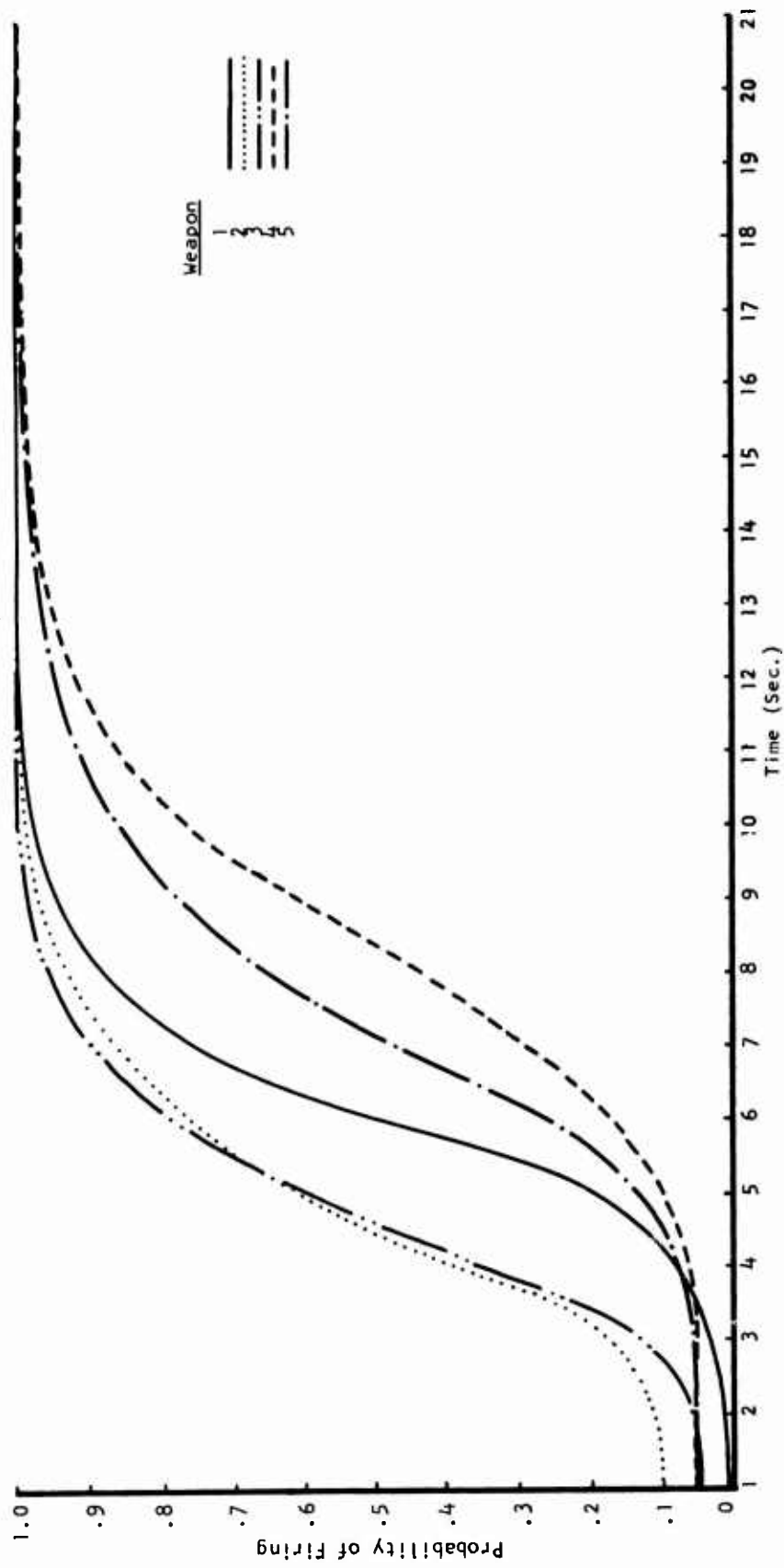
Fig. 52. Phase II, Group 4 — Probability of firing versus time for five sights.
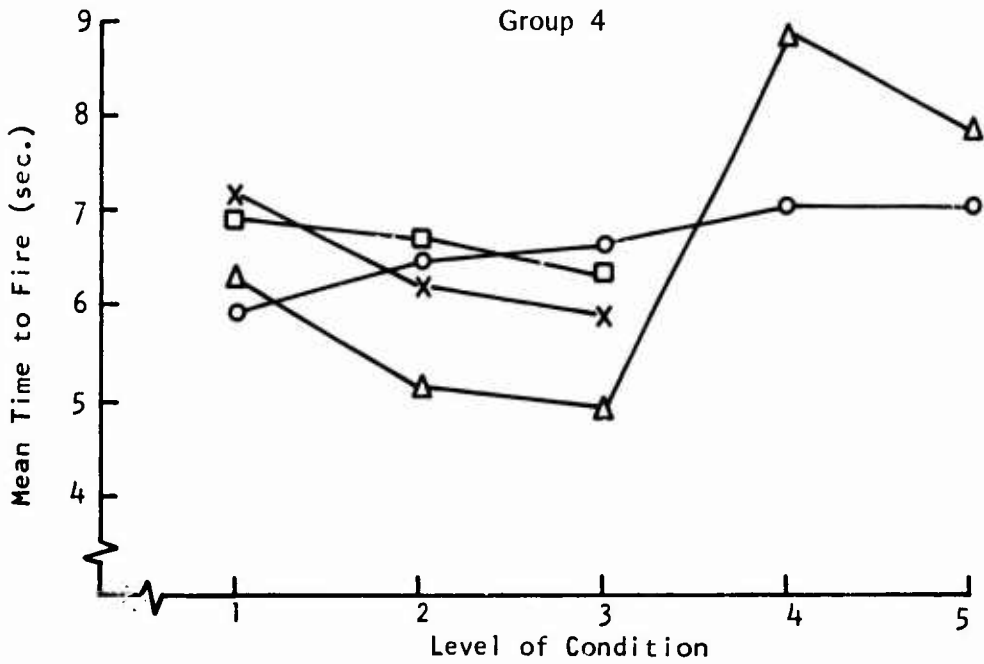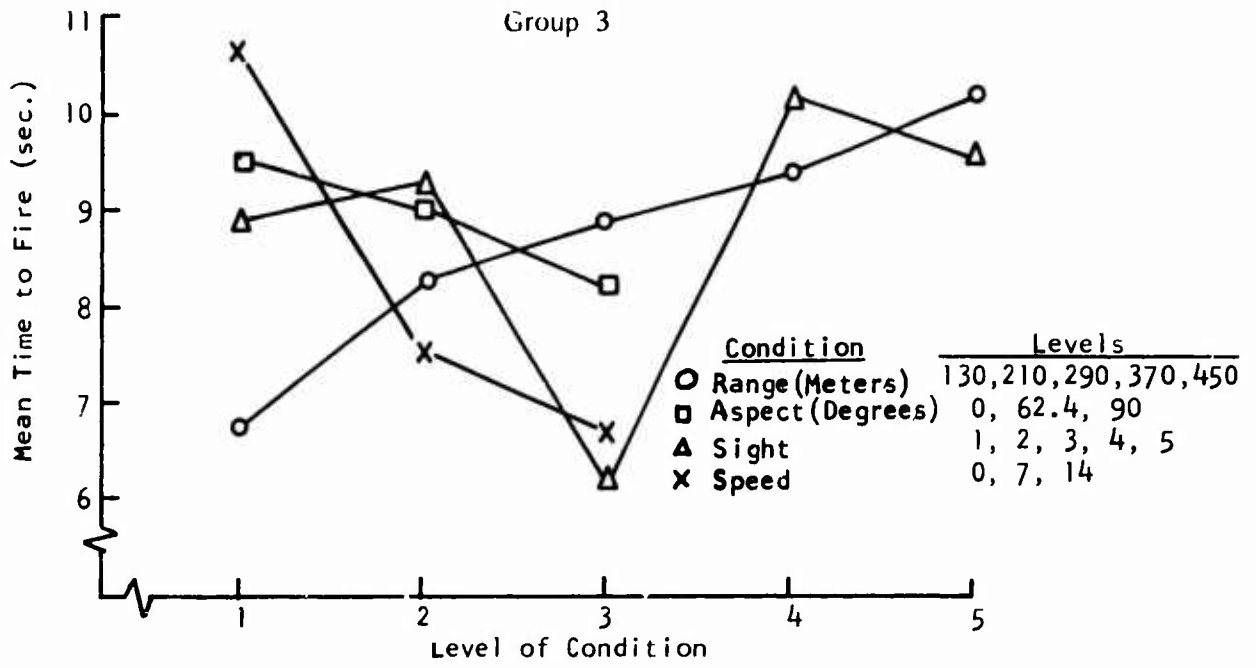
Fig. 53. Phase II, Groups 3 and 4. — Mean time to fire for each test condition.
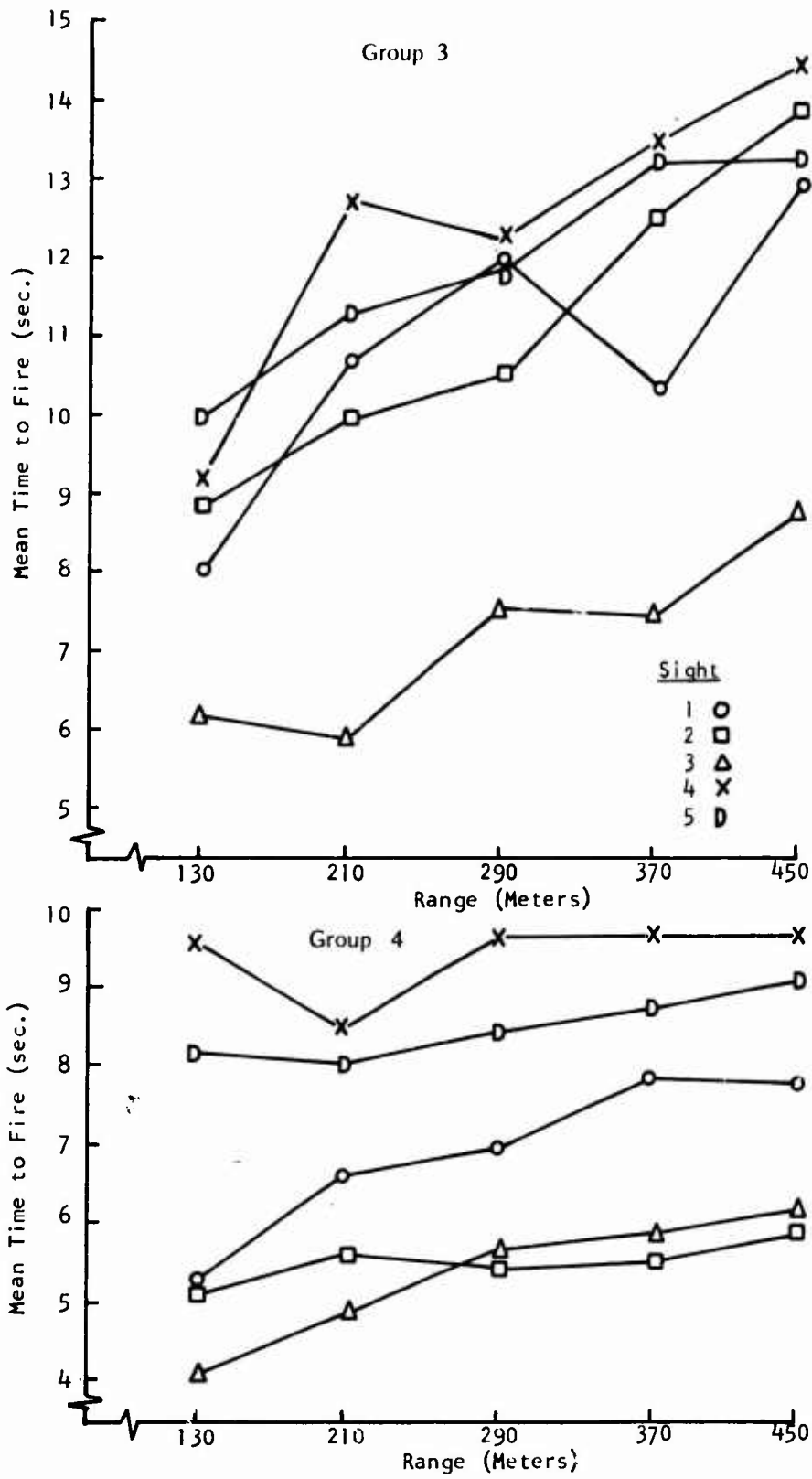
Fig. 54. Phase II, Groups 3 and 4 — Mean time to fire versus
range for five sights, stationary targets.
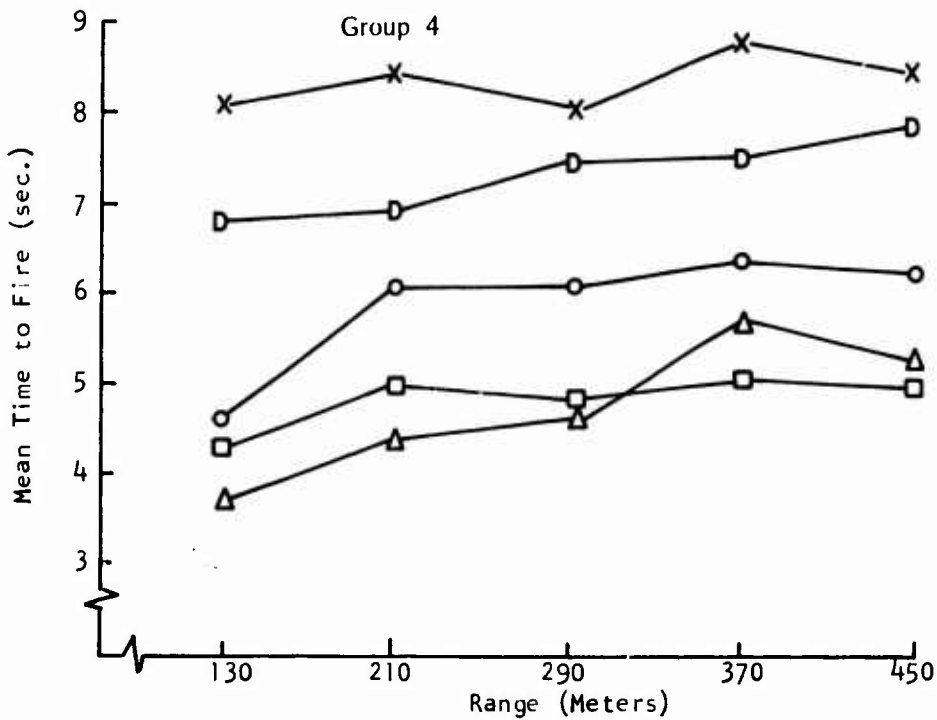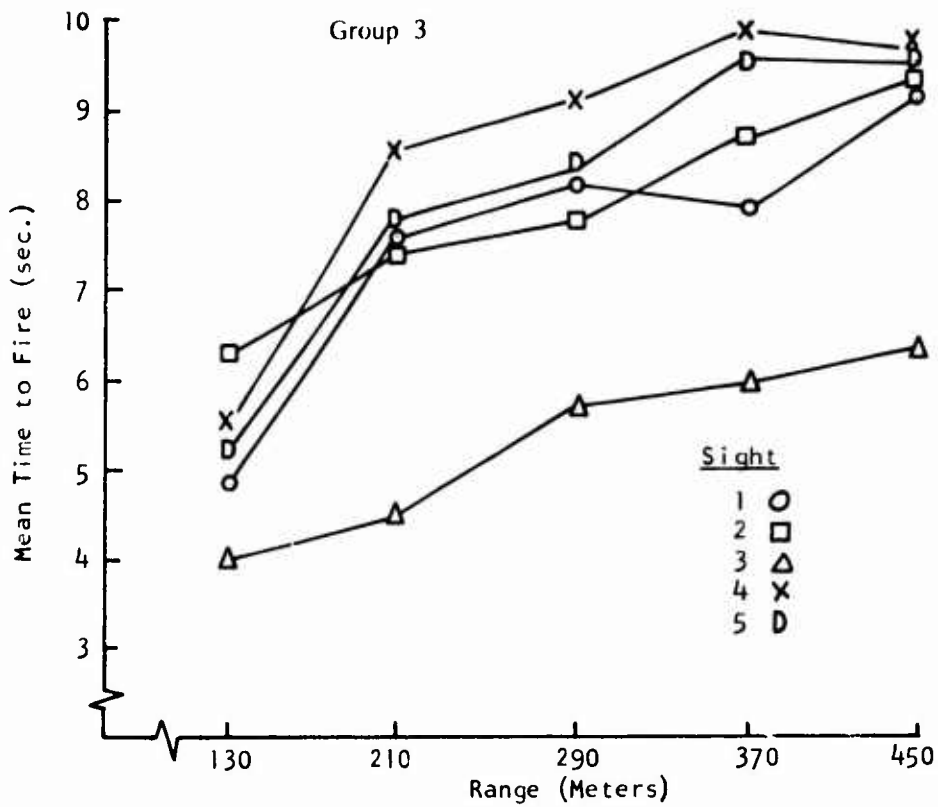
Fig. 55. Phase II, Groups 3 and 4 — Mean Time to Fire
Versus Range for Five Sights, 7-mph Targets

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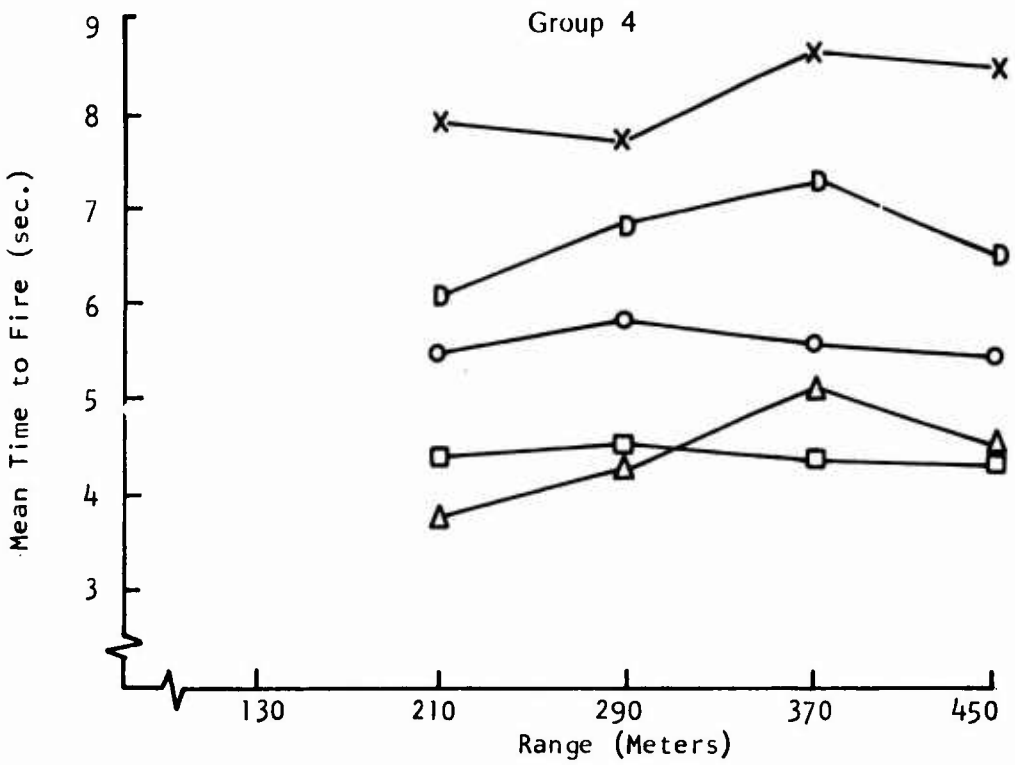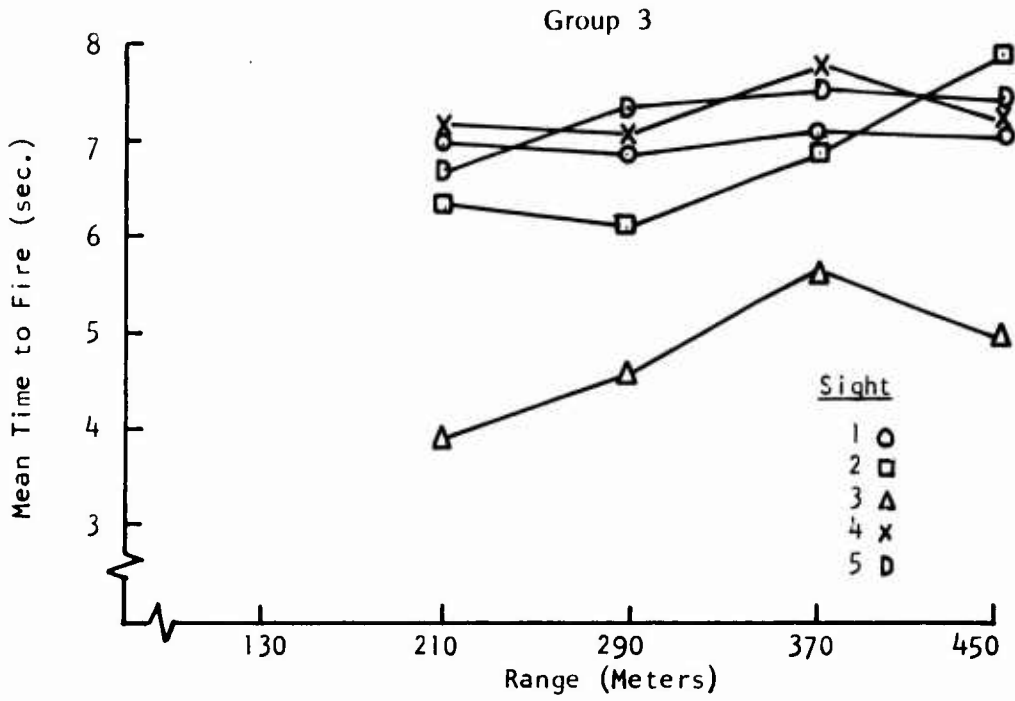
Fig. 56. Phase II, Groups 3 and 4 — Mean time to fire versus range for five sights, 14-mph targets.
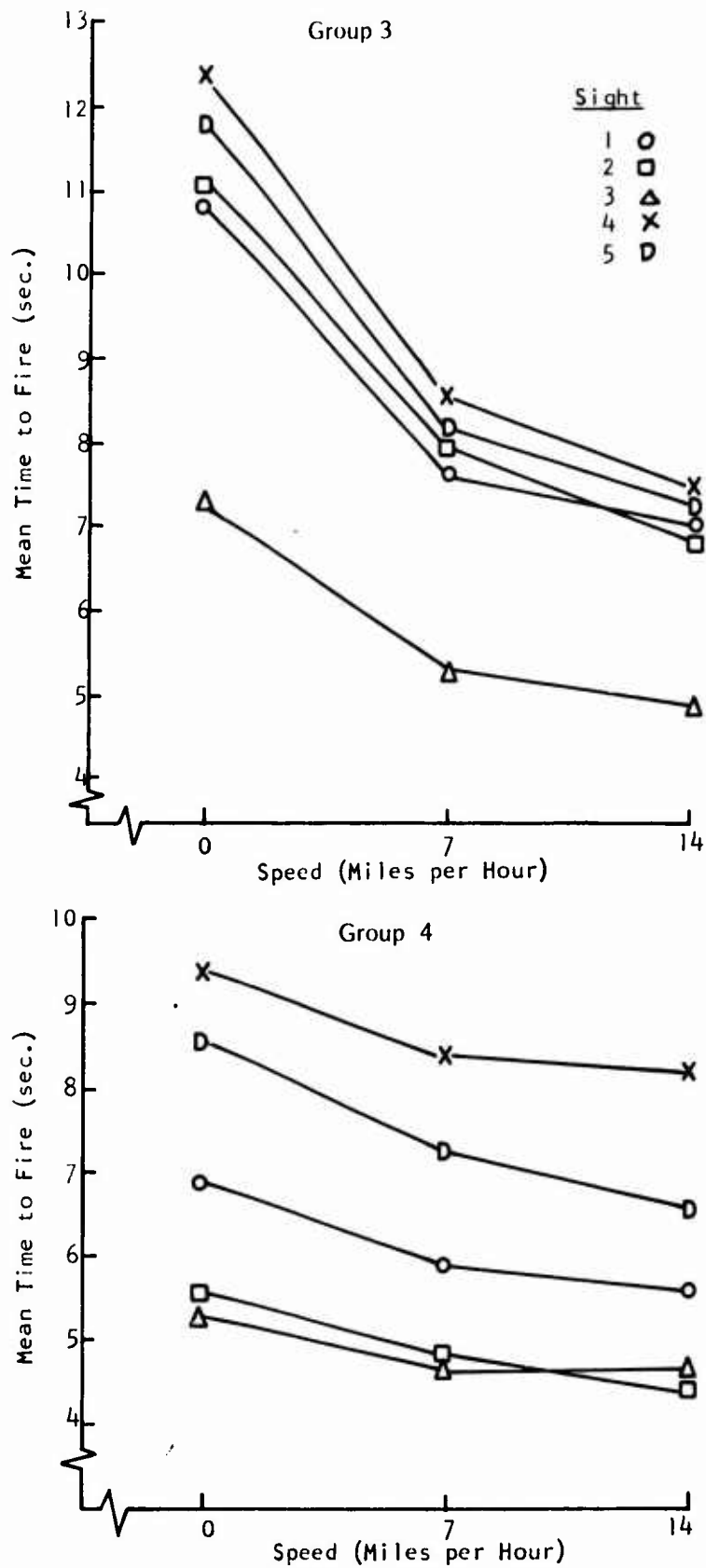
Fig. 57. Phase II, Groups 3 and 4 — Mean time to fire versus target speed for five sight systems.

Gunners' Sight Preferences

a. Questionnaires

The paired comparisons between sights in Questionnaire 1 tested to find whether gunner responses immediately after using the sight differed grossly from their responses at the end of testing (when all sights were rank ordered). Difficulties in administering the questionnaire made these comparisons between sights questionable, so they are not given here.

b. Subjects' Comments

Both Questionnaires 1 and 2 had a section for additional comments, and Questionnaire 2 had additional questions to prompt the subjects to comment on specific physical parameters of the sight (i.e., field of view, size of the stadia lines, and rear-aperture size for the non-optical sights). Subjects in groups 1 and 4 commented profusely, but there were only a few comments from group 2, and none from group 3. The comments are tabulated in Appendix F. The comments may be summarized briefly:

-Subjects in Phase I indicated that it was difficult to see the lines in the non-optical and 1X optical stadia sights.

-Subjects in Phase II made no comments about the stadia lines, not even for the improved Phase I non-optical sight tested with group 4.

-There were no comments about the size of the rear aperture of the non-optical sights.

-The subjects in Phase I reported that the limited field of view degraded their performance with all sights except the 3-power stadia sight. However, it is notable that the 3X sight had the smallest field of view, yet this was the only sight where the subjects did not report difficulty in seeing the stadia lines. Therefore, we believe that the comments about field of view actually referred to the visibility of the stadia lines.

-The subjects in Phase II indicated that, when using the ART sights (which had the smallest field of view), targets were "easy to lose" due to a limited field of view.

-The subjects in Phase I reported they preferred the 3-power stadia sight.

-The subjects in Phase II did not indicate a clear preference for any one sight, but they agreed they disliked the ART sights.

c. Preferential Ordering of the Sights

A nonparametric Friedman analysis-of-variance test analyzed the subjects' rank ordering of the sights (questionnaire 2), as shown in Table F3 (Appendix F). The mean sight preferences are shown graphically in Figures 58 and 59.

In Phase I, some of the differences in mean preferences fail to reach statistical significance, despite their clear, reproducible relationship in the graphs (Figure 58). Combining data for the two groups, all of the differences are highly significant statistically.
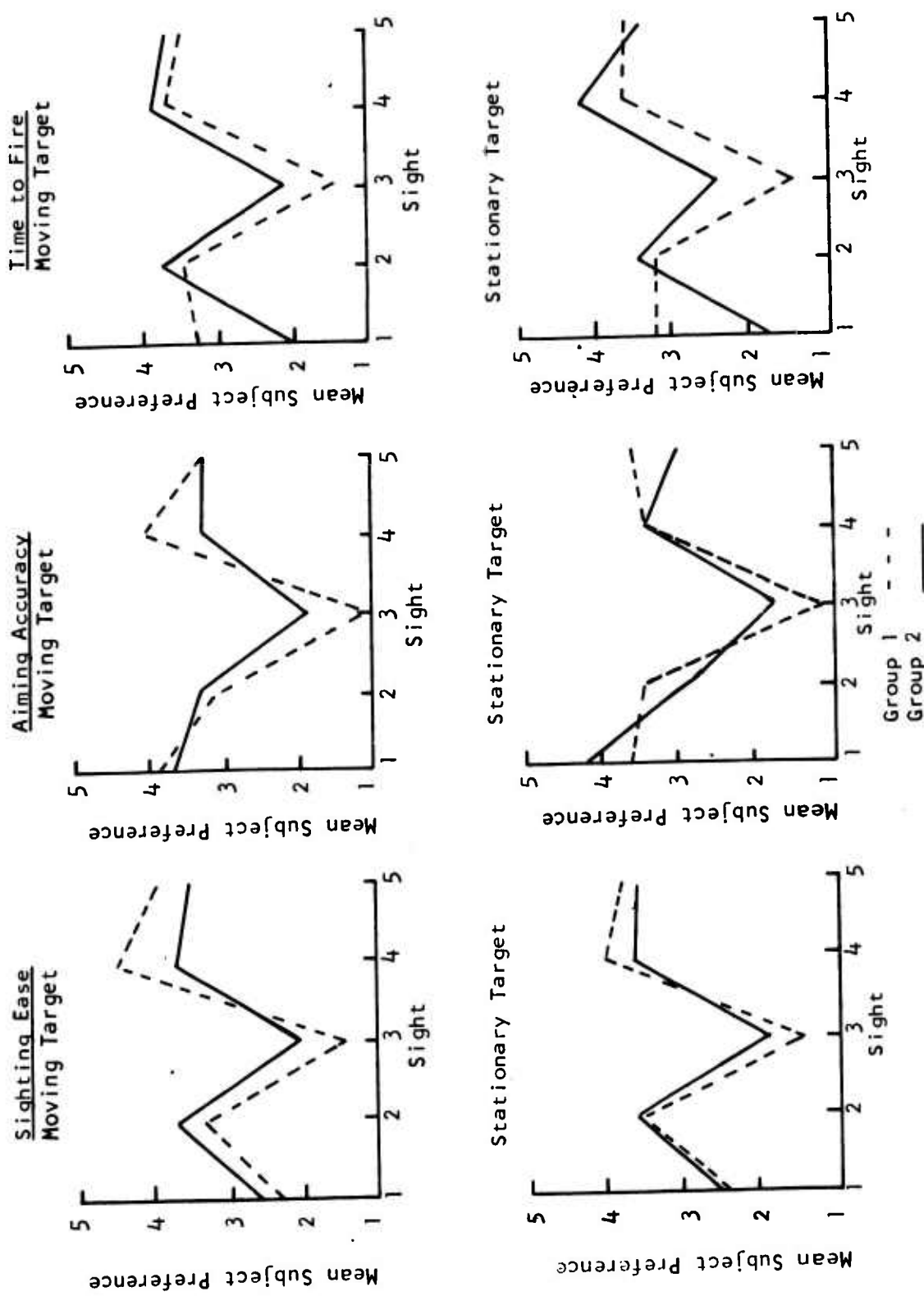
Fig. 58. Phase I — Mean preferences for sights, as reported in questionnaires.

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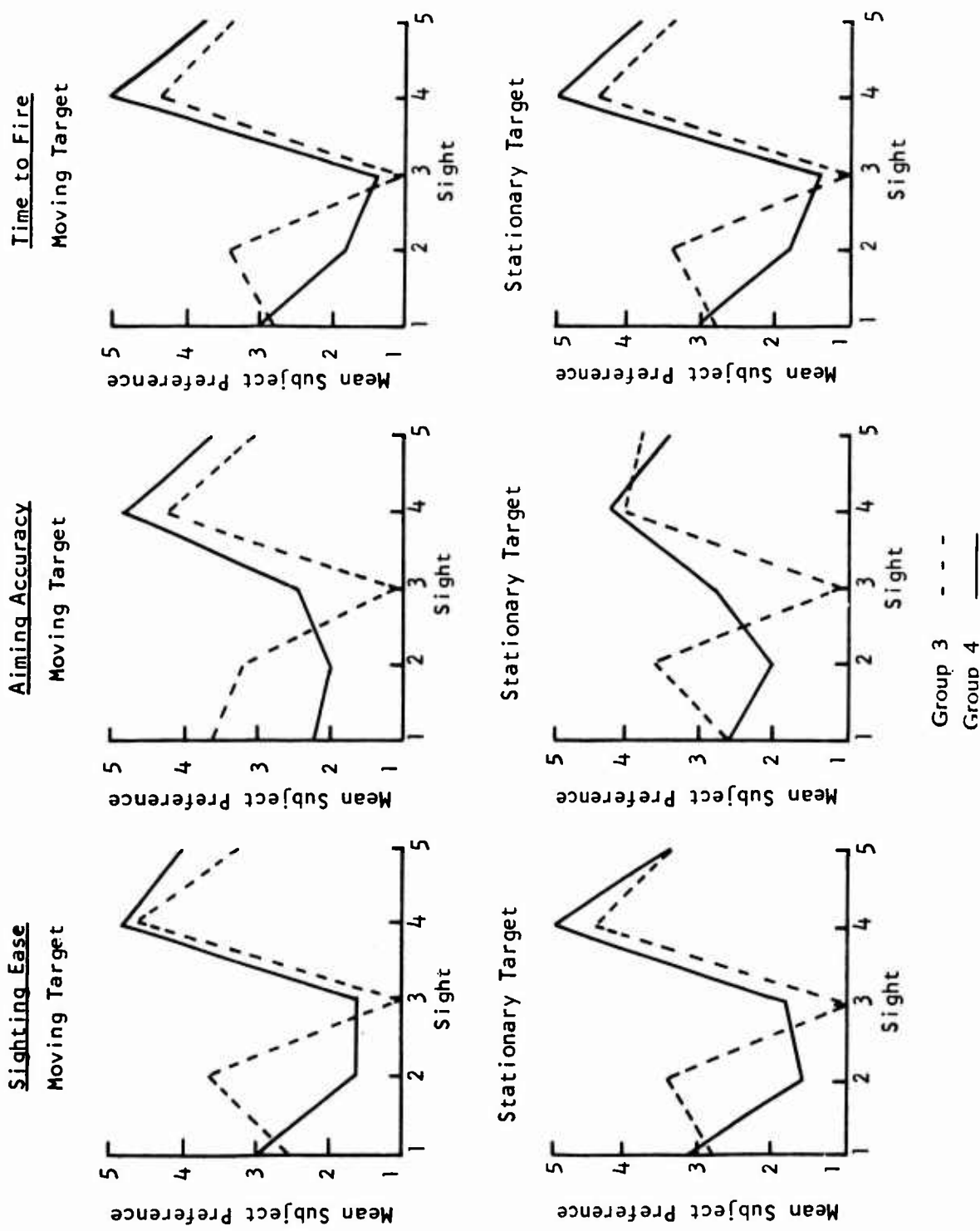
Fig. 59. Phase II — Mean preferences for sights, as reported in questionnaires.

Figure 58 shows that, in Phase I, the subjects chose the 3-power stadia sight (sight 3) as the best sight: the easiest to use, most accurate, and fastest to fire. The ordering of the other sights is not as apparent—sights 2, 4, and 5 were rated about the same; the rifle sight (sight 1) was considered relatively quick and easy to use, but not very accurate.

Figure 59 shows that, in Phase II, both groups of subjects named the man-silhouette ART sight (sight 4) as the most difficult to use, least accurate, and slowest sight. Group 3 chose the 3-power fixed-QE sight (sight 3) as the best sight. Group 4 considered the modified M72 sight (sight 2) as slightly more accurate than the 3-power fixed-QE sight, but a little slower to use. Except for the change in the responses caused by modifying sight 2 between groups, all of the subjects showed similar preferences.

Analysis of Fixed QE Firing Techniques

a. General

At the request of HEL, members of the Ground Warfare Division of the AMSAA (Dr. Michael Borowsky and Mr. Daniel Kirk) performed two separate analyses of fixed-QE firing techniques. They first evaluated single- and multiple fixed-QE firing techniques to determine optimum crossover ranges between QE s used with the rifle sights (sight 1, Phase I). The second analysis examined how aiming error affects hit probability for a single-fixed-QE firing technique.

b. Hit Probabilities for a Multiple-Fixed-QE Firing Technique

The analysis conducted prior to the experiment[21] presupposed a 1-mil (SD) gunner aiming error, and that the gunner estimated range with an error of 20 percent of range (SD). Also, the weapon's velocity was assumed to be 1200 fps, and only stationary, head-on targets were considered. Other parameters used in the analysis and a brief discussion of the computations are contained in Appendix H. Figures 60 and 61 (provided by AMSAA) show hit probabilities, respectively, for single- and multiple-fixed-QE techniques, and for conventional firing when the gunner uses visual range estimation and selects the appropriate range mark in the sight. As shown in Figure 60, for a 17-mil fixed-QE and 350-meter maximum-target-engagement range, a single fixed-QE sight gives a greater hit probability than conventional firing at all ranges closer than 325 meters. In Figure 61, the three-fixed-QE firing technique is shown to have a higher hit probability than conventional firing techniques at all ranges (except near 400 meters). The crossover ranges between QE s shown for this firing technique are those used for the rifle sight that was tested.

c. Hit Probabilities for a One-Fixed-QE Firing Technique

This analysis addressed: (1) bottom and center aim on the target; (2) 950 and 1,000 fps muzzle velocities (less than the previous analysis, and closer to the muzzle velocity demonstrated for the SMAWT weapon); (3) stationary head-on and side-on targets; (4) 300- and 350-meter maximum-target-engagement ranges; and (5) gunner aiming errors from 0.5 to 3 mils. The analysis showed that aiming at the target's center reduces hit probabilities for midrange targets, as does a maximum-target-engagement range of 350 meters. Smooth curves were hand-fitted to the data from Appendix H (which shows hit probabilities for 50-meter increments of range) for bottom

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[21] The rifle-sight aiming errors and the gunner's range-estimation errors measured in the experiment differed from those assumed in this analysis.

81mm RR V_o = 1200 f/s   C = .3442   D = T119E11
Prone Gunner Aiming at Base of
7.5' x 7.5' Target

— Q.E. = 15 ṁ if $0 \leq R_E \leq$ 300 $\overline{P}_H$ = .716
-- Q.E. = 17 ṁ if $0 \leq R_E \leq$ 350 $\overline{P}_H$ = .795
— Q.E. = 17 ṁ if $0 \leq R_E \leq$ 300 $\overline{P}_H$ = .731

Conventional Firing
20% Range Est Error
Aim at Target Center
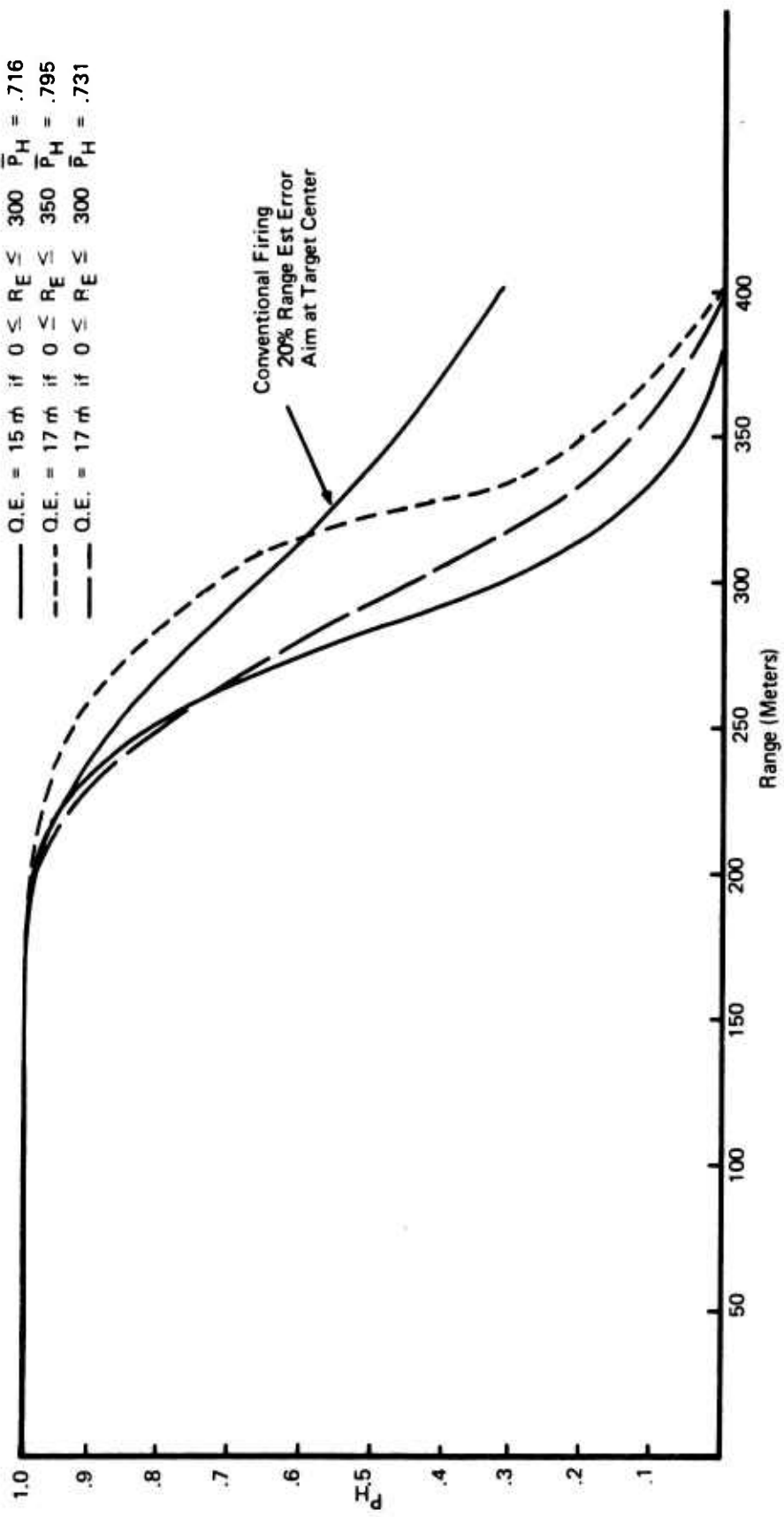
Fig. 60. Hit probability by range for one-fixed-QE firing techniques and conventional firing.

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Fig. 61. Hit probability by range for multiple fixed-QE firing techniques and conventional firing.

81mm RR V_O = 1200 f/s C = .3442 D = T119E11
Prone Gunner Aiming at Base of
7.5' x 7.5' Target

Q.E. = 17m if $0 \leq R_E \leq 350$ $\bar{P}_H$ = .674
     = 27m if $350 < R_E \leq 500$

Q.E. = 17m if $0 \leq R_E \leq 300$
     = 20m if $300 < R_E \leq 400$ $\bar{P}_H$ = .723
     = 27m if $400 < R_E \leq 500$

Conventional Firing
20% Range Est Error
Aim at Target Center

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aim, 950 fps muzzle velocity, 300-meter maximum range, and aiming errors from 0.5 to 3 mils. Two methods of computing hit probability were examined. The first—penalized gunner—scores a miss if a target is within range, and the gunner judges incorrectly that it is out of range and does not fire. The second—non-penalized gunner—only scores hits or misses if the gunner actually fires. These data are shown in Figure 62 for the penalized gunner, and in Figure 63 for the non-penalized gunner.[22]

Comparing the hit probabilities within each figure shows that aiming errors of 0.5 to 1.5 mils produce only small degradations in hit probabilities; however, aiming errors larger than 1.5 mils reduce hit probabilities much more. Comparison of the two figures shows that penalizing gunners for not firing at targets within the maximum-target-engagement range reduces the hit probability.

The results of the analysis indicate that:

-For the measured aiming errors with the rifle sights and the 3X sight (about 1.2 and 0.9 mils, respectively), there is no substantial difference in respective hit probabilities.

- For the muzzle velocities considered in the analysis, the weapon's maximum target-engagement range is about 300 meters.

-The aim point on the target should be at the target's base (bottom aim) for a single-fixed-QE.

Analysis of Hit Probabilities for the Phase I Stadia Sights and Rifle Sights with a
One-Fixed QE Firing Techniques

Subsequent to the conduct of the experiment, data for the Phase I sights were forwarded to the Concepts Analysis Laboratory of the U.S. Army Ballistic Research Laboratories for analysis of the hit probabilities associated with the length/width stadia sights and rifle sights with a single fixed QE. Details of the analysis (conducted by Mr. Robert Gschwind) are contained in Appendix J; a brief summary follows:

In the analysis, the weapon ballistic parameters used in the previous AMSAA analysis were used in determining hit probabilities for stationary head-on targets. The hit probabilities are shown in Figure 64. The labeling of the curves is as follows:

(a) "Graze-fire" and "graze-fire minus no-shoot" are, respectively, the non-penalized and penalized gunner as in the previous analysis, but with an aiming error as shown in the table in Appendix J (approximately 1.3 mils);

(b) "Iron sights" assumes that the gunner estimates range (21% = 1 standard deviation) and has a 35-meter one-standard-deviation error in setting the range scale with 100-meter range increments;

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[23]The hit probability for a non-penalized gunner is the probability of a hit, given a shot, $P(H/S)$, and for the penalized gunner it is $P(H/S)*P(F)$, where $P(F)$ is the probability that the gunner fires at the target, i.e., the probability of a hit, given a target.
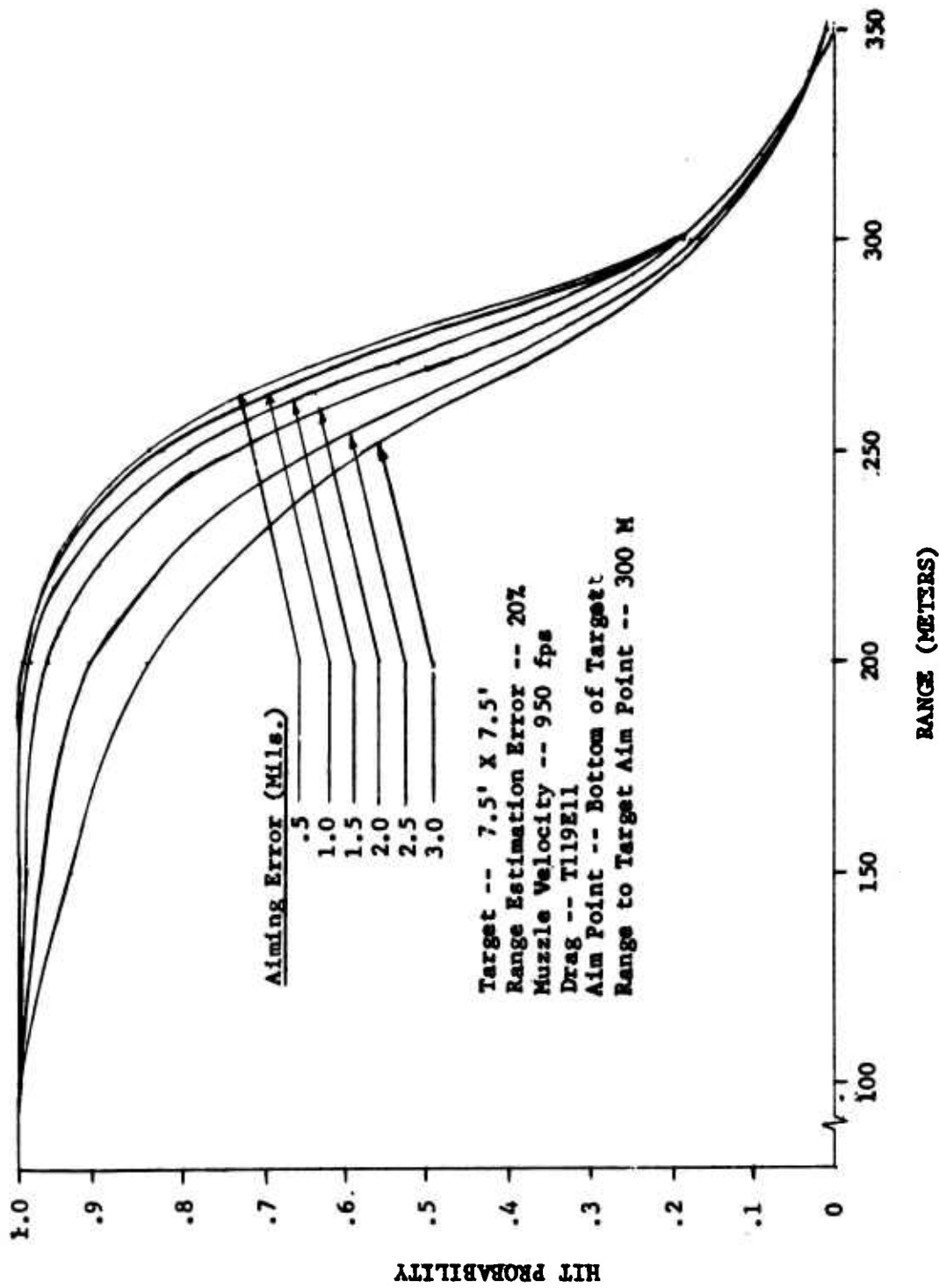
Fig. 62. Hit probability by range for a one-fixed-QE firing technique as a function of aiming error—Penalized gunner.

Aiming Error (Mils.)
.5
1.0
1.5
2.0
2.5
3.0

Target -- 7.5' X 7.5'
Range Estimation Error -- 20%
Muzzle Velocity -- 950 fps
Drag -- T119E11
Aim Point -- Bottom of Target
Range to Target Aim Point -- 300 M

RANGE (METERS)

HIT PROBABILITY

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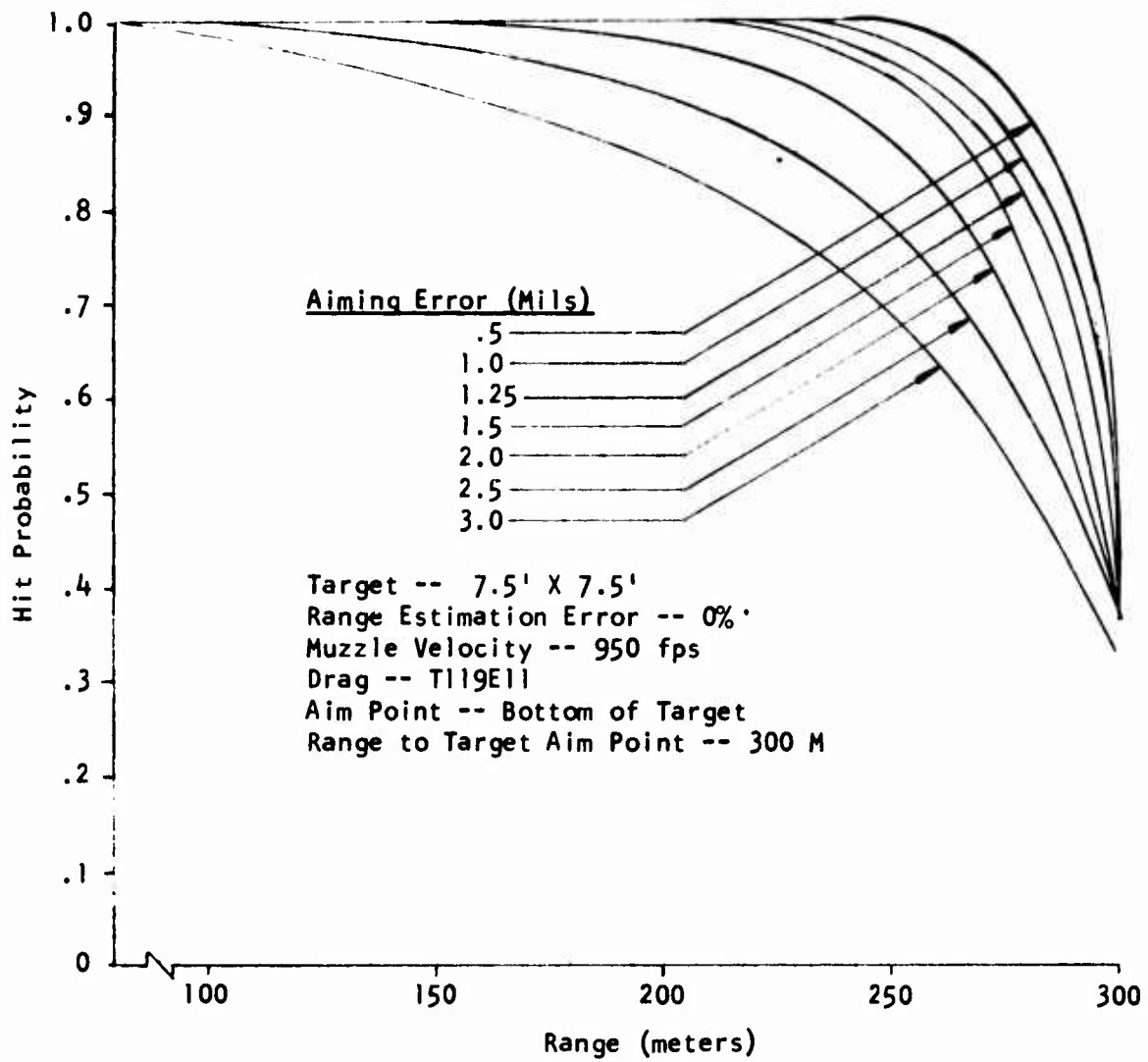
Fig. 63. Hit probability by range for a one-fixed-QE firing technique as a function of aiming error—Non-penalized gunner.

HIT PROBABILITY

7-1/2' x 7-1/2' TARGET, 950 FPS PROJECTILE
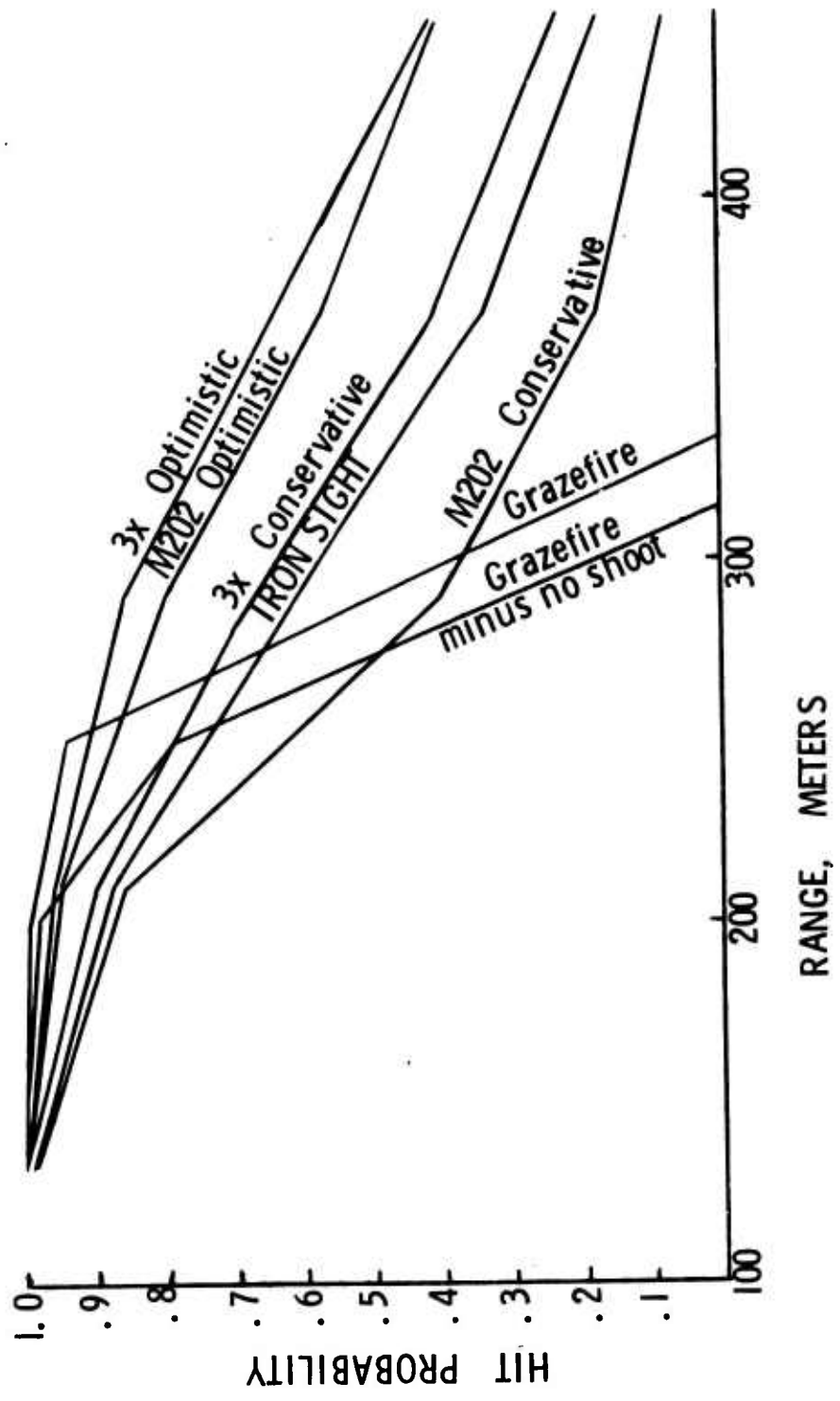
Fig. 64. Hit probability by range for the 3X and 1X length/width stadia sights, rifle sights with one fixed QE, and conventional firing.

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(c) "Conservative 3X" and "conservative M202" (the unity power sight) are computed using the measured biases and standard deviations combined over the three target aspects (for an all-aspect target), plus a 10-percent standard deviation in target dimensions, to allow for the weapon being fired at tank targets other than the one for which the stadia are designed; and

(d) "Optimistic 3X" and "optimistic M202" assume that the superelevation biases can be removed by suitably redesigning the stadia to fit a specific target, and firing only at that particular target.

Based on this analysis, BRL concluded that "..the current state-of-the-art of stadia performance isn't much different from the performance achieved with iron sights and human range error," and, although performance could be improved if the superelevation biases could be removed, solving this problem would create others: (1) "..increase the standard deviation;" (2) "..cause changes in aiming performance;" and (3) "..need to be tested before any potential benefits could be relied upon."

It was recommended that "..the most appropriate immediate solution [for the sighting system on a LAW-type weapon] appears to be some form of simple sight to be issued as part of the weapon with provision—some sort of dovetail or bracket—built into the weapon to accept a high-performance sight as a reusable accessory when it is developed and if it is available to the gunner when he needs it."

DISCUSSION

General

This experiment investigated performance measures of hit probability, time to fire, and subjective sight preferences.

Analysis of the data shows that the gunners fired low with the conventional length/width sights, and that they underestimated range both with the rifle sights and with the turret-stadia judgment gates. Major causes of superelevation and range biases were identified. A number of hypotheses have been formulated to explain other causes of these effects (Appendix L). This discussion considers, first, sights that show little or no promise of effective use on the weapon (most of the sights tested in Phase II); second, differences in firing times between sights; third, the subjects' sights preferences; and last, the performance of the better sights. It should be stressed,

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however, that—in performance, accuracy, or time to fire—none of the tested sights demonstrated significant improvements over conventional firing where the gunner makes an "eyeball" estimate of range to target, and then engages the target with iron sights.

Sights Giving Relatively Poor Performance

The ART sights tested in Phase II produced higher superelevation SDs (or lower precision) than the 1200-fps-weapon stadia sights tested in Phase I. Rejecting ART sights for use on a SMAWT weapon solely because of low precision is somewhat risky, since precision could only be estimated by extrapolations (due to the gross error in the design of the sights). As compared to the Phase I sights, the firing times increased substantially—almost doubled—because the ranging technique was more complex. This finding weighs against using the ART sights, especially in any circumstance that requires quick gunner response. Compared with the 3X sight, the ART sights are also much larger (Figure 6), and have smaller exit pupils, thus requiring more eye-relief, and consequent difficulty in acquiring targets.[23] To use the ART sight, the gunner had to support the front of the weapon while adjusting the ranging/ballistic cam; this procedure caused the weapon to jiggle, especially when tracking moving targets.

The RPG-7 height-stadia sight produced a higher superelevation SD than the least accurate length/width stadia sight designed for 1200-fps, the modified M72. With the RPG-7 sight, time to fire was 1 to 3 seconds longer than with the modified M72 sight tested in Phase II. Using height stadia for a tank shorter than the one used in this experiment would most likely increase the superelevation SD still more, because any obscuration of the vehicle's lower portion would conceal a larger percentage of its total height. For example, the T55 and T62 Soviet tanks are approximately 2.4 and 2.3 meters high, as compared to the 2.6-meter-high tank used here.

Based on the model used to predict an unaided gunner's range classification, the judgment gates in the turret-stadia sight gave range-estimation accuracy within 18 to 21 percent of the true range, which is no better then the unaided gunner. Targets larger or smaller than the one for which the stadia are designed will change superelevation more than for a conventional length/width stadia, when the target is near the crossover range between QEs. It is also likely that turrets may have equipment stowed at the rear, as well as having a gun mantlet (which was not used on the mockup turret); such equipment will degrade accuracy by masking the turret's circular shape.

Time to Fire

The most accurate sight tested in Phase I, the 3X sight (sight 3), also gave the longest firing time. However, the difference in time to fire between this sight and the modified M72 sight (sight 5), which was fired fastest, is only about 0.6 seconds and thus probably unimportant.

It is sometimes assumed that the gunner can use an optical sight quicker than a non-optical sight, because there is one less point to align. Yet in Phase I, the opposite is found; and even the rifle sight, which required the gunner to perform the largest number of tasks (estimate range, dial in superelevation, then aim), gave faster firing times than the optical sights. In Phase II, the 3X

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[24]On bright, sunny days, when the sun was in front of the gunners, testing was stopped because glare in the sight reduced target-acquisition capability.

turret-stadia sight, compared to the modified M72 sight, was quicker to use at close ranges (where QE-1 was used), but slower to use at longer ranges (where the other aim-points were used). Even so, the extreme differences are less than 0.6 seconds.

Subjects' Sight Preference

Of the three performance measures for which gunners rated the sights, only sighting ease was easy for the gunners to judge. Ratings of a sight's accuracy and time to fire may well reflect the gunner's "confidence" in the sight, because he was not given information about his actual performance. Results from Phase I show confidence does not necessarily measure performance because the gunners rated the 3X sight as quicker to use than the other stadia sights, when it was actually the slowest to use. The gunners' comments indicated that they judged stadia-line accuracy largely by their visibility. For the rifle sight, the need to estimate range caused the sight to have a low accuracy ratings, gunner's rated accuracy low because it had no aids for estimating range.

Although the subjects showed a clear dislike for the ART sights, they had no similar reluctance to use the other sights. For example, in Phase I, the modified M72 was rated low; while in Phase II, the same sight (with a better reticle) was rated on a par with the 3X turret-stadia sight. Comparing comments and ratings between test phases, the gunners apparently preferred (or had greater confidence in) a fixed-optical-power sight, with greater-than-unity magnification and length/width stadia, i.e., the 3X sight tested in Phase I.

Sights for a Light Antitank Weapon

After excluding most of the tested stadia sights because of their relatively poor performance, and having found that there is only a relatively small difference in aiming error between a rifle sight and a 3X sight, there is only a narrow range of choices of possible sights for a light antitank weapon. Possible sights are (1) a 3X length/width stadia sight; (2) a multi-fixed-QE rifle sight; or (3) if the weapon has a reduced range (about 300 meters), a single-fixed-QE rifle sight. The first gives performance only slightly better than for conventional firing; there is promise of improving its performance in the future, but only after considerable redesign and testing. The second does not appear to be a viable alternative to conventional firing because, at the longer ranges, it can give lower hit probabilities than conventional firing; however, additional testing should be conducted to determine the cause of the gunner's range-classification biases. The third sight is acceptable only for a weapon with 300-meter maximum range, and for use against tank targets (or targets nearly as high as a tank). Also, if the sight contains only a fixed-QE marker, the gunner will be unable to take advantage of situations where he has prior range information. One way to compensate for the limitations of fixed-QE is including both range information and a fixed-QE aimpoint in the sight.

If range information and a fixed-QE aimpoint are included in the sight, the range and target-height limitations associated with fixed-QE can be overcome. For tank targets (or targets at least as tall as a tank) at ranges less than 300 meters, the gunner would use the fixed-QE

aimpoint. For targets at known ranges, or targets beyond 300 meters, or targets smaller than a tank, the gunner would use conventional firing, setting the sight at the appropriate range line.

The sight could be a peep and post, the peep adjustable vertically for increments of range and with a fixed-QE battle sight setting. The sight could be hinged, like the M72 sight, to fold down for storage in the weapon when in the carry mode. When readying the weapon for firing, the peep could automatically be set at the fixed-QE setting for rapid target engagement. Another possible sight would be a peep and front reticle—similar to the M72 sight, but without stadia lines. The reticle would contain range markings plus a fixed-QE aimpoint, and the sight would fold down for storage in the weapon.[24]

Coincidence range finders and laser range finders are other possible weapon sights. A Coincidence range finder, although not limited in performance by target sizes, is large, heavy, and requires the use of a bipod or other steadying device. A laser range finder would be more accurate than any of the other sights, but present models cannot meet the range and weight limitations. These sights can therefore only be considered as future possibilities.

Selecting a sight is a difficult task. Although the 3X sight promises good performance against selected targets, it is not an integral part of the weapon, and its usefulness is limited to only a few of the many targets at which the weapon will be fired. When firing at targets where the stadia cannot be used, the gunner must use unaided visual techniques. The rifle sight, though not esthetically pleasing, is not limited to specific targets, and can be inexpensive, lightweight, and an integral part of the weapon. In selecting a sight for the weapon, much thought should be given to the number of times a gunner must "grab" a weapon and fire it as quickly as possible, then "grab" another weapon. If the gunner must fumble around pulling a sight out of a pouch or weapon end-cap, or if he must waste time changing sights from one weapon to another, his effectiveness will obviously be degraded.

CONCLUSIONS

1. Length/width stadia sights give faster firing and greater accuracy than the other stadia sights tested. To generalize abouth length/width stadia sights:

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[24] The nomenclature M72 has been used here to indicate the M72A1 and M72A2. It should be noted, however, that the sights differ in the earlier and later versions of the weapon. The early version, the M72, had a sight reticle containing range lines, but no stadia lines; the sight reticle was folded down into the weapon for storage and retained there by the end-cap. In the later versions, stadia lines were added to the reticle; also the sight reticle was stored folded back in line with the bore, in a channel on the weapon.

a. Because of the higher muzzle velocity assumed in designing the SMAWT weapon sights (1200 fps), they are much more accurate than the current M72 sight (designed for 475 fps). Unfortunately, the SMAWT weapon's muzzle velocity (approximately 1000 fps) was lower than assumed, so the sights will not perform as well as these tests indicate.

b. Superelevation SD is larger for half-stadia ranging than for full-stadia ranging, because smaller targets are harder to fit into the stadia, and the gunner must shift his aimpoint after ranging.

c. The superelevation SD increases with target speed.

d. The target's measured range (and the resultant superelevation) vary with target aspect. Target aspect causes an inherent range finding bias, and limits the sight's range finding precision.

e. The thickness of the stadia lines causes a negative superelevation bias.

f. The way gunners use the sights causes the superelevation to be lower than predicted from the separation of the stadia lines; this reduced superelevation is directly related to the target's size in mils and the slope of the stadia lines.

g. There is a negligible difference in time to fire, regardless of the sight used.

2. The 3X length/width stadia sight produces a higher hit probability than the unity sight—which in turn is better than nonoptical length/width stadia sights. However, none of these sights, as currently designed, give much better performance than iron sights and human range estimation. Redesigning the stadia may possibily improve the hit probabilities achievable with the 3X length/width stadia sights against certain targets, but substantial testing would be necessary to verify any potential benefits.

3. Against tank-targets, aiming errors with a 3X optical sight are slightly lower than those for a rifle sight. Thus, resultant hit probability will differ only slightly between the two sights.

4. For a fixed-QE firing technique:

a. Using turret-stadia judgment gates to classify target range (and select a corresponding QE) does not improve the gunner's rangefinding capability over that of the unaided gunner.

b. Unaided gunners, when classifying a target into one of three range categories tend to "fail-safe" by assigning doubtful targets to the middle range category.

c. If training can eliminate the gunners' range-classification bias, a 3-fixed-QE firing technique with rifle sights may improve hit probability over conventional firing for most of the weapon's effective range.

d. Against tank targets, a 3X optical sight gives only slightly better hit probability than rifle sights.

e. For a weapon with shorter range than the SMAWT weapon, where a single-fixed-QE firing technique is applicable, this technique can increase hit probability over conventional firing—except near the maximum range, where the hit probability will be less than for conventional firing. This conclusion assumes the gunner can aim as well at the base of a tank as he can at its center—which was the aim-point used in this experiment.

5. The stadia lines designed for the M72A2 stadia sight are incorrect, causing a range underestimation bias of about 5 percent.

RECOMMENDATIONS

1. The sight for the SMAWT weapon should be a simple sight, integral to the weapon, combining unaided range estimation and fixed-QE firing techniques. The sight could be either a peep-and-post sight with the peep height adjustable in range increments, or a peep-and-reticle sight with the reticle containing range increments; either should contain a fixed QE setting.

2. Further analysis and field testing should be conducted to determine the parameters and performance of simple sights that combine single-fixed-QE and unaided-range-estimation firing techniques. The selection of an aiming point on the target for use with fixed QE should be of primary concern in this testing. If, under field conditions, gunners can see (or estimate precisely) the base of a tank target, then that should be the aimpoint for fixed QE because it yields a higher hit probability over a greater target range then a center-of-mass aimpoint for fixed QE. If not, then a target center-of-mass aimpoint should be used with fixed QE. Although with this aimpoint, hit probability will not be higher than using conventional techniques, the gunner will have a quick-fire aimpoint.

3. An effort should be undertaken to optimize the design of length/width stadia sights (specifically, the reticle in the 3X sight) to reduce superelevation biases. The results of this effort should than be submitted to field testing, to determine whether it improves performance over current reticle designs.

4. The stadia lines in the M72 LAW sight should be redesigned to eliminate the range-estimation bias.

5. Although a laser sight is not currently available for a SMAWT-type weapon, more emphasis should be placed on developing a lightweight, integrated laser rangefinder/sight, since all of the sights tested have limited effectiveness.

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APPENDIX A

THE EFFECT OF TARGET ASPECT ON LENGTH/WIDTH

STADIA RANGING: AN ANALYSIS

The purpose of this analysis is to show the effect of target aspect angle and the resultant change in apparent target size on length/width stadia ranging. This effect is presented as a percent change in apparent target size relative to the tank size for which the stadia lines are designed. This, in turn, can be equated to a superelevation error at any given target range.

We assume here an "ideal" gunner—who does not make errors in selecting half- or full-stadia ranging, correctly brackets the image of the stadia, and does not have any cant angle between the stadia and the targets—and an infinitesimal stadia-centerline width.

The probable aspect angle of a tank target has a cardioid density function, with a maximum for head-on targets. For the sake of simplicity, we will assume that this function is circular, i.e., the aspect angle is uniformly distributed.

When ranging on a target, as described in Figure 1, the ideal gunner chooses half- or full-stadia ranging, depending upon how the target projection in the sight reticle appears. If the width of the tank appears greater than its length, the half-stadia is used for ranging. If the opposite holds, the full-stadia is used for ranging. The transition point between half- and full-stadia ranging is the angle at which the tank's apparent length and width are equal.

Two targets will be examined in this analysis: (1) the target size for which the stadia are designed, and (2) the target size and stadia design used in the experiment.

Figures 1A and 2A show the percent change in target size relative to the stadia versus aspect angle for these two targets. In each figure, the dotted line at the transition point divides the curve into half-stadia ranging on the left, and full-stadia ranging on the right. As is shown, the percent difference or aspect error is zero at three values of aspect angle.

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Change in Target Size as a Function of Target Presentation (Aspect) Angle

Target: Target Length = 2 Units   Width = 1 Unit

Stadia Reticle Design: Above Target
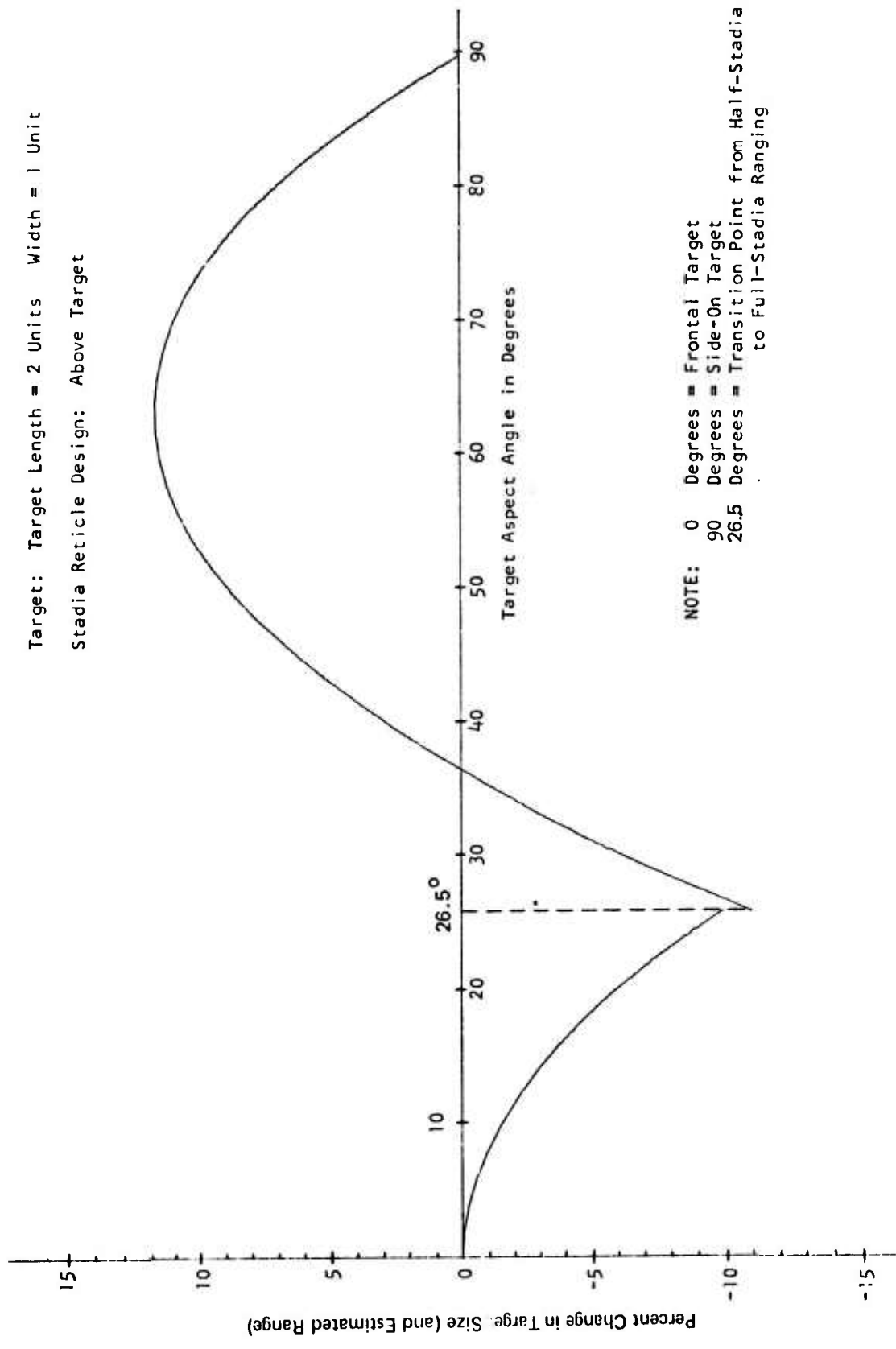
NOTE: 0 Degrees = Frontal Target
        90 Degrees = Side-On Target
        26.5 Degrees = Transition Point from Half-Stadia
                       to Full-Stadia Ranging

Fig. 1A. The effect of target aspect on the apparent size of a target
          and its range measured with length/width stadia-sights.

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Change in Target Size as a Function of Target Presentation (Aspect) Angle

Target: M60 Tank   Length = 6.95 Meters   Width = 3.63 Meters

Stadia Reticle Design: Averaged M60 Tank Dimensions
                          Length = 7.1 m
                          Width = 3.55 m

Target Aspect Angle in Degrees

Percent Change in Target Size (and Estimated Range)

NOTE: 0   Degrees = Frontal Target
         90   Degrees = Side-On Target
         27.6 Degrees = Transition Point from Half Stadia
                        to Full Stadia Ranging

Fig. 2A. Percent change in target size (and estimated range) with respect
          to length/width stadia design: M60 tank target

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We define the following:

Θ = Target aspect angle in degrees, where 0 degrees represents a head-on target

Θ_1 = Transition angle from half-stadia to full-stadia ranging

Θ_2 = Angle at which the apparent target size is a maximum

Θ_3 = Angle at which the aspect error is zero for half-stadia ranging

Θ_4 = Angle at which the aspect error is zero for full-stadia ranging

Θ_5 = Angle at which the aspect error is zero for full-stadia ranging ($\Theta_4 \leq \Theta_5$)

where $0^o \leq \Theta_3 < \Theta_1 < \Theta_4 \leq \Theta_5 < 90^o$

A = Target width

B = Target length

C = Target width used in design of the sight-reticle stadia-lines (Stadia-design width)

2C = Target length used in design of the sight-stadia-lines (Stadia-design length)

y = Apparent target size relative to stadia-design target (aspect error)

where $y = f(A, B, C, \Theta)$ $0^o \leq \Theta < 90^o$

y_1 = Aspect error for half-stadia ranging

y_2 = Aspect error for full-stadia ranging

Apparent target width = $A \cos \Theta$

Apparent target length = $B \sin \Theta$

$$y_1 = \frac{A}{C} \cos \Theta - 1 \qquad\qquad 0 \leq \Theta \leq \Theta_1 \tag{1}$$

$$y_2 = \frac{A}{2C} \cos \Theta + \frac{B}{2C} \sin \Theta - 1 \qquad \Theta_1 \leq \Theta < 90^o \tag{2}$$

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At the transition angle, Θ_1, the apparent vehicle width equals the apparent vehicle length and

$$A \cos \Theta_1 = B \sin \Theta_1$$

$$\Theta_1 = \arctan \frac{A}{B}$$

At $\Theta = \Theta_2$, the first derivative of (2) is zero, thus,

$$\frac{dy_2}{d\Theta} = 0 = \frac{A}{2C} \sin \Theta_2 - \frac{B}{2C} \cos \Theta_2$$

$$\Theta_2 = \arctan \frac{B}{A}$$

At $\Theta = \Theta_3$, we obtain from (1)

$$y_1 = \theta = \frac{A}{C} \cos \Theta_3 - 1$$

$$\Theta_3 = \arccos \frac{C}{A}$$

At $\Theta = \Theta_4, \Theta_5$ we obtain from (2)

$$y_2 = \theta = \frac{A}{2C} \cos \Theta_4 + B \sin \Theta_4 - 1 \qquad\qquad \Theta_1 < \Theta_4 \leq \Theta_2$$

This can be solved for O_4 by an iterative technique and since (y1) is symmetric about O_2

$$\Theta_5 = 2\Theta_2 - \Theta_4$$

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The negative aspect error, $D_{(-)}$ is the area under the curve defined by y_1 and y_2 (refer to Figs. 1A and 2A) for which the apparent target size is smaller than the stadia-design target.

$$D_{(-)} = \int_{\Theta_3}^{\Theta_1} y_1 d\Theta + \int_{\Theta_1}^{\Theta_4} y_2 d\Theta + \int_{\Theta_5}^{\pi/2} y_2 d\Theta$$

(3) $$D_{(-)} = \frac{A}{2C} \left[1 + \sin(\Theta_1) + \sin(\Theta_4) - 2\sin(\Theta_3) - \sin(\Theta_5) \right]$$ (3)

$$+ \frac{B}{2C} \left[\cos(\Theta_1) + \cos(\Theta_5) - \cos(\Theta_4) \right] - \left[\frac{\pi}{2} + \Theta_4 - \Theta_3 - \Theta_5 \right]$$

The positive aspect error $D_{(+)}$ is similarly defined as

$$D_{(+)} = \int_0^{\Theta_3} y_1 d\Theta + \int_{\Theta_4}^{\Theta_5} y_2 d\Theta$$

(4) $$D_{(+)} = \frac{A}{2C} \left[\sin(\Theta_5) + 2\sin(\Theta_3) - \sin(\Theta_4) \right]$$ (4)

$$+ \frac{B}{2C} \left[\cos(\Theta_4) - \cos(\Theta_5) \right] - (\Theta_3 + \Theta_5 - \Theta_4)$$

The average and mean errors are obtained from the following:

(5)   Average negative aspect error $= E_{(-)} = \dfrac{D_{(-)}}{\dfrac{\pi}{2} + \Theta_4 - \Theta_3 - \Theta_5}$ (5)

(6)   Average positive aspect error $= E_{(+)} = \dfrac{D_{(+)}}{\Theta_3 + \Theta_5 - \Theta_4}$ (6)

(7)   Average aspect error $= E = \dfrac{|D_{(-)}| + D_+}{\pi/2}$ (7)

(8)   Mean aspect error $= \bar{y} = \dfrac{D_{(-)} + D_{(+)}}{\pi/2}$ (8)

$$(9) \quad \text{RMS error} = \left[\frac{\displaystyle\int_{0}^{\Theta_1} (y_1)^2 \, d\Theta + \int_{\Theta_1}^{\pi/2} (y_2)^2 \, d\Theta}{\pi/2} \right]^{\frac{1}{2}} \quad (9)$$

If we assume that the stadia can be redesigned to eliminate the bias due to the mean aspect error then:

$$(10) \quad \text{Unbiased RMS} = \left[(\text{RMS Error})^2 - \bar{y}^2 \right]^{\frac{1}{2}} \quad (10)$$

If the target vehicle is the one for which the reticle is designed, then:

$A = C$

$B = 2C$

$\Theta_1 = 26.57^\circ$

$\Theta_2 = 63.44^\circ$

$\Theta_4 = 36.87^\circ$

$\Theta_3 = 0^\circ$

$\Theta_5 = 90^\circ$

$y_1 = \cos\Theta - 1 \qquad\qquad 0 \le \Theta \le 26.57^\circ$

$y_2 = .5\cos\Theta + \sin\Theta - 1 \qquad 26.57^\circ \le \Theta \le 90^\circ$

$D_- = -.0255$

$D_+ = .0889$

$E_- = \text{average negative error} = -4.0\%$

$E_+ = \text{average positive error} = 9.6\%$

$E = \text{average error} = 7.3\%$

$\bar{y} = \text{mean error} = 2.4\%$

RMS error = 7.4%

Unbiased RMS error = 7.0%

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The experiment reported herein used a target tank with dimensions

A = 3.63 meters

B = 6.95 meters

The length/width stadia reticles were designed by Frankford Arsenal using the averaged vehicle size.

$$C = \frac{2(A) + B}{4} = 3.55 \text{ meters}$$

For this reticle design and target vehicle:

θ_1 = 27.58°

θ_2 = 62.42°

θ_3 = 12.05°

θ_4 = 37.32°

θ_5 = 87.53°

D_- = -.0191

D_+ = .0639

E_- = 3.9%

E_+ - 5.9%

E = average error = 5.3%

$\bar{y}$ = mean error = 2.9%

RMS error = 6.3%

Unbiased RMS error = 5.6%

The apparent target sizes, relative to the stadia-design target at each of the three aspects used in the experiment, are:

1. 0 degrees   +2.3 percent

2. 62.4 degrees   +10.4 percent

3. 90 degrees   -2.1 percent

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APPENDIX B

DESCRIPTION AND OPERATION OF TESTED SIGHTS THAT DID

NOT USE CONVENTIONAL LENGTH/WIDTH STADIA RANGING

Since percentage change in apparent target size relative to the stadia design equates directly to percentage range-estimation error, the aspect errors shown here are the same as range-estimation errors. An interesting result is that the target for which the stadia were designed yielded a larger range-estimation error than the one of slightly different dimensions. Also, the method used to design the stadia did not yield optimum results, since there was a bias which inflated the RMS aspect error. By redesigning the stadia lines, the mean aspect error for either of the two cases may be eliminated and the unbiased RMS aspect error obtained.

As noted, the analysis did not include gunner errors. Since these errors are usually considered normally distributed and the aspect error is not, care must be taken in combining these errors. For the two targets considered in the analysis, 7 percent and 5.6 percent of range RMS (unbiased RMS aspect error) are upper bounds of range finder accuracy. Addition of gunner error and errors due to other sizes of targets will result in larger range finder errors.

This analysis assumed a sight reticle having an infinitesimal-width centerline. It can be shown that if the centerline has a controlled finite width, and if the separation of the stadia lines is properly selected, both the mean range overestimation for half-stadia ranging and the mean range underestimation for full-stadia ranging can be reduced, thus reducing the RMS range estimation error.

In order to optimize the design of length/width stadia, the sizes of major targets which will be ranged against should be suitably averaged by some method which considers relative importance and frequency of encountering the targets. However, the resulting range-finding error for any selected target may far exceed the errors shown in the two cases examined herein.

It is recommended that this analysis be continued in order to define a mathematical model for range-finding error which will include all the error sources for length/width stadia range finders.

POST-AND-PEEP (RIFLE SIGHTS) (SIGHT 1, FIGURE 2)

The post-and-peep rifle sight was the only non-range-finding sight examined in the experiment. The Soviet RPG-7 Antitank Weapon uses a rifle sight built into the weapon as a secondary or back-up sighting system, although its primary sight is a detachable optical sight. Since using an optical sight on the SMAWT weapon creates problems, HEL has urged consideration of this type of secondary or quick-fire sighting system for the weapon. In addition, such a sight is not limited only to vehicles of a particular size. If its performance is as good as the other sights, it could also be considered as a primary sight.

The sight consists of a front post and rear peep, fabricated to the dimensions of the M16 rifle sights. The rear peep has three selectable superelevations. When using this sight, the gunner estimates target range as near, mid or far—corresponding to ranges of 0-300, 300-400 and 400-500 meters. He then sets the superelevation with a three-position switch beside the rear peep, aims at the target's center of mass, as with a rifle, and fires.

The sight's accuracy is limited by the gunner's ability to estimate range (1 S.D. range estimation error = 21% of range).

PRG-7 2.5-POWER HEIGHT STADIA (SIGHT 1, FIGURE 3)

The RPG-7 2.5-Power Height Stadia Sight is based on the target vehicle's height, rather than its length or width. This sight was included in the experiment to evaluate its effectiveness for possible use on the SMAWT weapon, as well as against U.S. tanks.

The RPG-7 sight-reticle pattern is divided into two parts: a height stadia, and a vertical aiming line. When ranging, the gunner first adjusts the position of the vehicle to bracket its height with the stadia-lines and estimate its range. He then shifts the weapon to center the target at that range of the vertical scale on the target, and fires.

FIXED-QE TURRET STADIA-SIGHT (SIGHT 3, FIGURE 3)

The Fixed-QE Turret-Stadia Sight, which assumes the target has a circular turret, is not a true range finding sight in the sense used elsewhere. Depending on whether the turret appears larger or smaller than two fixed stadia in the reticle, one or the other of two aiming points is used. (Mr. Bernie Cobb, of MICOM, suggested using this type of sight). This design does not incur the aspect and length/width ratio errors found in length/width stadia sights, since the target is round. However, it is based on a smaller target dimension, which may be difficult to see because of obscuration caused by the gun mantlet and equipment stowed on the rear of the turret. When ranging, the gunner adjusts the top set of reticle lines onto the vehicle turret. If the turret width is greater than the line separation, the weapon is fired at this superelevation. If it is smaller, the weapon is elevated to fit the turret to the lower set of lines. Again, the weapon is fired at that superelevation if the turret is larger than the line separation. If the turret still appears smaller than the line separation, the target is out of range, and the weapon is not fired. This sight was the same 3X stadia sight that was used in Phase 1 (3), but with a new reticle.

ART LENGTH/WIDTH STADIA SIGHT (SIGHT 5, FIGURE 3)

When ranging with the ART Length/Width Stadia Sight, the optical power of the sight is adjusted (from 3- to 9-power) by a ring near the eyepiece; turning this ring varies the target image's size until it fits the reticle pattern's fixed size. A cam coupled to this ring is designed to match the weapon's trajectory, automatically changing superelevation appropriately as the optical power varies. Frankford Arsenal proposed including this sight (and the other ART-Scopes) in the experiment.

With this particular reticle pattern, the method of ranging is similar to that used with standard length/width stadia sights, except that the target image's size is adjusted to fit the reticle lines, rather than the opposite.

It is inherently difficult to use the ART-Scope sight against targets other than those for which it is designed, because the reticle pattern has no range lines. However, range information could be obtained from markings on the ballistic cam.

ART HEIGHT-STADIA SIGHT (SIGHT 2, FIGURE 3)

The ART Height-Stadia Sight is used in essentially the same way as the sight just described, except that the gunner brackets the target's height, rather than its length or width, in the reticle pattern. Although it is similar to the RPG-7 in using target height for ranging, it does not require either interpolating ranges or transferring information, as the RPG-7 does.

ART MAN-SILHOUETTE RANGE FINDER SIGHT (SIGHT 4, FIGURE 3)

This sight represents a still different approach to ranging, in that gunners need not bracket targets at all. Instead, the size of the target is varied until it appears in scale with the image of a man-silhouette. Although this sight may be used for diverse targets, its effectiveness depends heavily on the gunner's judgment.

APPENDIX C

PRE-TEST RANGE ESTIMATION AND SIGHT TRAINING AREA LAYOUT
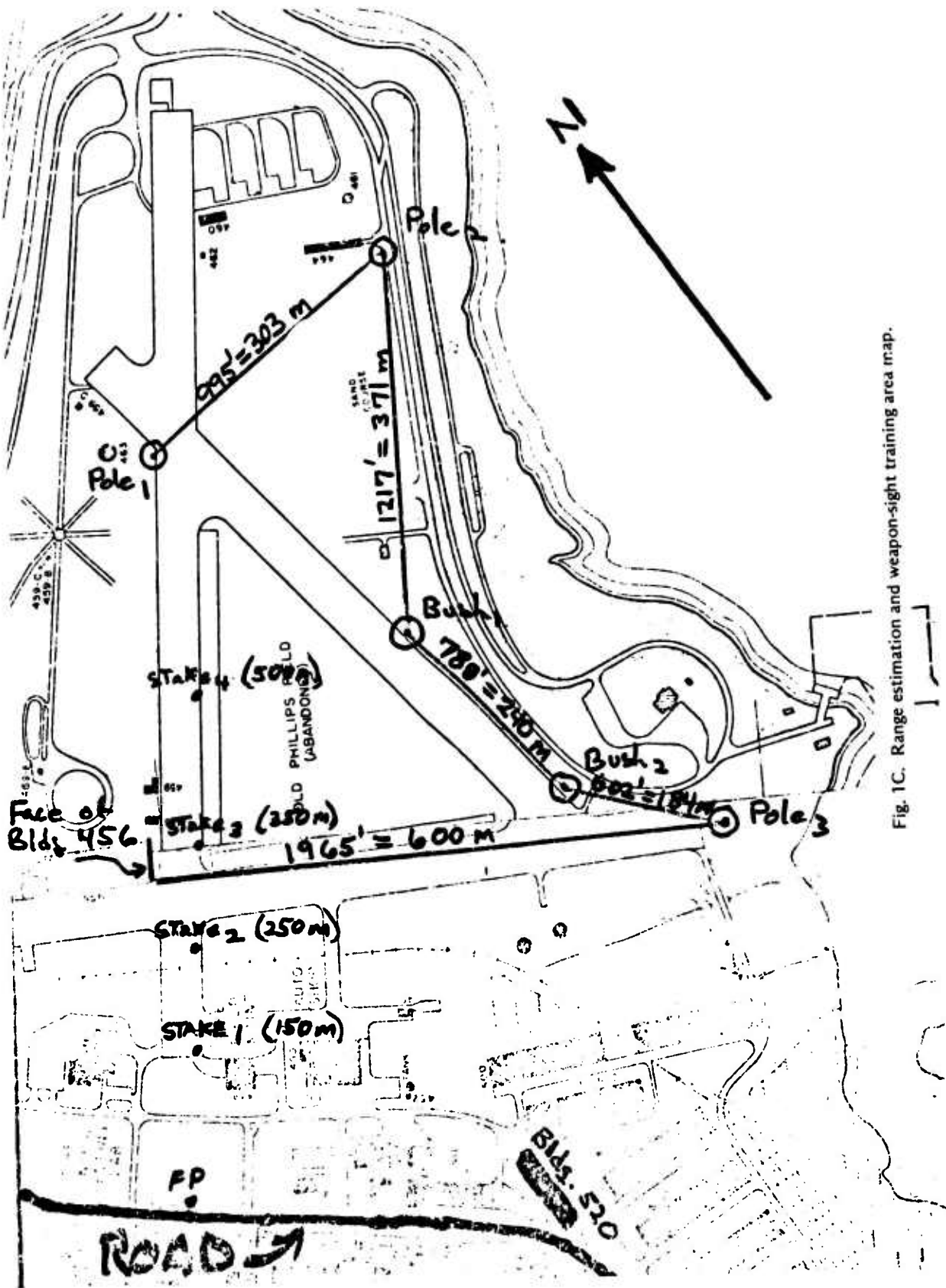
Fig. 1C. Range estimation and weapon-sight training area map.

Pole 2

N

995' = 303 m

1217' = 371 m

Pole 1

Bush 1

780' = 240 M

STAKE 4 (500 m)

OLD PHILLIPS (ABANDONED)

Bush 2

602' = 184 m

Pole 3

Face of Bldg 456

STAKE 3 (350 m)

1965' = 600 M

STAKE 2 (250 m)

STAKE 1 (150 m)

Bldg. 520

FP

ROAD
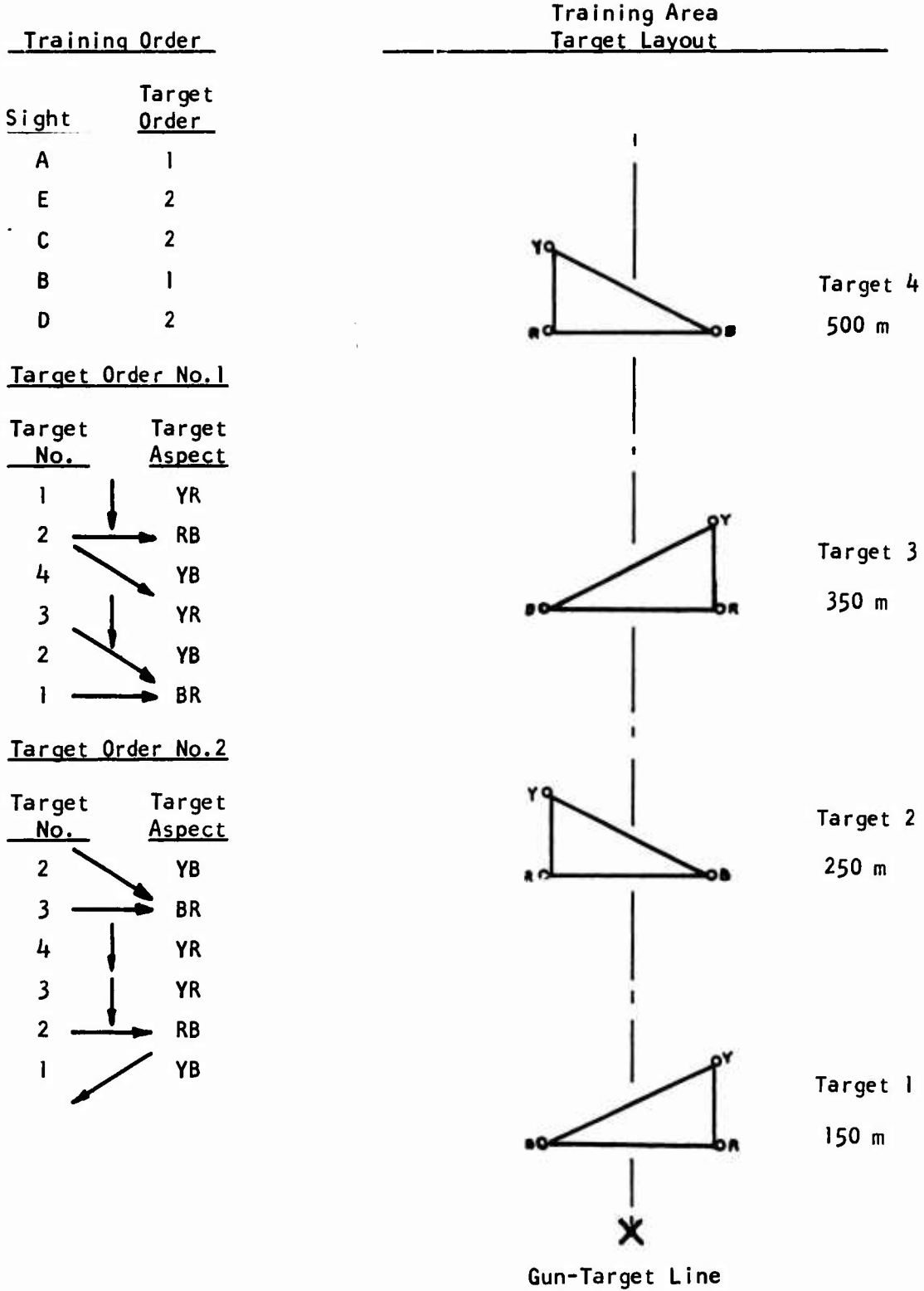
Fig. 2C. Pretest tripod sight training exercise.

APPENDIX D

TARGET PRESENTATION SEQUENCE

TABLE 1D

Sequence of Target Presentations Used in Main Test

Target Presentation	Target Order No. 1 Target	Aspect	Target Order No. 2 Target	Aspect	Target Order No. 3 Target	Aspect	Target Order No. 4 Target	Aspect
1	2	RB	9	RB	8	YR	3	YR
2	4	YR	7	YR	6	YB	5	YB
3	8	YB	3	YB	5	RB	6	RB
4	6	YR	5	YR	7	YR	4	YR
5	1	YB	1	YB	10	BR	10	RB
6	3	BR	8	BR	9	YR	2	YR
7	1	YR	1	YR	4	YB	7	YB
8	9	YB	2	YB	1	YR	1	YR
9	7	BR	4	BR	3	BR	8	BR
10	4	YB	7	YB	6	YR	5	YR
11	10	RB	10	BR	3	YB	8	YB
12	2	YR	9	YR	1	YB	1	YB
13	6	RB	5	RB	2	BR	9	BR
14	8	YR	3	YR	4	RB	7	RB
15	5	YB	6	YB	9	YB	2	YB

Note: Aspect codes B, Y, R correspond, respectively, to blue, yellow and red marker stakes shown in Figure 2. Color code pairs indicate target orientation e.g., RB indicates that the target moved across the red stake and stopped at the blue stake for a stationary target presentation.

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TABLE 2D

Main Test Target Order Matrix

Day	Stationary Replication 1	Moving Replication 1	Stationary Replication 2	Moving Replication 2
1	1	2	3	4
2	2	4	1	3
3	3	1	4	2
4	4	3	2	1
5	2	3	4	1

Numbers in Cells Denote Target Sequence Numbers

APPENDIX E

SIGHT-RETICLE MEASUREMENTS AND CORRESPONDENCE

AMXHE

SUBJECT: Missing Information, SMAWT Sight Program

Commander
USA Frankford Arsenal
ATTN: SMUFA-N4100 (Mr. J.T. Caldorola)
Philadelphia, PA 19137

1. References:

    a. Meeting at Frankford Arsenal, 19 Apr 72, subject: SMAWT Program.

    b. Meeting at HEL, 24-25 May 72, subject: SMAWT Program.

    c. Letter, AMXHE, this laboratory, 13 Jun 72, with 1st Ind, SMUFA-N4100, 6 Jul 72, subject: SMAWT Program.

    d. Meeting at HEL, 18 Jul 72, subject: SMAWT Program.

    e. Meeting at BRL, 2 Aug 72, subject: SMAWT Program.

    f. Letter, SMUFA-N4100, your command, 15 Sep 72, subject: SMAWT, Sight Reticle Data.

    g. Letter, SMUFA-N4100, your command, 7 Nov 72, subject: SMAWT, Sight Reticle Data.

2. We have recently completed the planned sight evaluation experiment for the SMAWT Program. During the conduct of Phase II of the experiment, we noted that performance of the Fixed QE sight was different than expected. Subsequent receipt of data from FA (reference g) revealed this difference to be due to large discrepancy between our target size and that assumed by FA in design of the sight reticle. The HEL target size is the one proposed by Mr. Cobb (2.8-meter diameter turret), the proponent of the sight, at the SMAWT meeting, reference a. HEL's plan to build a mock-up 2.8-meter diameter turret for the sight was discussed in all of the above-referenced meetings (at which FA had representatives).

3. The resulting incompatibility between the HEL target diameter and that assumed by FA has caused a serious gap in the data obtained in the HEL sight study. In letter, reference g, which provided data on the Fixed QE sight, a footnote states that this gap can be filled and "valid test data can be obtained by revising range values for the go/no-go crossover point." This is not entirely clear: revised range values based on 2.8-meter turret and 8- and 6-mil go/no-go gates are 338 and 467 meters respectively, the latter value being greater than the maximum target range of 450 meters, with a resultant small percentage of no-go decisions. It has been our experience in attempting to extrapolate data from small samples that validity is often questionable. Moreover, the effects of target angular subtense and its rate of change on the human processes involved in making a go/no-go decision are not clear. Since we are not aware of a technique for overcoming these objections to the use of extrapolated data, request you provide the necessary information implied in reference g.

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AMXHE
SUBJECT: Missing Information, SMAWT Sight Program

4. Sight reticle data conveyed to HEL as inclosures to references f and g and other data provided by FA are incomplete and require clarification. The required additional information is listed in Inclosure 1.

5. The information described in paragraphs 3 and 4 above is required by HEL no later than 7 Jan 73 in order to comply with the AMC SMAWT Program deadline.

6. The contact point for this information is Mr. Dominick Giordano, AUTOVON 870-3345.

1 Incl   JOHN D. WEISZ
as   Director

CF:
CDR, MICOM
ATTN: AMSMI-RFL (Mr. B. Cobb)
Redstone Arsenal, AL 35809

Dir, BRL
ATTN: AMXBR-IB (Mr. J. Frankle)
APG, MD 21005

SIGHT INFORMATION DATA GAPS

1. Request clarification and further technical information on sight reticle data contained herein. The required information is listed below as questions pertaining to the various reticles (Incl 1).

    a. Reticle pattern numbers 41590, 41592, 41593, and 41594:

Are the first and last lines of data for each reticle the maximum and minimum stadia line separation on the reticle? If so, why are there such large differences in elevation and resultant maximum and minimum ranges among the 1200 ft/sec reticles?

    b. Reticle pattern number 41591:

        (1) Are the indicated measurements of line separation taken from the middle of lines?

        (2) What is the nominal line thickness in mils?

        (3) What is the horizontal distance in mils from the center line of the reticle pattern to either side of the judgment gates?

        (4) What is the vertical distance in mils from the center cross to the bottom of the center line on the reticle pattern?

    c. Reticle pattern number 41595:

        (1) What are the vertical and horizontal distances in mils from the center cross on the reticle pattern to the base of the man-silhouettes at a reference sight elevation and optical power?

        (2) What are the heights of the man-silhouettes at a reference sight elevation and optical power?

    d. Reticle pattern numbers 41595, 41597 and 41598:

        (1) What is the optical power of the sight with respect to sight elevation in mils? If one reference value can be provided, the other values will be computed using values given in the second and third columns of data for each sight reticle.

        (2) Are indicated measurements of line separation taken from the middle of lines?

        (3) What is the nominal line thickness in mils at a reference optical power?

2. Information is also requested on optical characteristics of each optical sight used to house the aforementioned reticle patterns. This information should include exit pupil size, field of view, resolution, eye relief and measured parallax.

3. Are the expressions of R (range in meters) as a function of E (elevation in milliradians) shown in Inclosure 1 the formulae used to compute values in the design of the reticle pattern, or are they quadratic fits to the resultant fabricated reticle pattern assembled into the sight housing? If the former, what are the differences among formulae for the 1200 ft/sec reticles (41590, 41592, 41594) attributable to?
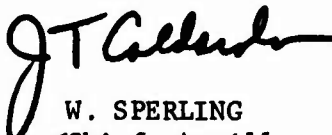
SUBJECT: SMAWT, Sight Reticle Data

Director
Human Engineering Laboratory
ATTN: AMXRD-HEL, Mr. J. Torre
U. S. Army Aberdeen Research & Development Center
Aberdeen Proving Ground, Maryland   21005

1. Inclosed is data you requested pertaining to the four reticle
patterns to be used in Phase I of SMAWT Test Program. Data pertaining to
the remaining four reticle patterns to be used in Phase II of SMAWT Test
Program will be provided when available.

2. It should be noted that slight deviations from nominal design data
result from manufacturing tolerances on reticle pattern and focal length
of sight objective. Since a telescope can be designed to minimize these
effects (adjustable focal length), the test data should be reduced based
on the actual measured angular subtense data given.

FOR THE COMMANDER:

W. SPERLING
Chief, Artillery, Infantry and
Armored Weapons Division, FCDED

4 Incl
as

RETICLE 41590

This reticle is a conventional stadia/ballistic type reticle based on ballistic data for 81mm, 3.5 lb., 1200 ft/sec initial velocity and a tank 7.1 meters long and 3.55 meters wide. It was assembled into an Advanced LAW 3X Sight. Angular subtense data measured for 3 mil elevation increments is given below. Column A refers to angular subtense from center line to one stadia line (middle of lines) and Column B lists angular subtense across full stadia pattern (middle of line).

Elevation (mils)	A (mils)	B (mils)
6	25.04	49.38
9	17.50	34.73
12	13.79	27.48
15	11.39	22.69
18	9.77	19.50
21	8.61	17.22
24	7.71	15.48
27	7.05	14.15
30	6.50	13.02
33	6.03	12.12
36	5.64	11.34

Nominal Line Width = 0.3 mil

RETICLE 41592

This reticle is a conventional stadia/ballistic type reticle based on ballistic data for 81mm, 3.5 lb., 1200 ft/sec initial velocity and a tank 7.1 meters long and 3.55 meters wide. It was assembled into a Reflecting Sight. Angular subtense data measured for 3 mil elevation increments is given below. Column A refers to angular subtense from center line to one stadia line (middle of lines) and Column B lists angular subtense across full stadia pattern (middle of lines).

Elevation (mils)	A (mils)	B (mils)
6	23.22	47.42
9	16.80	34.39
12	13.31	27.22
15	10.82	22.29
18	9.19	18.97
21	8.08	16.59
24	7.20	14.80
27	6.46	13.40
30	5.96	12.35
33	5.54	11.59
36	5.29	11.14
39	5.10	10.86

Nominal Line Width = 2.63 mils

RETICLE 41593

This reticle is a conventional stadia/ballistic reticle based on original M72 reticle pattern ballistic data (475 ft/sec initial velocity) and a tank 7.1 meters long and 3.55 meters wide. It is to be assembled to test device by HEL/AAI. Angular subtense data given below is based on measured reticle pattern data and spacing between reticle and rear (peep) sight of 19.78 inches.

Elevation (mils)	A (mils)	B (mils)
41.17	22.77	45.48
46.31	20.14	40.30
51.45	18.13	36.31
56.59	16.65	32.28
61.72	15.43	30.90
66.85	14.45	29.00
71.97	13.71	27.51
77.10	13.06	26.17
82.22	12.44	24.92
87.33	11.88	23.78
92.44	11.37	22.78
97.54	10.91	21.87
102.64	10.49	21.08
107.74	10.23	20.53

Nominal Line Width = 0.46 mils

RETICLE 41594

This reticle is a conventional stadia/ballistic reticle based on ballistic data for 81mm, 3.5 lb., 1200 ft/sec initial velocity and a tank 7.1 meters long and 3.55 meters wide. It is to be assembled to test device by HEL/AAI. Angular subtense data given below is based on measured reticle pattern data and spacing between reticle and rear (peep) sight of 19.78 inches.

Elevation (mils)	A (mils)	B (mils)
7.72	20.27	40.46
10.30	15.76	31.32
12.87	13.06	25.84
15.45	11.18	22.20
18.02	9.90	19.68
20.60	8.85	17.64
23.17	8.57	16.04
25.74	7.47	14.83
28.32	6.93	13.73
30.89	6.47	12.87
33.46	6.07	12.12

Nominal Line Width = 0.48 mils

DEPARTMENT OF THE ARMY

FRANKFORD ARSENAL Miss McGrody/saz/348-5645

PHILADELPHIA, PENNSYLVANIA 19137

IN REPLY REFER TO:
COMMANDING OFFICER
FRANKFORD ARSENAL
ATTN: SMUFA- N4100   7 November 1972

SUBJECT: SMAWT, Sight Reticle Data

Director
Human Engineering Laboratory
ATTN: AMXRD-HEL, Mr. J. Torre
Aberdeen Proving Ground, Md. 21005

1. Inclosed is data you requested pertaining to the four reticle patterns
to be used in Phase II of SMAWT Test Program.

2. As mentioned in 15 September 1972 letter to your agency, subject as
above, the slight deviations from nominal design data result from manu-
facturing tolerances on the reticle pattern and focal length of sight
objective. Since a telescope can be designed to minimize these effects.
(adjustable focal length), the test data should be reduced based on the
actual measured angular subtense data given.

FOR THE COMMANDER:

4 Incl   W. SPERLING
1. Reticle 41591 data   Chief, Artillery, Infantry and
2. Reticle 41595 data   Armored Weapons Division, FCDED
3. Reticle 41597 data
4. Reticle 41598 data

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RETICLE 41591

This reticle is a go/no go, fixed Quadrant Elevation (QE) type based on ballistic data for the 81mm, 3.5 lb, 1200 ft/sec round. The two judgment gates are based on a turret size of 2.39* meters at 300 meters and 400 meters. The reticle was assembled into an Advanced LAW 3X Sight. Angular subtense data is given in diagram.

E = 8.0 mils

D = 14.3 mils

C = 8.4 mils

F = 6.0 mils
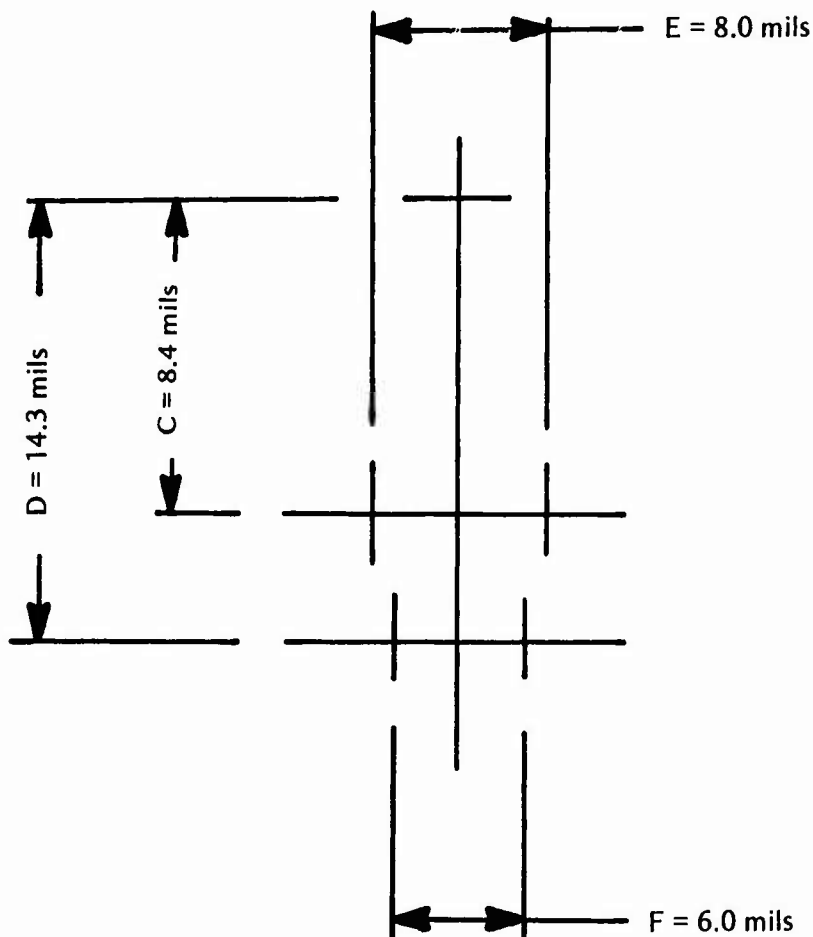
*NOTE: The 2.39 meter value was assumed prior to HEL's decision to mock-up turret. Valid test data can be obtained by revising range values for the go/no go crossover point.

RETICLE 41595

This reticle is a man silhouette type based on a 5'10" man. The reticle was assembled into an ART scope (Adjustable Ranging Telescope) which provides superelevation via a ballistic cam as the magnification is changed while ranging to a target. Ranging is accomplished by changing the magnification of the target with respect to the man silhouette of the reticle where the range desired is attained when the man is in proper proportion to the tank.. Angular subtense data of the man kneeling and standing is given below for incremental elevation measurements starting at the maximum magnification.

Elevation (mils)	Kneeling (mils)	Standing (mils)
0	2.75	3.64
.77	2.89	3.81
1.54	3.06	4.00
2.31	3.16	4.20
3.08	3.36	4.42
3.85	3.59	4.74
4.62	3.96	5.30
5.39	4.42	5.89
6.16	4.98	6.62
6.93	5.96	7.89
7.70	8.18	10.85
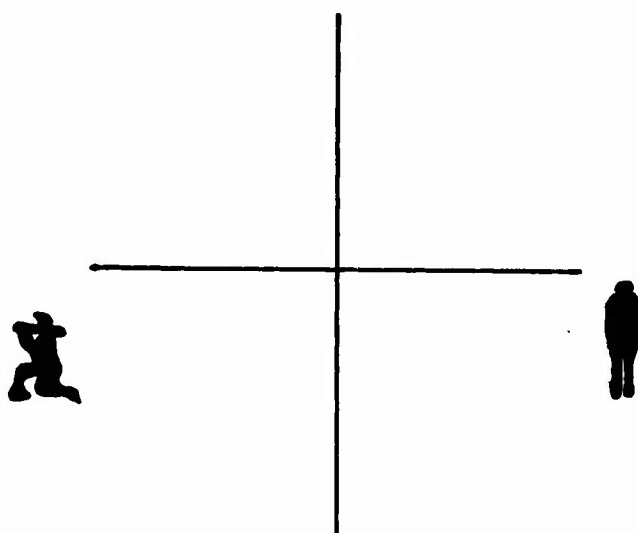
RETICLE 41597

This reticle is based on a tank 7.1 meters long and 3.55 meters wide. The reticle was assembled into an ART scope (Adjustable Ranging Telescope) which provides superelevation via a ballistic cam as the magnification is changed while ranging to a target. Ranging is accomplished by bracketing the target within the reticle lines as the magnification is changed. Angular subtense data is given below for incremental elevation measurements starting at the maximum magnification.

Elevation (mils)	A (mils)	B (mils)
0	7.24	14.47
1.00	7.68	15.35
2.00	8.13	16.25
2.99	8.78	17.55
3.99	9.55	19.09
4.99	10.55	21.10
5.99	11.84	23.68
6.98	13.34	26.67
7.98	15.64	31.27
8.98	18.26	36.51
9.98	21.11	42.20
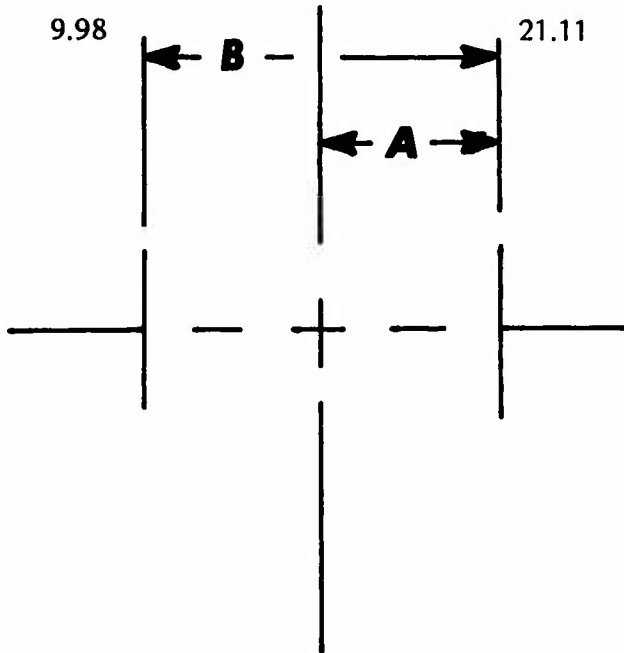
RETICLE 41598

This reticle is based on a tank height of 2.6 meters. The reticle was assembled into an ART scope (Adjustable Ranging Telescope) which provides superelevation via a ballistic cam as the magnification is changed while ranging to a target. Ranging is accomplished by bracketing the target within the reticle lines as the magnification is changed. Angular subtense data is given below for incremental elevation measurements starting at the maximum manification.

Elevation (mils)	A (mils)	B (mils)
0	2.67	5.32
.91	2.85	5.68
1.83	2.99	5.96
2.74	3.17	6.32
3.65	3.37	6.73
4.57	3.72	7.41
5.48	4.14	8.25
6.40	4.61	9.20
7.31	5.35	10.68
8.22	6.31	12.58
9.14	7.77	15.50
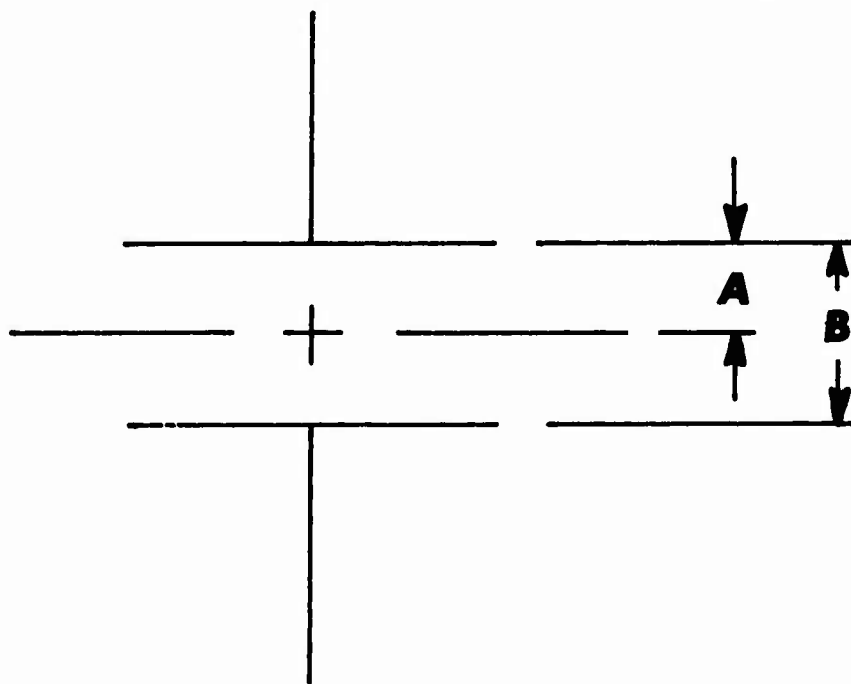
Transcription of handwritten response to HEL letter of 22 Dec 72
obtained from Frankford Arsenal personnel at SMAWT meeting of
15 Feb 73, HQ AMC, Alexandria, VA.

1. a. Reticle pattern numbers 41590, 41592, 41593 and 41594

        No. Data pertaining to the maximum and minimum stadia line
separation on the reticles is not required for conduct of tests or
for reduction of resultant data

    b. Reticle pattern number 41591:

        (1) Yes

        (2) 0.25 mil

        (3) Pattern is symmetrical. Angular subtense from center line
to judgement gates are 4.0 mils and 3.0 mils for near and far gates
respectively. $(\frac{8.0}{2} = 4.0, \frac{6.0}{2} = 3.0)$

        (4) This dimension should have no bearing on the conduct of
tests. However, if desired, it could be measured after testing has been
completed. Nominal design value is .060 inch which for a nominal EFL
objective would result in an angular subtense of 27.2 mils. If the test
is planned properly, extrapolating data from small samples could certainly
be avoided. Moreover, since the difference between actual and assumed
turret diameters is so small, it is surprising that HEL is concerned
about extrapolation data, if necessary, especially in light of the
assumptions made in planning and conducting the previous stadia range-
finder test on a finite screen using projected 16mm film to simulate
targets.

3. Additional data requested in Incl 1 of basic letter was either given
verbally to cognizant HEL personnel or is not considered essential to
the conduct of tests and reduction of resultant data. However, answers
to these questions are given in Inclosure 1 of this letter. Any additional
measured data pertaining to these sights can be provided after testing is
completed if the sights are made available for the required length of time.

2. With the large line widths necessitated for this simple reflex sight
are factors which will undoubtedly degrade performance attainable with
this sight. Exact measurements can be made following conduct of testing
if desired.

a. Advanced LAW Sight (Reticles 41590 & 41591)

Magnification	3.0 X
Field of View	12°
Exit Pupil Diameter	4mm
Eye Relief	1.0
Resolution	≤ 20 seconds (Eye limited)
Parallax	< 0.1 mil (100 meters to infinity)

b. Reflecting Sight (Reticle 41592)

Magnification	1.0 X
Field of View	N/A (Non-image forming system)
Exit Pupil Dia	0.75 inch
Eye Relief	~ 1.5
Resolution	≤ 60 seconds (Eye limited)
Parallax	-

c. M72 Sight (Reticle 41593 and 41594)

Magnification	1.0 X
Field of View	N/A (Non-image forming system)
Exit Pupil Dia	2.5mm
Eye Relief	-
Resolution	≤ 60 seconds (Eye limited)
Parallax	< 4.0 mils

d. ART Scope (Reticles 41595, 41597 and 41598)

Magnification	3 X	9 X
Fields of View	7.0°	2.3°
Exit Pupil Diameters	12mm	4mm
Eye Relief	3 to 4 in	3 to 4 in
Resolution	≤ 20	≤ 10 seconds

3. It is not entirely clear what is meant by this question. Equations giving best fit for Range vs. Elevation were given HEL during the meeting on 10 Oct 1972. These equations represent best fit of measured data. The slight deviations from nominal design data were explained in letter SMUFA-N4100 dated 15 September, subject: SMAWT Sight Reticle Data (Reference f); i.e., manufacturing tolerances on reticle pattern and focal length of sight objectives.

Reticle Study
27 Sept 1972

$$R_{41590} = .8196 + 26.79E - .5176E^2 + .0115E^3 - .0001156E^4$$

$$R_{41592} = .6672 + 31.05E - 1.346E^2 + .0678E^3 - .00156E^4 - .0000113E^5$$

$$R_{41953} = .4351 + 3.34E + .0315E^2 - .000533E^3 + .00000219E^4$$

$$R_{41594} = .6773 + 25.44E + .0336E^2 + .00324E^3$$

R in meters
E in milliradians

APPENDIX F

SAMPLE QUESTIONNAIRES AND TABULATION OF THE
SUBJECTS' COMMENTS IN QUESTIONNAIRES 1 AND 2

QUESTIONNAIRE 1

Booth _____ Sys _____ Sub. _____ Day _____

SIGHT STUDY

In comparison to the sight you used yesterday, rate the sight you used today with respect to the following: (Today's sight was _____ than yesterday; sight.)

1. Ease of sighting (aiming).

NON-MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

2. Accuracy.

NON-MOVING TARGETS

	a lot	a little	same	a little	a lot	
MORE (INACCURATE)	1	2	3	4	5	MORE (ACCURATE)

MOVING TARGETS

	a lot	a little	same	a little	a lot	
MORE (INACCURATE)	1	2	3	4	5	MORE (ACCURATE)

3. How rapidly could you aim the sight?

NON-MOVING TARGETS

	a lot	a little	same	a little	a lot	
(FASTER)	1	2	3	4	5	(SLOWER)

MOVING TARGETS

	a lot	a little	same	a little	a lot	
(FASTER)	1	2	3	4	5	(SLOWER)

4. How easy was it to aim the sight on long range targets?

NON-MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

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5. How easy was it to aim the sight on <u>short range</u> targets?

NON-MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

MOVING TARGETS

	a lot	a little	same	a little	a lot	
(EASIER)	1	2	3	4	5	(HARDER)

6. Which sight would you prefer to use?

    ( ) the one you used today   ( ) the one you used yesterday

7. Additional comments about the sight, if you desire: _____

_____

_____

_____

_____

_____

_____

_____

_____

1. Rate the sights used in this study with respect to the following:
(place the letter designation of the sight in the appropriate blank space
according to your rating, e.g., <u>C</u> <u>E</u> <u>A</u> <u>D</u> <u>B</u>).

    a. Ease of sighting (aiming)

NON-MOVING TARGETS

(easiest)   _____ _____ _____ _____ _____ (hardest)

MOVING TARGETS

(easiest)   _____ _____ _____ _____ _____ (hardest)

    b. Accuracy

NON-MOVING TARGETS

(least accurate)   _____ _____ _____ _____ _____ (most accurate)

MOVING TARGETS

(least accurate)   _____ _____ _____ _____ _____ (most accurate)

    c. Aiming speed

NON-MOVING TARGETS

(slowest)   _____ _____ _____ _____ _____ (fastest)

MOVING TARGETS

(slowest)   _____ _____ _____ _____ _____ (fastest)

    d. Sighting on distant targets

NON-MOVING TARGETS

(easiest)   _____ _____ _____ _____ _____ (hardest)

MOVING TARGETS

(easiest)   _____ _____ _____ _____ _____ (hardest)

e. Sighting on near targets

NON-MOVING TARGETS

(easiest) _____ _____ _____ _____ _____ (hardest)

MOVING TARGETS

(easiest) _____ _____ _____ _____ _____ (hardest)

2. Did any of the sights cause you difficulty in acquiring targets due to limited field of view (can't see a wide enough area)?

    ( ) yes   ( ) no   if yes, which sight(s) _____

3. Did any of the sights cause you to lose targets due to limited field of view?

    ( ) yes   ( ) no   if yes, which sight(s) _____

4. Did the size of any of the stadia lines cause you difficulty in aiming?

    ( ) yes   ( ) no   if yes, explain which sight(s) and why _____

    _____

    _____

    _____

5. Did the size of any of the peep sights cause you difficulty in aiming?

    ( ) yes   ( ) no   if yes, explain which sight(s) and why _____

    _____

    _____

    _____

6. Additional comments about the sights, if you desire: _____

    _____

    _____

    _____

    _____

2

TABLE 1F

Summary of Questionnaire No. 1 Comments

P - PHASE   G - GROUP   S - SUBJECT

P	G	S	Sight	Comparison with Previous Day's Sight
1	1	1	1	
			2	--was easier in that you didn't have to estimate distance.
			3	The telescopic sight and heavier, darker lines made it much easier and faster to aim. It gives a much clearer picture.
			4	n/c
			5	It was hard to get a good sight picture if there was dust hanging in the air around the tank or if the light was just right. Overall, though, it was much easier to use than 4. System 4 was too light in color to get a good sight picture.
	2		2	
			3	--is very accurate to use and requires less time to apply effective fire.
			5	n/c
			1	--too much lost time in range estimation with a greater degree of inaccuracy.
			4	The stadia in this sight is a hassle. Once sighted in on a moving target, while following it the shifting of the weapon makes you lose the stadia completely, then you have to reposition yourself and try to get another sight picture without losing the stadia.
	3		3	
			5	Due to the heavy black lines in the stadia of yesterday's sight, it was easier to distinguish the stadia lines.
			4	Due to the fact you had to get a good sight picture, it made it harder to sight and took a slight time longer to sight.
			2	The sight lines--were a little harder to see causing you to have a little harder time sighting on long-range targets, thereby throwing off your speed and accuracy.
			1	--was a little faster to use, but due to the fact that you had to estimate range, I felt it would be a little more inaccurate.
	4		4	
			1	n/c
			2	I kept losing the reticle when target was against the (tree) line.
			5	Hair lines too thin. Harder to aim on target when target is in a shaded area or against dark background.
			3	n/c

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P	G	S	Sight	Comparison with Previous Day's Sight
I	1	5	5	
			4	n/c
			1	--is easy to work and sight on the targets. I think that it is a very good sight.
			3	So far the best, easy to work with and accurate.
			2	n/c
I	2	1	1	
			5	n/c
			2	Was better than 5. Sighting rapidity on target and estimated accuracy were very efficient, also much more conventional.
			3	n/c
			4	Prefer this over all other systems--compact and distinct--.
		3	3	
			1	n/c
			5	Lines too thin.
			4	n/c
			2	n/c
		5	5	
			2	n/c
			4	Lines hard to see, easy to lose.
			1	n/c
			3	n/c
II	4	1	1	
			5	More accurate and easier to use.
			2	--by far easier to use than others.
			3	Highly inaccurate, too confusing.
			4	Too time consuming in setting range adjustments.
		2	2	
			4	Slower and a lot harder to use, especially on moving targets. Bad also with lots of sun. Very time taking.
			3	Good sight but can't say about accuracy. Easy to use.
			5	n/c
			1	Pretty simple to use. Sometimes I get confused.
		3	3	
			1	n/c
			5	Good sight for a man with three hands and static targets.
			4	This and 5 will never be good sights for an antitank weapon.
			2	This one is the best.

2

P	G	S	Sight	
II	4	4	4	
			3	Easier, faster and more accurate.
			1	Was a bit slower.
			2	n/c
			5	n/c
		5	5	
			2	Was much easier to use and did not require adjustment. --slightly easier to look through and identify the target and hold it to aim on target.
			4	Not as easy or accurate to use. Took an awful lot of estimating, and even under ideal conditions was hard to use.
			1	Far superior to anything used so far, accurate and easy to use. I wouldn't mind using it in combat.
			3	This was slightly easier to use but I prefer the accuracy of 1.

3

Summary of Questionnaire No. 2 Answers and Comments

P - PHASE   G - GROUP   S - SUBJECT

Q2.	P	G	S	Answer		Q3.	P	G	S	Answer
	I	1	4	2; 5			I	1	-	None
			5	2						
		2	1	1; 5				2	1	2; 5
			3	5					5	3 (On moving target)
			5	4						
	II	4	1	4			II	4	1	4
			5	4; 5					2	4
									5	4; 5

Q4.

G	S	Comment on sight
1	1	4 - caused more difficulty than any other. The transparency of the line, along with the wideness caused some difficulty. System 5 was also difficult to use if the light was a little on the bright side or there was dust or haze in the air.
	2	4 - tendency to lose lines on moving target.
	3	2 and 5 - due to the fine stadia lines of these sights, it was difficult to aim on long distance targets.
	4	2 and 5 - the lines are too thin and disappear in shadows or dark background.
2	2	4 - lose the lines, too thick.
	3	4 - lines too big.
	4	2 - lines too thin; 4 - lines either blur or lose them.

Q5. (Administered only in Phase I)
No comments in either group.

Q6.	P	G	S	Comment on sight
	I	1	1	3 - gave a much clearer picture, the lines of the stadia were easy to see against any background with a sharper picture.
			2	3 - seems to be more efficient for military use due to the ease and speed with which one can sight in on, track, and place effective fire on a target.
		2	1	4 - an all purpose sight, the best if fired properly.
			3	1 - couldn't aim accurately and range estimation took time.
			5	2 - the best one.

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11	4	1	Combination of 3 and 5 would be good.
		2	4 - is terrible.
		3	4 - was too hard to aim; 2 - will be the best and easiest for the troops to learn how to use. It will also be the cheapest to use. 4 and 5 - could not handle gun and aim sight at the same time.

TABLE 3F

Summary of "Friedman Two-Way Analysis of Variance"
on Subject Questionnaire Data

Question	Type of Target	— Friedman Test Statistic (T) —				
		Group 1	Group 2	Group 1 and 2	Group 3	Group 4
Sighting Ease	Moving	11.7*	4.5	14.8**	14.4**	16.3**
	Stationary	10.4*	5.7	15.8**	12.6*	15.2**
Aiming Accuracy	Moving	11.4*	3.8	13.8**	11.7*	11.2*
	Stationary	10.1*	7.2	15.8**	12.3*	5.6
Time to Fire	Moving	6.6	6.7	11.4**	12.6*	17.3**
	Stationary	6.7	8.2	10.9*	12.6*	17.1**

Levels of significance: ** = .01
  * = .05

APPENDIX G

TABLES OF SUPERELEVATION MEANS AND STANDARD
DEVIATIONS, AIMING ERROR STANDARD DEVIATIONS
AND AZIMUTH STANDARD DEVIATIONS

Tables G1 through G11 contain means and standard deviations for sight superelevations Tables G12 through G15 contain azimuth standard deviations, sorted by selected independent variables of target range, speed, and aspect. All tables are organized by sights, and subject groups tested with the sights; and in tables G9 and G10, the data are dichotomized by aim point.

Columns 1 through 3 in the tables give, respectively, target speed, aspect, and range. The three levels of target speed (1 through 3) correspond to 0, 7, and 14 mph. The three levels of target aspect (1 through 3) correspond to 1, 62.4, and 90 degrees, with 0 degrees representing a head-on target. The five levels of target range (1 through 5) correspond to 130, 210, 290, 370, and 450 meters.

The summary data shown in tables G1 through G7 were compiled by combining the data points for both groups into a single sample—in contrast to the main text, where summary data considered the SD s for each group as independent estimates of the population SD (thus ignoring biases between groups).

Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect
Phase I, Sight I

S P E E D	A S P E C T	R A N G E	Group 1			Group 2			Combined		
			MEAN	SD	N	MEAN	SD	N	MEAN	SD	N
1	1	1	.10	1.31	8.	.75	1.66	9.	.44	1.49	17.
1	1	2	-.61	1.26	10.	.10	1.20	9.	-.28	1.25	19.
1	1	3	-.30	.85	10.	-.00	1.28	11.	-.14	1.08	21.
1	1	4	-.32	1.36	11.	-.07	1.45	10.	-.20	1.37	21.
1	1	5	-.42	.60	8.	-.04	1.32	10.	-.21	1.05	18.
1	2	1	-.10	.81	9.	1.06	2.18	10.	.51	1.74	19.
1	2	2	-.20	1.27	7.	.41	1.49	10.	.16	1.39	17.
1	2	3	.03	1.28	9.	.42	1.53	10.	.24	1.39	19.
1	2	4	-.45	.87	14.	.75	1.19	10.	.05	1.16	24.
1	2	5	-.61	.65	8.	.75	1.31	10.	.14	1.25	18.
1	3	1	-.16	1.20	11.	.75	1.04	10.	.27	1.19	21.
1	3	2	-.54	1.22	9.	.26	2.05	10.	-.12	1.71	19.
1	3	3	-.15	.77	9.	.03	1.63	11.	-.05	1.29	20.
1	3	4	-.12	.84	9.	-.03	1.55	11.	-.04	1.25	20.
1	3	5	-1.00	1.05	11.	-.65	.97	10.	-.83	1.00	21.
2	1	1	-.47	2.15	11.	.29	1.28	13.	-.06	1.74	24.
2	1	2	-.76	1.69	10.	-.09	1.50	10.	-.43	1.60	20.
2	1	3	-.33	.82	10.	-.82	1.40	11.	-.58	1.16	21.
2	1	4	-.40	1.39	10.	-.09	1.41	11.	-.24	1.37	21.
2	1	5	-.23	1.81	10.	-.38	1.60	10.	-.31	1.67	20.
2	2	1	.19	1.72	10.	-.29	1.24	10.	-.05	1.48	20.
2	2	2	-.40	1.16	13.	.34	.99	9.	-.10	1.13	22.
2	2	3	-.86	.70	11.	.26	1.61	9.	-.36	1.29	20.
2	2	4	-.46	1.41	12.	.33	.98	10.	-.10	1.27	22.
2	2	5	-1.29	.94	9.	-.65	1.43	11.	-.94	1.24	20.
2	3	1	-.68	.84	9.	.57	1.72	9.	-.05	1.46	18.
2	3	2	-.81	1.20	10.	-.10	1.67	10.	-.46	1.46	20.
2	3	3	-.64	1.12	10.	-.69	1.10	10.	-.66	1.08	20.
2	3	4	-.66	.55	10.	-.52	1.76	11.	-.04	1.43	21.
2	3	5	-.55	.74	7.	-.54	1.38	9.	-.55	1.11	16.
3	3	2	-.48	1.14	12.	.11	1.77	9.	-.23	1.43	21.
3	3	3	-.66	1.32	10.	-.03	1.95	12.	-.32	1.68	22.
3	3	4	-.72	.95	10.	.16	1.83	10.	-.28	1.49	20.
3	3	5	-.28	1.35	10.	.10	1.61	10.	-.09	1.46	20.

Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect, Phase I, Sight 2

SPEED	ASPECT	RANGE	Group 1			Group 2			Combined		
			MEAN	SD	N	MEAN	SD	N	MEAN	SD	N
1	1	1	69.71	.00	1.	.00	.00	.	69.71	.00	1.
1	1	2	58.38	17.79	9.	53.27	7.17	8.	55.98	13.70	17.
1	1	3	69.72	8.70	10.	73.51	8.53	8.	71.41	8.59	18.
1	1	4	88.09	13.58	12.	87.22	18.94	8.	87.75	15.46	20.
1	1	5	102.04	9.40	9.	82.73	9.47	3.	97.22	12.52	12.
1	2	1	.00	.00	.	.00	.00	.	.00	.00	.
1	2	2	54.17	3.00	8.	56.06	7.26	10.	55.22	5.70	18.
1	2	3	74.12	2.76	12.	75.82	3.86	10.	74.89	3.33	22.
1	2	4	96.47	7.91	15.	97.99	5.16	6.	96.91	7.14	21.
1	2	5	109.42	2.62	2.	104.17	.00	1.	107.67	3.55	3.
1	3	1	.00	.00	.	44.71	.00	1.	44.71	.00	1.
1	3	2	54.59	1.52	10.	58.62	6.63	10.	56.60	5.12	20.
1	3	3	78.65	5.32	11.	80.62	6.17	10.	79.59	5.68	21.
1	3	4	103.37	6.93	9.	103.01	4.98	7.	103.21	5.96	16.
1	3	5	110.57	.00	1.	103.67	.00	1.	107.12	4.88	2.
2	1	1	49.81	.00	1.	.00	.00	.	49.81	.00	1.
2	1	2	54.45	3.64	9.	53.17	3.40	8.	53.85	3.48	17.
2	1	3	71.00	10.51	11.	71.19	7.70	9.	71.08	9.12	20.
2	1	4	83.84	13.70	10.	86.46	15.74	9.	85.08	14.34	19.
2	1	5	97.88	5.90	10.	81.17	16.69	2.	95.09	9.80	12.
2	2	1	.00	.00	.	.00	.00	.	.00	.00	.
2	2	2	55.43	9.01	11.	56.12	4.62	9.	55.74	7.20	20.
2	2	3	75.43	6.42	11.	81.70	13.52	9.	78.25	10.44	20.
2	2	4	96.88	6.63	12.	100.09	7.79	8.	98.16	7.10	20.
2	2	5	106.77	6.07	3.	100.02	11.53	2.	104.07	8.08	5.
2	3	1	.00	.00	.	50.71	.00	1.	50.71	.00	1.
2	3	2	54.01	4.54	9.	59.09	6.60	11.	56.80	6.19	20.
2	3	3	78.37	6.14	10.	82.18	9.65	10.	80.28	8.11	20.
2	3	4	98.56	8.47	9.	96.09	12.72	5.	97.68	9.77	14.
2	3	5	.00	.00	.	96.97	.00	1.	96.97	.00	1.
3	3	2	56.96	3.43	12.	63.48	9.75	10.	59.92	7.61	22.
3	3	3	83.68	6.83	10.	82.00	5.42	13.	82.73	5.99	23.
3	3	4	105.71	4.75	9.	99.75	8.26	7.	103.10	6.97	16.
3	3	5	111.07	.00	1.	100.17	.85	2.	103.80	6.32	3.

Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect
Phase I, Sight 3

SPEED	ASPECT	RANGE	Group 1 MEAN	Group 1 SD	Group 1 N	Group 2 MEAN	Group 2 SD	Group 2 N	Combined MEAN	Combined SD	Combined N
1	1	1	4.53	3.11	9.	3.01	2.81	8.	3.81	2.98	17.
1	1	2	8.40	2.02	9.	7.00	1.76	8.	7.74	1.98	17.
1	1	3	11.21	2.07	10.	12.28	1.95	9.	11.72	2.03	19.
1	1	4	15.59	1.71	12.	15.91	.59	7.	15.71	1.39	19.
1	1	5	19.16	1.82	9.	19.50	3.16	7.	19.30	2.41	16.
1	2	1	2.47	1.78	10.	1.74	1.85	10.	2.10	1.81	20.
1	2	2	8.22	1.52	8.	6.39	2.14	10.	7.20	2.06	18.
1	2	3	11.68	1.14	11.	12.12	1.69	10.	11.89	1.41	21.
1	2	4	14.85	1.29	15.	15.25	1.51	10.	15.01	1.36	25.
1	2	5	19.25	1.56	7.	21.29	3.28	10.	20.45	2.83	17.
1	3	1	2.24	3.49	12.	2.50	1.14	10.	2.36	2.64	22.
1	3	2	8.23	.87	10.	8.07	1.12	10.	8.15	.98	20.
1	3	3	12.59	.96	11.	11.51	1.52	11.	12.05	1.36	22.
1	3	4	16.68	.83	9.	17.49	2.44	10.	17.11	1.86	19.
1	3	5	21.39	1.74	11.	22.59	2.61	9.	21.93	2.20	20.
2	1	1	5.33	3.14	11.	3.17	2.57	9.	4.36	3.03	20.
2	1	2	7.89	1.44	10.	8.28	1.50	8.	8.06	1.44	18.
2	1	3	11.22	2.06	10.	11.37	2.08	9.	11.29	2.01	19.
2	1	4	14.52	1.82	10.	16.36	2.27	9.	15.39	2.20	19.
2	1	5	17.13	2.54	10.	19.10	2.62	7.	17.94	2.68	17.
2	2	1	3.28	3.88	11.	2.11	1.85	10.	2.72	3.07	21.
2	2	2	7.08	1.64	13.	7.16	2.19	10.	7.12	1.85	23.
2	2	3	11.51	1.16	10.	11.88	1.93	9.	11.69	1.53	19.
2	2	4	16.05	1.45	11.	16.43	2.05	10.	16.23	1.73	21.
2	2	5	19.24	2.21	10.	20.03	3.54	11.	19.65	2.94	21.
2	3	1	3.28	2.54	8.	2.21	2.11	10.	2.69	2.31	18.
2	3	2	8.19	1.41	8.	6.42	3.39	11.	7.17	2.83	19.
2	3	3	11.96	1.17	12.	12.42	2.31	10.	12.17	1.75	22.
2	3	4	16.62	1.67	10.	17.45	2.13	11.	17.05	1.93	21.
2	3	5	21.21	1.97	9.	20.19	1.35	9.	20.70	1.72	18.
3	3	2	8.27	1.65	11.	9.14	2.19	10.	8.69	1.92	21.
3	3	3	12.98	1.27	10.	12.40	1.93	12.	12.67	1.65	22.
3	3	4	16.11	2.71	11.	16.04	2.24	10.	16.08	2.44	21.
3	3	5	21.08	1.61	10.	21.65	3.08	11.	21.38	2.45	21.

Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect
Phase I, Sight 4

SPEED	ASPECT	RANGE	Group 1			Group 2			Combined		
			MEAN	SD	N	MEAN	SD	N	MEAN	SD	N
1	1	1	3.00	3.32	10.	1.52	2.99	8.	2.34	3.18	18.
1	1	2	7.28	1.34	9.	8.08	2.05	8.	7.66	1.70	17.
1	1	3	9.99	1.84	10.	10.37	1.86	8.	10.16	1.80	18.
1	1	4	13.49	2.26	11.	12.90	3.65	9.	13.23	2.90	20.
1	1	5	16.85	3.19	8.	15.58	4.50	6.	16.31	3.70	14.
1	2	1	2.24	1.49	9.	1.61	1.79	10.	1.91	1.64	19.
1	2	2	6.89	2.05	7.	6.65	1.40	10.	6.75	1.64	17.
1	2	3	9.56	1.81	12.	9.85	3.49	10.	9.69	2.64	22.
1	2	4	13.71	2.60	15.	14.52	2.45	9.	14.01	2.52	24.
1	2	5	16.92	1.74	8.	16.21	2.29	9.	16.54	2.02	17.
1	3	1	2.56	1.41	10.	2.33	2.39	10.	2.44	1.92	20.
1	3	2	7.02	1.46	10.	6.68	2.37	10.	6.85	1.92	20.
1	3	3	11.00	1.90	11.	9.73	1.78	11.	10.37	1.91	22.
1	3	4	13.24	1.17	9.	14.83	2.48	11.	14.12	2.11	20.
1	3	5	17.08	.80	10.	18.22	1.39	9.	17.62	1.24	19.
2	1	1	3.56	1.93	11.	1.67	3.21	11.	2.62	2.76	22.
2	1	2	6.98	1.69	9.	6.60	4.17	8.	6.81	3.01	17.
2	1	3	10.13	2.63	11.	10.43	2.99	8.	10.26	2.71	19.
2	1	4	11.64	2.49	10.	12.61	3.89	9.	12.10	3.17	19.
2	1	5	12.98	2.78	10.	13.85	4.16	6.	13.30	3.26	16.
2	2	1	1.50	4.04	10.	.90	1.52	10.	1.20	2.99	20.
2	2	2	6.95	1.58	12.	7.05	2.56	10.	7.00	2.03	22.
2	2	3	9.71	1.78	11.	9.77	1.49	9.	9.73	1.61	20.
2	2	4	13.53	1.86	12.	14.37	3.27	10.	13.91	2.56	22.
2	2	5	16.03	1.98	10.	16.14	2.08	11.	16.09	1.98	21.
2	3	1	.96	2.07	8.	2.51	2.34	10.	1.82	2.30	18.
2	3	2	7.33	2.36	8.	7.43	3.20	11.	7.39	2.80	19.
2	3	3	11.03	1.81	11.	9.92	1.35	10.	10.50	1.66	21.
2	3	4	15.18	1.96	10.	14.82	4.03	11.	14.99	3.14	21.
2	3	5	17.81	2.39	9.	17.74	2.47	9.	17.78	2.36	18.
3	3	2	8.18	2.00	12.	8.71	3.41	10.	8.42	2.67	22.
3	3	3	10.54	.95	10.	11.94	4.81	13.	11.33	3.68	23.
3	3	4	14.09	2.67	12.	14.46	3.30	10.	14.26	2.91	22.
3	3	5	17.29	2.91	8.	18.43	2.96	8.	17.86	2.89	16.

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SPEED	ASPECT	RANGE	Group 1			Group 2			Group 4		
			MEAN	SD	N	MEAN	SD	N	MEAN	SD	N
1	1	1	-.07	1.73	8.	-.96	1.68	7.	2.85	2.02	7.
1	1	2	6.27	3.16	10.	5.99	2.04	8.	6.21	2.94	6.
1	1	3	9.59	2.68	10.	8.38	1.66	9.	10.42	4.22	11.
1	1	4	13.09	2.53	10.	11.20	3.02	9.	13.20	3.08	9.
1	1	5	14.09	3.37	10.	16.22	4.50	6.	15.31	3.81	7.
1	2	1	-.39	.64	9.	.88	2.74	10.	1.22	3.02	9.
1	2	2	7.22	2.51	8.	6.25	1.62	10.	6.61	2.10	10.
1	2	3	9.89	1.19	10.	10.53	3.12	10.	11.83	2.78	10.
1	2	4	13.29	1.97	16.	13.82	2.21	10.	14.76	2.04	10.
1	2	5	17.35	2.86	7.	18.01	2.90	10.	16.77	2.50	10.
1	3	1	-.04	1.18	11.	.25	2.28	10.	.64	1.85	11.
1	3	2	7.90	1.65	9.	5.01	1.58	10.	8.29	1.96	10.
1	3	3	11.13	1.27	11.	11.05	2.42	11.	12.78	1.87	10.
1	3	4	15.86	1.57	9.	14.63	1.03	11.	16.40	1.96	11.
1	3	5	17.28	1.95	8.	18.82	2.44	10.	18.66	2.12	11.
2	1	1	-1.47	2.12	10.	-.35	1.20	8.	1.44	3.01	10.
2	1	2	5.95	3.29	9.	6.57	2.23	7.	6.69	3.37	10.
2	1	3	9.14	2.74	11.	6.57	2.05	9.	8.41	2.15	10.
2	1	4	10.98	3.16	10.	10.55	2.49	8.	13.46	3.25	10.
2	1	5	13.57	2.35	10.	18.87	4.49	7.	12.98	3.13	6.
2	2	1	-.63	2.87	9.	-.98	2.75	10.	1.49	2.26	10.
2	2	2	6.74	2.17	13.	5.02	2.02	9.	6.56	2.78	10.
2	2	3	9.90	2.13	11.	9.79	1.99	9.	10.76	1.82	9.
2	2	4	13.84	1.96	12.	13.65	1.87	10.	13.82	2.36	11.
2	2	5	16.00	1.33	9.	16.15	3.01	11.	17.33	2.29	10.
2	3	1	-1.07	1.78	8.	-.03	2.70	10.	1.07	1.29	10.
2	3	2	7.60	1.97	9.	7.12	1.61	11.	6.49	1.96	10.
2	3	3	12.08	2.13	10.	10.96	2.05	9.	10.55	2.25	11.
2	3	4	15.55	2.08	10.	15.47	1.85	11.	13.76	1.83	9.
2	3	5	18.15	2.95	8.	18.06	2.50	9.	17.02	2.91	11.
3	3	2	6.46	1.14	10.	5.66	1.81	9.	5.95	3.46	10.
3	3	3	11.06	1.91	9.	10.92	2.81	13.	11.91	2.20	10.
3	3	4	14.99	2.20	9.	15.86	2.28	11.	15.18	2.13	11.
3	3	5	17.70	1.94	8.	19.16	3.40	10.	18.00	3.22	8.

Superelevation Means and Standard Deviations Sorted by Range and Speed
Phase I, Sight 5 (continued) and Phase II, Sight 2

SPEED	SPECT	RANGE	Combined MEAN	SD	N		SPEED	SPECT	RANGE	Group 3 MEAN	SD	N
1	1	1	.58	2.38	22.		1	1	1	-1.03	2.13	4.
1	1	2	6.16	2.66	24.		1	1	2	1.60	1.27	4.
1	1	3	9.53	3.14	30.		1	1	3	4.73	1.33	3.
1	1	4	12.52	2.91	28.		1	1	4	5.55	1.85	4.
1	1	5	15.01	3.74	23.		1	1	5	7.45	1.00	4.
1	2	1	.58	2.41	28.		1	2	1	-1.27	1.79	4.
1	2	2	6.65	2.03	28.		1	2	2	1.35	1.44	4.
1	2	3	10.75	2.56	30.		1	2	3	2.67	1.48	6.
1	2	4	13.85	2.09	36.		1	2	4	5.90	.42	4.
1	2	5	17.38	2.69	27.		1	2	5	7.90	1.19	4.
1	3	1	.29	1.77	32.		1	3	1	-.67	1.12	4.
1	3	2	7.04	2.26	29.		1	3	2	1.65	.88	4.
1	3	3	11.62	2.01	32.		1	3	3	2.23	.17	4.
1	3	4	15.61	1.70	31.		1	3	4	5.80	1.68	4.
1	3	5	18.33	2.22	29.		1	3	5	7.02	.78	4.
2	1	1	-.11	2.55	28.		2	1	1	-.83	.50	4.
2	1	2	6.40	2.98	26.		2	1	2	1.75	2.06	4.
2	1	3	8.13	2.52	30.		2	1	3	3.95	1.38	4.
2	1	4	11.74	3.19	28.		2	1	4	5.85	1.10	4.
2	1	5	15.03	4.10	23.		2	1	5	7.03	1.53	3.
2	2	1	-.02	2.77	29.		2	2	1	-1.65	1.45	4.
2	2	2	6.20	2.38	32.		2	2	2	1.75	2.53	4.
2	2	3	10.13	1.97	29.		2	2	3	3.80	1.45	5.
2	2	4	13.78	2.02	33.		2	2	4	5.50	2.36	4.
2	2	5	16.50	2.37	30.		2	2	5	7.77	1.90	6.
2	3	1	.06	2.14	28.		2	3	1	-1.55	1.00	4.
2	3	2	7.05	1.83	30.		2	3	2	.55	1.56	4.
2	3	3	11.18	2.18	30.		2	3	3	2.63	1.96	4.
2	3	4	14.98	2.03	30.		2	3	4	5.97	1.07	4.
2	3	5	17.68	2.75	28.		2	3	5	6.74	2.00	5.
3	3	2	6.04	2.31	29.		3	3	2	.98	.32	4.
3	3	3	11.27	2.37	32.		3	3	3	3.48	.86	5.
3	3	4	15.37	2.16	31.		3	3	4	5.75	1.24	4.
3	3	5	18.36	2.93	26.		3	3	5	5.73	1.42	3.

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Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect
Phase II, Sight 1

SPEED	ASPECT	RANGE	Group 3 MEAN	SD	N	Group 4 MEAN	SD	N	Combined MEAN	SD	N
1	1	1	-1.26	1.37	9.	.00	.92	7.	-.71	1.32	16.
1	1	2	4.21	2.25	11.	2.98	3.29	9.	3.66	2.76	20.
1	1	3	8.27	4.32	10.	8.52	2.55	10.	8.40	3.46	20.
1	1	4	14.61	3.36	9.	14.95	4.25	10.	14.74	3.75	19.
1	1	5	16.39	2.56	9.	16.48	5.08	8.	16.43	3.82	17.
1	2	1	-.14	2.39	8.	.60	1.17	8.	.23	1.85	16.
1	2	2	5.22	2.28	10.	2.73	2.84	9.	4.04	2.80	19.
1	2	3	9.56	4.61	13.	7.88	1.24	9.	8.87	3.67	22.
1	2	4	16.42	3.56	10.	13.84	3.93	7.	15.36	3.82	17.
1	2	5	18.00	6.00	6.	17.80	6.43	7.	17.89	5.97	13.
1	3	1	-1.06	.33	7.	.08	.60	9.	-.42	.76	16.
1	3	2	4.11	3.37	8.	4.30	3.58	9.	4.21	3.38	17.
1	3	3	7.29	3.05	11.	8.09	3.43	9.	7.65	3.16	20.
1	3	4	12.06	3.38	8.	12.36	4.69	10.	12.23	4.04	18.
1	3	5	16.36	6.53	8.	19.61	3.89	8.	17.99	5.46	16.
2	1	1	-.23	2.30	8.	.23	1.08	7.	-.01	1.79	15.
2	1	2	4.33	3.66	10.	4.49	3.07	9.	4.41	3.30	19.
2	1	3	9.78	4.25	9.	8.12	1.34	10.	8.91	3.11	19.
2	1	4	13.87	3.87	9.	13.77	3.71	11.	13.82	3.68	20.
2	1	5	18.43	4.61	6.	15.70	3.88	9.	16.79	4.26	15.
2	2	1	-.76	1.15	7.	.97	.94	7.	.11	1.35	14.
2	2	2	3.86	2.31	7.	2.12	4.38	10.	2.84	3.68	17.
2	2	3	7.88	3.15	11.	8.80	5.93	9.	8.30	4.50	20.
2	2	4	15.34	4.74	9.	15.75	3.47	10.	15.56	4.01	19.
2	2	5	18.55	4.88	10.	16.72	3.50	10.	17.63	4.24	20.
2	3	1	-1.59	1.45	7.	-.52	.96	6.	-1.09	1.32	13.
2	3	2	4.58	3.09	9.	3.21	3.69	8.	3.94	3.35	17.
2	3	3	10.03	3.82	10.	8.82	3.13	10.	9.42	3.46	20.
2	3	4	14.71	4.28	9.	15.49	2.52	8.	15.08	3.48	17.
2	3	5	18.46	4.61	9.	16.69	5.09	9.	17.57	4.80	18.
3	3	2	4.12	2.25	9.	3.91	2.95	9.	4.02	2.55	18.
3	3	3	9.27	3.88	10.	7.95	4.46	8.	8.68	4.07	18.
3	3	4	13.48	4.87	9.	12.51	4.50	7.	13.06	4.58	16.
3	3	5	19.52	4.84	8.	15.26	.65	5.	17.88	4.30	13.

Superelevation Means and Standard Deviations for Each Aim-Point (QE-1 and QE-2) Sorted by Range, Speed and Aspect Phase II, Sight 3, Group 3

SPEED	ASPECT	RANGE	QE-1			QE-2		
			MEAN	SD	N	MEAN	SD	N
1	1	1	8.24	.98	10.	.00	.00	.
1	1	2	8.58	.92	11.	.00	.00	.
1	1	3	8.32	.56	5.	14.34	.55	5.
1	1	4	.00	.00	.	14.46	.86	10.
1	1	5	.00	.00	.	14.00	.74	7.
1	2	1	8.79	1.42	8.	.00	.00	.
1	2	2	8.94	.84	10.	.00	.00	.
1	2	3	8.79	1.05	11.	15.35	.49	2.
1	2	4	8.66	1.04	5.	14.72	1.60	5.
1	2	5	.00	.00	.	14.39	1.22	7.
1	3	1	8.04	.92	9.	.00	.00	.
1	3	2	8.88	.79	10.	.00	.00	.
1	3	3	8.23	.74	9.	13.40	.57	2.
1	3	4	8.47	.32	3.	14.33	1.40	7.
1	3	5	.00	.00	.	14.58	1.26	9.
2	1	1	7.99	.90	9.	.00	.00	.
2	1	2	8.63	1.12	11.	.00	.00	.
2	1	3	7.48	.77	5.	14.62	.49	4.
2	1	4	8.00	.00	1.	14.22	.95	9.
2	1	5	.00	.00	.	14.06	1.25	5.
2	2	1	9.03	.81	6.	.00	.00	.
2	2	2	8.35	.73	8.	.00	.00	.
2	2	3	7.99	.66	8.	14.30	.39	4.
2	2	4	8.40	1.45	3.	14.56	.81	7.
2	2	5	.00	.00	.	14.41	.92	9.
2	3	1	8.39	.96	8.	.00	.00	.
2	3	2	8.70	.99	10.	.00	.00	.
2	3	3	8.42	1.48	6.	14.58	.32	4.
2	3	4	9.60	.71	4.	14.57	1.04	6.
2	3	5	.00	.00	.	14.23	.77	7.
3	3	2	8.49	1.24	9.	14.40	.00	1.
3	3	3	8.70	1.21	8.	15.83	1.53	3.
3	3	4	9.37	1.07	3.	14.77	.78	6.
3	3	5	.00	.00	.	14.27	.92	8.
1	0	1	8.34	1.11	27.	.00	.00	.
1	0	2	8.79	.84	31.	.00	.00	.
1	0	3	8.50	.88	25.	14.36	.84	9.
1	0	4	8.59	.81	8.	14.48	1.18	22.
1	0	5	.00	.00	.	14.34	1.09	23.
2	0	1	8.4?	.95	23.	.00	.00	.
2	0	2	8.58	.96	29.	.00	.00	.
2	0	3	7.99	1.02	19.	14.50	.40	12.
2	0	4	8.95	1.15	8.	14.42	.90	22.
2	0	5	.00	.00	.	14.27	.92	21.
3	0	2	8.49	1.24	9.	14.40	.00	1.
3	0	3	8.70	1.21	8.	15.83	1.53	3.
3	0	4	9.37	1.07	3.	14.77	.78	6.
3	0	5	.00	.00	.	14.27	.92	8.

Superelevation Means and Standard Deviations for Each Aim-Point (QE-1 and QE-2) Sorted by Range, Speed and Aspect
Phase II, Sight 3, Group 4

SPEED	ASPECT	RANGE	QE-1			QE-2		
1	1	1	6.99	1.33	8.	.00	.00	.
1	1	2	7.34	1.47	1C.	.00	.00	.
1	1	3	7.78	.73	5.	14.20	.74	5.
1	1	4	7.20	.00	2.	14.36	.66	7.
1	1	5	.00	.00	.	13.65	.26	4.
1	2	1	8.50	.57	7.	.00	.00	.
1	2	2	7.63	1.08	9.	.00	.00	.
1	2	3	8.04	.57	7.	13.90	1.98	2.
1	2	4	7.35	.49	2.	13.97	.78	8.
1	2	5	.00	.00	.	14.50	.59	4.
1	3	1	7.76	.67	8.	.00	.00	.
1	3	2	3.27	.84	1C.	.00	.00	.
1	3	3	7.90	.98	8.	14.35	1.06	2.
1	3	4	7.58	.97	4.	14.42	.56	6.
1	3	5	.00	.00	.	13.83	.87	8.
2	1	1	7.24	1.69	9.	.00	.00	1.
2	1	2	8.CO	1.36	9.	14.60	.00	1.
2	1	3	7.89	.62	7.	13.43	1.32	3.
2	1	4	7.20	.85	2.	14.10	.85	9.
2	1	5	.00	.00	.	14.42	1.09	5.
2	2	1	9.12	1.42	10.	.00	.00	1.
2	2	2	7.79	1.40	9.	16.10	.00	1.
2	2	3	7.44	.98	8.	13.30	.85	2.
2	2	4	8.03	1.24	3.	13.75	1.37	8.
2	2	5	.00	.00	.	14.00	.57	6.
2	3	1	8.03	.89	7.	.00	.00	.
2	3	2	7.48	1.45	8.	.00	.00	1.
2	3	3	8.34	.66	1C.	14.40	.00	1.
2	3	4	7.30	.00	1.	14.51	.54	7.
2	3	5	.C0	.00	.	13.99	.90	7.
3	3	2	7.51	.94	9.	.00	.00	2.
3	3	3	7.C3	.69	7.	13.85	.49	2.
3	3	4	8.50	.57	2.	13.98	.60	6.
3	3	5	.C0	.C0	.	14.07	.82	4.
1	0	1	7.72	1.09	23.	.00	.C0	.
1	0	2	7.75	1.19	29.	.00	.00	.
1	0	3	7.92	.76	20.	14.17	.97	9.
1	0	4	7.43	.69	8.	14.23	.68	21.
1	C	5	.00	.00	.	13.55	.74	16.
2	0	1	8.18	1.59	26.	.00	.00	.
2	0	2	7.77	1.36	26.	15.35	1.06	2.
2	0	3	7.92	.83	25.	13.55	1.01	6.
2	0	4	7.63	.98	6.	14.10	1.C0	24.
2	0	5	.C0	.00	.	14.11	.84	18.
3	0	2	7.51	.94	9.	.00	.00	2.
3	0	3	7.24	.87	8.	13.85	.49	2.
3	0	4	8.50	.57	2.	13.98	.60	6.
3	0	5	.00	.C0	.	14.07	.82	4.

Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect,
Phase II, Sight 4

S P E E D	S P E E D	A S P E C T	A R A N G E	Group 3		
S P E E D	S P E E D	A S P E C T	A R A N G E	MEAN	SD	N
1	1	1		1,59	1,98	10.
1	1	2		2,03	,96	10,
1	1	3		3,77	2,03	9.
1	1	4		4,56	1,86	9,
1	1	5		5,18	1,78	10,
1	2	1		1,19	1,08	10,
1	2	2		1,51	1,95	10,
1	2	3		2,75	1,65	12,
1	2	4		4,26	2,70	9,
1	2	5		4,86	1,19	9,
1	3	1		,99	1,66	8.
1	3	2		1,99	2,02	10,
1	3	3		2,59	1,83	10,
1	3	4		3,27	2,20	10,
1	3	5		4,46	1,51	10,
2	1	1		2,63	2,12	10,
2	1	2		3,42	2,42	11,
2	1	3		3,93	1,86	9,
2	1	4		4,48	1,26	9,
2	1	5		4,63	2,05	9,
2	2	1		2,37	1,97	9,
2	2	2		1,96	1,54	9,
2	2	3		3,10	1,40	12,
2	2	4		4,33	2,21	10,
2	2	5		5,33	2,39	12,
2	3	1		2,73	1,80	7,
2	3	2		2,47	2,04	9,
2	3	3		4,05	2,08	10,
2	3	4		4,30	1,52	10,
2	3	5		5,90	1,59	10,
3	3	2		1,84	1,79	9,
3	3	3		3,71	2,61	10,
3	3	4		3,80	1,24	9,
3	3	5		5,34	1,49	9,

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Superelevation Means and Standard Deviations Sorted by Range, Speed and Aspect
Phase II. Sight 5

SPEED	ASPECT	RANGE	Group 3 MEAN	Group 3 SD	Group 3 N	Group 4 MEAN	Group 4 SD	Group 4 N	Combined MEAN	Combined SD	Combined N
1	1	1	.24	2.06	10	.72	1.98	10	.48	1.98	20
1	1	2	3.01	3.21	11	.32	2.27	10	1.73	3.06	21
1	1	3	3.09	1.22	9	4.85	2.23	10	4.02	1.99	19
1	1	4	6.14	2.20	10	4.67	1.37	9	5.44	1.96	19
1	1	5	7.15	1.74	10	6.16	2.76	10	6.66	2.30	20
1	2	1	.64	2.85	9	-.81	1.33	9	-.08	2.29	18
1	2	2	-.19	1.98	10	1.08	1.57	9	.41	1.86	19
1	2	3	3.13	1.36	13	2.80	1.40	9	3.00	1.35	22
1	2	4	4.55	.80	10	4.54	.87	10	4.55	.82	20
1	2	5	7.33	1.52	10	7.40	.51	8	7.36	1.15	18
1	3	1	-.67	1.04	7	-.51	1.15	11	-.57	1.08	18
1	3	2	1.45	1.52	10	.69	1.50	9	1.09	1.52	19
1	3	3	3.70	1.02	10	3.11	1.03	9	3.42	1.04	19
1	3	4	5.78	1.21	10	5.20	1.10	10	5.49	1.16	20
1	3	5	8.12	1.09	10	8.74	.72	10	8.43	.95	20
2	1	1	.62	3.33	10	-.17	.91	10	.23	2.41	20
2	1	2	1.88	2.64	11	1.83	2.95	10	1.86	2.72	21
2	1	3	4.01	2.43	9	3.75	.78	10	3.87	1.72	19
2	1	4	6.72	2.46	10	5.20	2.80	9	6.00	2.67	19
2	1	5	6.41	2.34	9	5.43	2.38	10	5.89	2.35	19
2	2	1	.80	2.51	8	1.01	3.29	9	.91	2.86	17
2	2	2	.46	2.32	8	1.07	2.35	10	.80	2.29	18
2	2	3	2.95	1.78	10	2.64	1.34	10	2.79	1.54	20
2	2	4	5.59	2.65	10	.42	1.29	10	5.51	2.03	20
2	2	5	6.65	1.62	11	.49	2.12	10	7.05	1.88	21
2	3	1	1.32	2.42	6	-1.24	2.52	7	-.06	2.72	13
2	3	2	2.08	1.49	9	.58	3.17	10	1.29	2.57	19
2	3	3	3.42	1.91	10	3.10	1.03	11	3.25	1.48	21
2	3	4	5.23	.80	9	5.76	3.04	8	5.48	2.11	17
2	3	5	8.11	1.69	10	7.32	2.27	10	7.72	1.99	20
3	3	2	.61	1.23	10	1.68	2.13	9	1.12	1.75	19
3	3	3	2.85	1.13	10	3.58	1.18	9	3.19	1.18	19
3	3	4	5.28	1.63	8	6.84	1.87	10	6.14	1.89	18
3	3	5	7.56	1.67	10	8.07	1.67	10	7.81	1.65	20

Azimuth Standard Deviations Sorted by Range, Speed and Aspect
Phase 1, Group 1

SPEED	ASPECT	RANGE	Sight 1		Sight 2		Sight 3		Sight 4		Sight 5	
			SD	N	SD	N	SD	N	SD	N	SD	N
1	1	1	1.15	9.	0.00	1.	0.91	9.	0.95	10.	1.48	8.
1	1	2	0.93	10.	1.68	9.	1.15	9.	1.61	9.	1.50	10.
1	1	3	0.93	10.	1.18	10.	0.84	10.	0.58	10.	1.76	10.
1	1	4	1.06	11.	1.21	12.	0.63	12.	1.43	11.	0.85	10.
1	1	5	0.82	8.	1.33	9.	0.69	9.	1.28	8.	2.07	10.
1	2	1	2.65	9.	0.00	0.	1.43	10.	2.66	9.	2.72	9.
1	2	2	2.05	7.	1.95	8.	1.41	8.	1.70	7.	1.99	8.
1	2	3	1.91	9.	1.50	12.	1.22	11.	1.21	12.	1.09	10.
1	2	4	1.46	14.	1.36	15.	1.13	15.	1.04	15.	1.44	16.
1	2	5	1.93	8.	0.42	2.	0.98	7.	0.88	8.	1.32	7.
1	3	1	1.49	12.	0.00	0.	1.80	12.	2.16	10.	1.55	11.
1	3	2	2.26	9.	1.88	10.	1.91	10.	2.34	10.	1.52	9.
1	3	3	1.99	9.	1.81	11.	1.14	11.	1.27	11.	0.97	11.
1	3	4	1.36	9.	1.58	9.	0.83	9.	1.12	9.	1.70	9.
1	3	5	1.44	11.	0.00	1.	0.61	11.	0.99	10.	1.24	8.
2	1	1	0.83	11.	0.00	1.	1.14	11.	1.57	11.	1.08	10.
2	1	2	1.79	10.	1.56	9.	0.93	10.	2.87	9.	1.58	9.
2	1	3	0.68	10.	1.48	11.	0.86	10.	1.01	11.	1.79	11.
2	1	4	1.12	10.	2.09	10.	0.76	10.	1.37	10.	1.40	10.
2	1	5	1.29	10.	0.94	10.	0.75	10.	1.33	10.	1.28	10.
2	2	1	2.88	11.	0.00	0.	2.30	11.	2.04	10.	2.44	9.
2	2	2	2.14	13.	2.36	11.	2.43	13.	1.81	12.	2.78	13.
2	2	3	2.00	11.	3.03	11.	0.97	10.	1.91	11.	2.21	11.
2	2	4	1.92	12.	2.46	12.	1.53	11.	2.04	12.	1.25	12.
2	2	5	1.04	9.	1.18	3.	1.59	10.	1.64	10.	2.23	9.
2	3	1	3.01	9.	0.00	0.	2.45	8.	4.65	8.	3.06	8.
2	3	2	3.03	10.	2.03	9.	2.39	8.	4.06	8.	2.84	9.
2	3	3	1.95	10.	1.76	10.	1.69	12.	2.06	11.	3.55	10.
2	3	4	1.41	10.	1.80	9.	1.47	10.	1.99	10.	1.72	10.
2	3	5	0.96	7.	0.00	0.	1.65	9.	2.87	9.	1.87	8.
3	3	2	2.13	12.	5.97	12.	2.82	11.	3.10	12.	2.60	10.
3	3	3	1.71	10.	1.74	10.	2.26	10.	1.58	10.	2.48	9.
3	3	4	1.40	11.	2.63	9.	1.75	11.	0.90	12.	2.01	9.
3	3	5	2.44	10.	0.00	1.	1.47	10.	1.21	8.	2.38	8.

Azimuth Standard Deviations Sorted by Range, Speed and Aspect
Phase I, Group 2

S P E E D	S S P E C T	R A N G E	A S P E C T	Sight 1 SD	Sight 1 N	Sight 2 SD	Sight 2 N	Sight 3 SD	Sight 3 N	Sight 4 SD	Sight 4 N	Sight 5 SD	Sight 5 N
1	1	1		2.02	10.	0.00	0.	6.23	8.	0.78	8.	1.58	7.
1	1	2		2.57	10.	1.87	8.	0.96	8.	2.67	8.	0.65	8.
1	1	3		1.10	11.	1.40	8.	1.62	9.	2.59	8.	2.08	9.
1	1	4		1.72	11.	1.17	8.	1.23	7.	2.97	9.	1.72	9.
1	1	5		2.72	10.	1.14	3.	0.65	7.	0.97	6.	2.06	5.
1	2	1		5.27	10.	0.00	0.	2.27	10.	3.19	10.	1.94	10.
1	2	2		2.23	10.	1.33	10.	1.86	10.	2.25	10.	1.87	10.
1	2	3		1.14	10.	1.25	10.	1.27	10.	1.67	10.	1.61	10.
1	2	4		1.46	10.	0.82	6.	1.27	10.	1.10	9.	1.12	10.
1	2	5		1.25	10.	0.00	1.	1.50	10.	1.43	9.	1.41	10.
1	3	1		3.15	10.	0.00	1.	1.68	10.	5.82	10.	2.21	10.
1	3	2		2.59	10.	1.69	10.	2.07	10.	1.64	10.	1.51	10.
1	3	3		2.08	11.	1.24	10.	1.55	11.	1.30	11.	2.30	11.
1	3	4		1.43	11.	0.53	7.	1.06	10.	1.34	11.	1.58	11.
1	3	5		1.39	10.	0.00	1.	1.44	9.	0.82	9.	1.07	10.
2	1	1		1.41	13.	0.00	0.	5.26	9.	1.55	11.	1.35	8.
2	1	2		1.70	10.	1.78	8.	0.87	8.	2.55	8.	1.38	7.
2	1	3		1.36	11.	1.37	9.	1.01	9.	2.00	8.	0.96	9.
2	1	4		2.20	11.	1.03	9.	1.87	9.	1.56	9.	1.74	8.
2	1	5		1.00	10.	1.34	2.	0.73	7.	0.78	6.	0.59	7.
2	2	1		3.52	10.	0.00	0.	3.12	10.	4.00	10.	1.90	10.
2	2	2		1.75	10.	2.61	9.	1.68	10.	2.41	10.	3.03	9.
2	2	3		2.48	9.	1.60	9.	2.34	9.	3.53	9.	1.61	9.
2	2	4		2.82	10.	2.59	8.	1.43	10.	2.02	10.	1.90	10.
2	2	5		1.57	11.	1.84	2.	1.68	11.	2.18	11.	1.27	11.
2	3	1		3.25	10.	0.00	1.	3.29	10.	4.21	10.	3.13	10.
2	3	2		3.71	10.	1.30	11.	4.38	11.	1.31	11.	2.25	11.
2	3	3		4.15	9.	3.14	10.	1.80	10.	2.83	10.	3.19	9.
2	3	4		3.19	11.	2.10	5.	1.82	11.	1.97	11.	2.06	11.
2	3	5		1.46	9.	0.00	1.	1.38	9.	1.52	9.	1.85	9.
3	3	2		1.69	10.	2.23	10.	2.79	10.	2.66	10.	1.12	9.
3	3	3		2.45	12.	1.72	13.	1.74	12.	2.50	13.	2.33	13.
3	3	4		2.82	10.	2.04	7.	2.42	10.	1.72	10.	2.86	11.
3	3	5		2.33	10.	1.48	2.	0.75	11.	1.93	8.	1.51	10.

Azimuth Standard Deviations Sorted by Range, Speed and Aspect
Phase II, Group 3

SPEED	ASPECT	RANGE	Sight 1 SD	Sight 1 N	Sight 2 SD	Sight 2 N	Sight 3 SD	Sight 3 N	Sight 4 SD	Sight 4 N	Sight 5 SD	Sight 5 N
1	1	1	0.96	9.	1.91	4.	0.73	11.	1.79	10.	1.10	10.
1	1	2	3.43	11.	0.61	4.	0.74	11.	1.31	10.	1.28	10.
1	1	3	3.59	10.	0.25	3.	0.85	10.	1.16	9.	1.48	9.
1	1	4	1.58	9.	0.91	4.	0.71	10.	0.65	9.	0.91	10.
1	1	5	0.85	8.	1.06	4.	0.73	7.	0.76	10.	1.63	10.
1	2	1	2.19	8.	2.73	4.	1.72	10.	3.43	10.	2.58	9.
1	2	2	2.45	10.	0.97	4.	2.25	10.	2.37	10.	1.96	10.
1	2	3	1.70	13.	1.58	6.	1.25	13.	1.62	12.	1.26	13.
1	2	4	1.77	10.	1.47	4.	1.57	10.	1.67	9.	1.27	10.
1	2	5	1.14	6.	1.49	4.	2.20	7.	1.19	9.	1.48	10.
1	3	1	1.59	7.	6.24	4.	2.63	9.	2.10	8.	2.86	7.
1	3	2	3.10	8.	3.16	3.	2.44	10.	2.37	10.	2.77	10.
1	3	3	2.05	11.	1.30	4.	1.88	11.	1.95	10.	1.23	10.
1	3	4	1.61	8.	1.78	4.	1.58	10.	1.84	10.	1.80	10.
1	3	5	0.88	8.	1.85	4.	1.75	9.	1.53	10.	1.36	10.
2	1	1	3.45	8.	1.20	4.	2.45	9.	1.60	10.	3.50	10.
2	1	2	0.91	10.	1.31	4.	3.66	11.	1.49	11.	1.62	11.
2	1	3	1.30	9.	1.01	4.	1.70	9.	1.24	9.	2.31	9.
2	1	4	1.71	9.	0.80	4.	0.80	10.	1.33	9.	1.10	10.
2	1	5	1.17	6.	0.57	3.	0.90	5.	1.52	9.	3.01	9.
2	2	1	2.26	7.	3.06	4.	2.82	8.	5.48	9.	3.02	8.
2	2	2	4.54	7.	1.95	4.	2.89	8.	4.40	9.	3.24	8.
2	2	3	2.02	11.	1.41	5.	2.68	12.	3.47	12.	2.90	10.
2	2	4	1.63	9.	2.46	4.	1.55	10.	2.46	10.	1.98	10.
2	2	5	2.81	10.	2.11	6.	1.91	10.	3.02	11.	1.46	11.
2	3	1	3.65	7.	2.25	4.	1.98	9.	3.67	7.	3.54	6.
2	3	2	4.48	9.	5.75	4.	2.71	10.	5.25	9.	2.74	9.
2	3	3	2.60	9.	2.72	4.	3.33	10.	3.66	10.	2.51	10.
2	3	4	2.68	9.	1.54	4.	1.99	10.	2.77	10.	2.82	9.
2	3	5	0.75	9.	2.36	5.	1.26	8.	3.39	10.	2.93	10.
3	3	2	5.25	9.	3.88	4.	4.15	10.	3.46	9.	2.89	10.
3	3	3	3.25	10.	1.16	5.	3.98	11.	4.51	10.	3.61	10.
3	3	4	1.60	9.	2.99	4.	1.90	9.	4.41	9.	1.62	8.
3	3	5	2.43	7.	3.01	3.	2.43	8.	2.93	9.	3.48	10.

Azimuth Standard Deviations Sorted by Range, Speed and Aspect
Phase II, Group 4

SPEED	ASPECT	RANGE	Sight 1 SD	Sight 1 N	Sight 2 SD	Sight 2 N	Sight 3 SD	Sight 3 N	Sight 4 SD	Sight 4 N	Sight 5 SD	Sight 5 N
1	1	1	1.30	7.	1.73	7.	7.81	8.	1.56	10.	2.49	10.
1	1	2	1.30	9.	1.23	6.	1.51	10.	1.21	10.	2.44	10.
1	1	3	1.20	10.	1.61	11.	1.23	10.	1.64	11.	1.72	10.
1	1	4	1.09	10.	2.22	9.	0.84	9.	1.38	10.	1.27	9.
1	1	5	0.62	8.	1.57	7.	1.12	6.	1.65	10.	1.64	10.
1	2	1	2.05	8.	1.52	9.	1.85	8.	2.50	10.	2.48	9.
1	2	2	1.27	9.	1.99	10.	2.49	10.	1.81	10.	1.91	9.
1	2	3	1.48	9.	1.06	10.	1.30	10.	3.13	10.	2.29	9.
1	2	4	0.84	7.	1.41	10.	1.60	9.	1.36	10.	1.80	10.
1	2	5	1.18	7.	0.99	10.	1.91	6.	1.44	10.	1.03	8.
1	3	1	4.09	9.	3.65	11.	3.70	10.	2.64	11.	3.32	11.
1	3	2	1.98	9.	2.14	10.	3.20	10.	4.05	10.	2.45	9.
1	3	3	2.06	9.	2.25	10.	1.96	10.	3.26	10.	1.91	9.
1	3	4	2.30	10.	1.12	11.	1.53	10.	1.64	11.	1.02	10.
1	3	5	1.43	8.	0.93	11.	1.32	9.	0.88	11.	1.31	10.
2	1	1	0.70	7.	1.22	10.	1.33	9.	4.16	10.	3.35	10.
2	1	2	0.98	9.	1.36	10.	1.42	10.	1.83	10.	1.55	10.
2	1	3	0.96	10.	2.01	10.	1.38	10.	1.57	10.	2.39	10.
2	1	4	1.05	11.	2.52	10.	1.16	11.	0.88	11.	1.46	9.
2	1	5	1.42	9.	1.52	6.	0.83	5.	1.84	10.	2.39	10.
2	2	1	1.48	7.	3.82	10.	3.26	10.	5.77	10.	2.67	9.
2	2	2	2.18	10.	2.32	10.	3.04	10.	2.48	9.	2.37	10.
2	2	3	2.00	9.	2.36	9.	2.22	10.	2.72	10.	3.09	10.
2	2	4	2.60	10.	1.62	11.	2.39	11.	1.69	11.	2.65	10.
2	2	5	2.17	9.	1.34	10.	1.97	5.	2.77	10.	2.22	10.
2	3	1	1.53	6.	3.47	10.	1.93	10.	1.96	11.	2.92	7.
2	3	2	3.68	8.	2.48	10.	2.37	10.	4.36	10.	4.36	10.
2	3	3	1.85	10.	2.04	11.	3.18	11.	2.70	11.	2.88	11.
2	3	4	1.61	8.	1.96	9.	3.40	8.	2.43	9.	1.96	8.
2	3	5	2.00	9.	1.74	11.	2.31	8.	3.39	9.	3.18	10.
3	3	2	3.33	9.	2.11	10.	4.97	8.	5.c8	10.	3.70	8.
3	3	3	1.76	8.	3.00	10.	3.47	9.	3.06	9.	2.23	9.
3	3	4	1.11	7.	2.37	11.	1.85	8.	3.25	10.	4.34	10.
3	3	5	2.25	5.	2.16	8.	1.17	5.	2.63	9.	2.96	10.

APPENDIX H

HIT PROBABILITIES FOR FIXED QE FIRING TECHNIQUES
(Computed by the U. S. Army Materiel Systems Analysis Activity)

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AMXSY-GI   1 November 1972

SUBJECT: HEL Sighting Experiment - Fixed Q.E. Techniques of Fire

Director
US Army Human Engineering Laboratory
ATTN: Mr. D. Giordano
Building 520

1. The results of our calculations to determine the optimum fixed quadrant
elevations for several sighting techniques to be tested in the HEL sighting
test (SMAWT program) are presented and discussed in the following paragraphs.
All of the calculations are based on an 81mm system with an initial velocity
of 1200 f/s.

2. Single Fixed Quadrant Elevation: The optimum single fixed Q.E. is
approximately 17 mils with a decision range of 350 meters. The decision
range is the estimated range beyond which the gunner will no longer fire.
Hit probability versus range is given in Figure 1 with a comparison to com-
peting fixed Q.E.'s and to the conventional method of aiming.

3. Multi-fixed Q.E. Sighting Technique: The results of this investigation
are presented in Figure 2. The solid curve represents a 2-fixed quadrant
elevation procedure. If the estimated target range is less than or equal
to 350 meters, a fixed quadrant elevation of 17ｼ is used. If the estimated
target range is greater than 350 meters and less than or equal to 500 meters,
a fixed quadrant elevation of 27ｼ is used. The dotted curve represents a
3-fixed quadrant elevation procedure. If the estimated target range is less
than or equal to 300 meters, a fixed quadrant elevation of 17ｼ is used. If
the estimated range is greater than 300 meters and less than or equal to
400 meters, a fixed quadrant elevation of 20ｼ is employed. If the estimated
range to the target is greater than 400 meters and less than or equal to
500 meters, then a fixed quadrant elevation of 27ｼ is used. The conventional
method of fire is also indicated.

AMXSY-GI
SUBJECT: HEL Sighting Experiment - Fixed Q.E. Techniques of Fire

4. In the calculations the following one sigma values were used:

    crosswind: 11 feet per second
    wind gustiness: 3.3 feet per second
    aiming error: 1ɱ
    round to round error: .9ɱ
    cant error: 30ɱ
    range estimation error: 20 percent of the actual range.

FOR THE DIRECTOR:

2 Incl
as

MORGAN G. SMITH
Chief, Ground Warfare Division

Note: 2 Inclosures are shown as Fig ___ and ___ .

AMXSY-GI   19 November 1973

SUBJECT: Graze Fire (Fixed Q.E.) Hit Probabilities

Director
US Army Human Engineering Laboratory
ATTN: AMXRD-HEL (Mr. Giordano)

1. The inclosed hit probability estimates are forwarded in response to
your verbal request. The specific items addressed in this correspondence
are for a projectile (rocket or recoilless) having muzzle velocities of
950 and 1000 feet per second using the Fixed Q.E. or Graze Fire Method
of fire control. The Fixed Q.E. method of fire control means that the
gunner puts the same point of his sight reticle on the same point on the
target for all ranges out to a specified maximum range.

2. For this exercise, four methods of Fixed Q.E. fire control were exa-
mined. These methods were aiming at the vertical target center and the
bottom edge of the target at 300 and 350 meters. Table 1 presents the
trajectory characteristics of the four methods of Fixed Q.E. at the two
velocity levels.

3. Table 2 presents hit probability as a function of range, aiming error,
Fixed Q.E. method and muzzle velocity. Aiming error was varied from 0.5
mils to 2.0 mils in .25 mil increments and from 2.0 to 3.0 mils in .5 mil
increments. The first column of Table 2 is target range in meters. The
next two columns are the horizontal and vertical fixed biases in inches.
The next two columns (columns 4 and 5) are the horizontal and vertical
dispersions in inches. The next column (Column 6) is hit probability
against a 7 1/2 foot square target assuming no range estimation error.
The next column is the same thing against a target 15 feet wide by 7 1/2
feet high. Column 8 is the probability that the gunner estimates the target
to be less than the go, no-go range the system is designed for. That is,
the gunners' instructions are to fire only if he estimates the target
to be less than 300 meters; if he estimates the target to be greater than
300 meters he is instructed not to fire. If range estimation is equal to
20 percent of range, a target which is actually at 250 meters will have a

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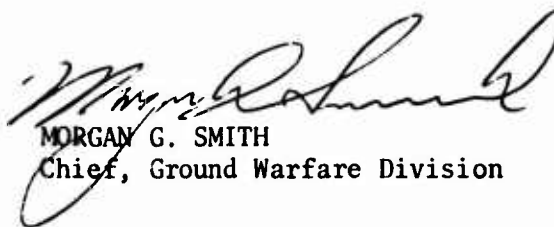
probability of being engaged of .84. Actually 16 percent of the time the gunner will estimate this 250 meter range to be beyond the 300 meter capability of the system and will not fire. The last two columns (columns 9 and 10) present hit probabilities against the 7 1/2 foot target and the 15 x 7 1/2 foot target for a range estimation error of 20 percent. Actually these last two columns are merely columns 6 and 7 multiplied by column 8.

4. Any questions regarding these data can be addressed to Daniel Kirk, AV 870-4545 or Arnold Newman, AV 870-4488.

FOR THE DIRECTOR:

2 Incl
as

MORGAN G. SMITH
Chief, Ground Warfare Division

CF:
AMCRD-MT (Mr. E. Sedlak)
AMXBR-IB (Mr. J. Frankle)
AMSMI-RFL (Mr. B. Cobb)
SARWV-RDD-SE (Mr. M. Dale)
SMUFA-N4100 (Miss E. McGrody)

TABLE 1   TRAJECTORY CHARACTERISTICS

Muzzle Velocity (ft/sec)	Fixed Q.E. Range (m)	Aimpoint*	Elevation Angle (mil)	Max Ordinate (m)
950	300	TC	24.40	2.25
950	300	TB	20.00	1.52
950	350	TC	27.86	2.90
950	350	TB	24.00	2.17
1000	300	TC	22.64	2.12
1000	300	TB	18.78	1.48
1000	350	TC	25.68	2.71
1000	350	TB	22.35	2.07

*TC - Center of Target (3.75 feet above ground)
TB - Bottom Edge of Target

TABLE 2 FIXED Q.E. HIT PROBABILITIES

SIGMA AIM = .50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 300. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	TOTAL HIT PROB (15.0 x 7.5)
100.	.00	25.59	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	41.73	7.28	5.97	.70806	.70806	1.00000	.70806	.70806
200.	.00	42.52	10.91	7.96	.62229	.62231	.99379	.61842	.61845
250.	.00	29.13	15.37	9.95	.94142	.94464	.84134	.79206	.79477
300.	.00	.00	20.76	11.94	.96965	.99982	.50000	.48483	.49991
350.	.00	-45.12	27.13	13.93	.44831	.49611	.23753	.10648	.11784
400.	.00	-111.81	34.53	15.92	.00001	.00001	.10565	.00000	.00000
450.	.00	-192.13	43.01	17.91	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	52.62	19.90	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 350. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	TOTAL HIT PROB (15.0 x 7.5)
100.	.00	39.37	4.39	3.98	.92140	.92140	1.00000	.92140	.92140
150.	.00	61.02	7.28	5.97	.00364	.00364	1.00000	.00364	.00364
200.	.00	69.68	10.91	7.96	.00097	.00097	.99991	.00097	.00097
250.	.00	62.99	15.37	9.95	.03518	.03530	.97725	.03438	.03450
300.	.00	40.55	20.76	11.94	.62583	.64530	.79767	.49921	.51474
350.	.00	.00	27.13	13.93	.90170	.99786	.50000	.45085	.49693
400.	.00	-58.66	34.53	15.92	.15781	.19365	.26599	.04198	.05151
450.	.00	-135.83	43.01	17.91	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.36	52.62	19.90	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = .50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 330. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	TOTAL HIT PROB (15.0 x 7.5)
100.	.00	8.15	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	7.28	5.97	1.00000	1.00000	1.00000	1.00000	1.00000
200.	.00	8.94	10.91	7.96	.99996	.99996	.99375	.99375	.99379
250.	.00	-13.50	15.37	9.95	.99582	.99923	.84134	.83782	.84069
300.	.00	-48.94	20.76	11.94	.35952	.37070	.50000	.17976	.18535
350.	.00	-136.91	27.13	13.93	.00000	.00000	.23753	.00000	.00000
400.	.00	-190.04	34.53	15.92	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	43.01	17.91	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	52.62	19.90	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 350. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	TOTAL HIT PROB (15.0 x 7.5)
100.	.00	19.57	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	38.86	7.28	5.97	.84814	.84814	1.00000	.84814	.84814
200.	.00	39.25	10.91	7.96	.76494	.76495	.99991	.76487	.76490
250.	.00	25.08	15.37	9.95	.97402	.97736	.97725	.95186	.95512
300.	.00	-74.84	20.76	11.94	.96943	.99959	.79767	.77328	.79734
350.	.00	-48.15	27.13	13.93	.37065	.41018	.50000	.18533	.20509
400.	.00	-118.62	34.53	15.92	.00000	.00000	.26599	.00000	.00000
450.	.00	-202.48	43.01	17.91	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	52.62	19.90	.00000	.00000	.06681	.00000	.00000

RANGE — BIAS — STANDARD DEVIATION — PROBABILITY OF HIT — PROBABILITY OF ESTIMATING RANGE — TOTAL HIT PROBABILITY

SIGMA AIM = .75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	25.59	4.89	4.53	.99999	.99999	1.00000	.99999	.99999
150.	.00	41.73	7.97	6.79	.68495	.68495	1.00000	.68495	.68495
200.	.00	42.52	11.73	9.06	.60778	.60785	.99379	.60400	.60409
250.	.00	29.13	16.29	11.32	.91426	.91953	.84134	.76921	.77365
300.	.00	.00	21.75	13.59	.96056	.99704	.50000	.48028	.49952
350.	.00	-45.12	28.16	15.85	.44229	.46629	.23753	.10506	.11784
400.	.00	-111.81	35.59	18.11	.00009	.00011	.10565	.00001	.00001
450.	.00	-192.13	44.09	20.38	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	53.72	22.64	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	39.37	4.89	4.53	.89303	.89303	1.00000	.89303	.89303
150.	.00	61.02	7.97	6.79	.00915	.00915	1.00000	.00915	.00915
200.	.00	69.68	11.73	9.06	.00322	.00322	.99991	.00322	.00322
250.	.00	62.99	16.29	11.32	.05564	.05601	.97725	.05442	.05473
300.	.00	40.55	21.75	13.59	.60411	.62831	.79767	.48188	.50110
350.	.00	.00	28.16	15.85	.88593	.99409	.50000	.44297	.49704
400.	.00	-58.66	35.59	18.11	.17890	.22276	.26598	.04759	.05925
450.	.00	-135.83	44.09	20.38	.00000	.00000	.13326	.00000	.00000
500.	.00	-232.36	53.72	22.64	.00000	.00000	.06661	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	8.15	4.89	4.53	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	7.97	6.79	.99999	.99999	1.00000	.99999	.99999
200.	.00	8.94	11.73	9.06	.99984	.99997	.99379	.99363	.99374
250.	.00	-13.50	16.29	11.32	.99158	.99730	.84134	.83426	.83904
300.	.00	-48.94	21.75	13.59	.37106	.38593	.50000	.18553	.19296
350.	.00	-106.81	28.16	15.85	.00004	.00005	.23753	.00001	.00001
400.	.00	-180.04	35.59	18.11	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	44.09	20.38	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	53.72	22.64	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	19.57	4.89	4.53	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	38.86	7.97	6.79	.81707	.81707	1.00000	.81707	.81707
200.	.00	39.25	11.73	9.06	.73718	.73717	.99991	.73702	.73711
250.	.00	25.08	16.29	11.32	.95526	.96077	.97725	.93353	.93891
300.	.00	-4.84	21.75	13.59	.95983	.98828	.79767	.76563	.79630
350.	.00	-48.15	28.16	15.85	.37488	.42065	.50000	.18744	.21032
400.	.00	-118.62	35.59	18.11	.00002	.00002	.26599	.00001	.00001
450.	.00	-202.48	44.09	20.38	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	53.72	22.64	.00000	.00000	.06661	.00000	.00000

RANGE TO TARGET AIMPOINT = 300. CENTER
SIGMA AIM = 1.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	25.59	5.52	5.20	.99991	.99991	1.00000	.99991	.99991
150.	.00	41.73	8.85	7.80	.66248	.66248	1.00000	.66248	.66248
200.	.00	42.52	12.80	10.40	.59398	.59424	.99379	.59029	.59055
250.	.00	29.00	17.50	13.00	.87991	.88891	.84134	.74031	.74786
300.	.00	.00	23.06	15.60	.94528	.99599	.50000	.47264	.49799
350.	.00	-45.12	29.55	18.20	.43361	.49621	.23753	.10304	.11786
400.	.00	-111.81	37.03	20.80	.00051	.00065	.13565	.00005	.00007
450.	.00	-192.13	45.57	23.40	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	55.22	26.00	.00000	.00000	.02275	.00000	.00000

RANGE TO TARGET AIMPOINT = 350. CENTER
SIGMA AIM = 1.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	39.37	5.52	5.20	.86053	.86053	1.00000	.86053	.86053
150.	.00	61.02	8.85	7.80	.02000	.02000	1.00000	.02000	.02000
200.	.00	69.68	12.80	10.40	.00882	.00882	.99991	.00882	.00882
250.	.00	62.99	17.50	13.00	.08236	.08320	.77725	.08049	.08131
300.	.00	40.55	23.06	15.60	.58105	.61222	.50000	.46348	.48835
350.	.00	.00	29.55	18.20	.86050	.98429	.26599	.43025	.49215
400.	.00	-58.66	37.03	20.80	.19833	.25182	.13326	.05275	.06698
450.	.00	-135.83	45.57	23.40	.00004	.00005	.06661	.00000	.00001
500.	.00	-202.36	55.22	26.00	.00000	.00000		.00000	.00000

RANGE TO TARGET AIMPOINT = 300. BOTTOM
SIGMA AIM = 1.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	8.15	5.52	5.20	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	8.85	7.80	.99993	.99993	1.00000	.99993	.99993
200.	.00	8.94	12.80	10.40	.99974	.99974	.99379	.99309	.99353
250.	.00	-13.50	17.50	13.00	.98225	.90230	.84134	.82641	.83487
300.	.00	-48.94	23.06	15.60	.37988	.40026	.50000	.18994	.20013
350.	.00	-106.81	29.55	18.20	.00034	.00030	.23753	.00007	.00008
400.	.00	-180.04	37.03	20.80	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	45.57	23.40	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	55.22	26.00	.00000	.00000	.02275	.00000	.00000

RANGE TO TARGET AIMPOINT = 350. BOTTOM
SIGMA AIM = 1.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	19.57	5.52	5.20	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	38.86	8.85	7.80	.78441	.78441	1.00000	.78441	.78441
200.	.00	39.25	12.80	10.40	.70952	.70983	.99991	.70945	.70977
250.	.00	25.06	17.50	13.00	.92778	.93728	.97725	.90668	.91595
300.	.00	-4.84	23.06	15.60	.94357	.99418	.79767	.75285	.79303
350.	.00	-48.15	29.55	18.20	.37618	.43029	.50000	.18809	.21515
400.	.00	-118.62	37.03	20.80	.00016	.00020	.26599	.00004	.00005
450.	.00	-202.48	45.57	23.40	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	55.22	26.00	.00000	.00000	.06661	.00000	.00000

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RANGE | BIAS | | STANDARD DEVIATION | | PROBABILITY OF HIT | | PROBABILITY OF | TOTAL HIT PROBABILITY |

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)

SIGMA AIM = 1.25 MILS   VEL IN FPS = 950.0   DRAG =T.19E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

(METERS)	X(INCHES)	Y(INCHES)	X(INCHES)	Y(INCHES)	(7.5 X 7.5)	(15.0 X 7.5)	ESTIMATING RANGE	(7.5 X 7.5)	(15.0 X 7.5)
100.	.00	25.59	6.24	5.95	.99945	.99945	1.00000	.99945	.99945
150.	.00	41.73	9.86	8.93	.64289	.64289	1.00000	.64288	.64289
200.	.00	42.52	14.05	11.91	.58168	.58247	.99379	.57807	.57884
250.	.00	29.13	18.94	14.88	.84191	.85691	.84134	.70833	.72095
300.	.00	.00	24.65	17.86	.92113	.98799	.50000	.46057	.49400
350.	.00	-45.12	31.24	20.84	.42317	.49572	.23753	.10051	.11779
400.	.00	-111.81	38.80	23.82	.00190	.00247	.10565	.00020	.00024
450.	.00	-192.13	47.40	26.79	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	57.09	29.77	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 950.0   DRAG =T.19E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

(METERS)	X(INCHES)	Y(INCHES)	X(INCHES)	Y(INCHES)	(7.5 X 7.5)	(15.0 X 7.5)	ESTIMATING RANGE	(7.5 X 7.5)	(15.0 X 7.5)
100.	.00	39.37	6.24	5.95	.82798	.82798	1.00000	.82798	.82798
150.	.00	61.02	9.86	8.93	.03641	.03641	1.00000	.03641	.03641
200.	.00	62.99	14.05	11.91	.01910	.01912	.99991	.01910	.01912
250.	.00	40.55	18.94	14.88	.11135	.11333	.97725	.10881	.11075
300.	.00	.00	24.65	17.86	.55774	.59822	.79767	.44489	.47719
350.	.00	-58.66	31.24	20.84	.82405	.96533	.50000	.41203	.48267
400.	.00	-135.83	38.80	23.82	.21346	.27739	.26599	.05678	.07378
450.	.00	-202.36	47.40	26.79	.00023	.00033	.13326	.00003	.00004
500.	.00	-202.36	57.09	29.77	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 950.0   DRAG =T.19E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

(METERS)	X(INCHES)	Y(INCHES)	X(INCHES)	Y(INCHES)	(7.5 X 7.5)	(15.0 X 7.5)	ESTIMATING RANGE	(7.5 X 7.5)	(15.0 X 7.5)
100.	.00	8.15	6.24	5.95	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	9.86	8.93	.99956	.99957	1.00000	.99956	.99957
200.	.00	8.94	14.05	11.91	.99741	.99876	.99379	.99121	.99256
250.	.00	-13.50	18.94	14.88	.96562	.98282	.84134	.81242	.82689
300.	.00	-48.94	24.65	17.86	.38467	.41259	.50000	.19234	.20630
350.	.00	-106.81	31.24	20.84	.00128	.00150	.23753	.00030	.00034
400.	.00	-180.04	38.80	23.82	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	47.40	26.79	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	57.09	29.77	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 950.0   DRAG =T.19E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

(METERS)	X(INCHES)	Y(INCHES)	X(INCHES)	Y(INCHES)	(7.5 X 7.5)	(15.0 X 7.5)	ESTIMATING RANGE	(7.5 X 7.5)	(15.0 X 7.5)
100.	.00	19.57	6.24	5.95	.99999	.99999	1.00000	.99999	.99999
150.	.00	38.86	9.86	8.93	.75413	.75414	1.00000	.75413	.75414
200.	.00	39.25	14.05	11.91	.68444	.68538	.99991	.68438	.68532
250.	.00	25.08	18.94	14.88	.89374	.90966	.97725	.87341	.88897
300.	.00	-4.84	24.65	17.86	.91820	.98484	.79767	.73242	.78558
350.	.00	-48.15	31.24	20.84	.37405	.43818	.50000	.18703	.21909
400.	.00	-118.62	38.80	23.82	.00075	.00098	.26599	.00020	.00026
450.	.00	-202.48	47.40	26.79	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	57.09	29.77	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = 1.50 MILS   DRAG =T119E11   VEL IN FPS = 950.0   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	25.59	7.01	6.76	.99796	.99796	1.00000	.99796	.99796
150.	.00	41.73	10.97	10.14	.62643	.62644	1.00000	.62643	.62646
200.	.00	42.52	15.44	13.52	.57073	.57277	.99379	.56719	.56921
250.	.00	29.13	20.57	16.90	.80244	.82613	.84134	.67513	.69506
300.	.00	.00	26.46	20.28	.88686	.97286	.50000	.44343	.48643
350.	.00	-45.12	33.20	23.67	.41063	.49457	.23753	.09754	.11747
400.	.00	-111.81	40.87	27.05	.00493	.00657	.10565	.00052	.00069
450.	.00	-192.13	49.55	30.43	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	59.30	33.81	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.50 MILS   DRAG =T119E11   VEL IN FPS = 950.0   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	39.37	7.01	6.76	.79753	.79753	1.00000	.79753	.79753
150.	.00	61.02	10.97	10.14	.05704	.05707	1.00000	.05706	.05707
200.	.00	69.68	15.44	13.52	.03385	.03397	.99991	.03384	.03396
250.	.00	62.99	20.57	16.90	.13943	.14355	.97725	.13626	.14028
300.	.00	40.55	26.46	20.28	.53460	.58644	.79767	.42643	.46778
350.	.00	.00	33.20	23.67	.77747	.93639	.50000	.38874	.46819
400.	.00	-58.66	40.87	27.05	.22364	.29824	.26599	.05948	.07933
450.	.00	-135.83	49.55	30.43	.00090	.00132	.13326	.00012	.00018
500.	.00	-202.36	59.30	33.81	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = 1.50 MILS   DRAG =T119E11   VEL IN FPS = 950.0   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	8.15	7.01	6.76	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	10.97	10.14	.99829	.99833	1.00000	.99829	.99833
200.	.00	3.94	15.44	13.52	.99259	.99614	.99379	.98643	.98996
250.	.00	-13.50	20.57	16.90	.94077	.94855	.84134	.79151	.81489
300.	.00	-48.94	26.46	20.28	.38533	.42269	.50000	.19269	.21135
350.	.00	-106.81	33.20	23.67	.00372	.00448	.23753	.00088	.00104
400.	.00	-180.04	40.87	27.05	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	49.55	30.43	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	59.30	33.81	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.50 MILS   DRAG =T119E11   VEL IN FPS = 950.0   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 x 7.5)	TOTAL HIT (15.0 x 7.5)
100.	.00	19.57	7.01	6.76	.99992	.99992	1.00000	.99992	.99992
150.	.00	38.86	10.97	10.14	.72755	.72755	1.00000	.72755	.72758
200.	.00	39.25	15.44	13.52	.66232	.66469	.99991	.66226	.66463
250.	.00	25.08	20.57	16.90	.85545	.88071	.97725	.83599	.86068
300.	.00	-4.84	26.46	20.28	.88291	.96852	.79767	.70427	.77256
350.	.00	-48.15	33.20	23.67	.36867	.44402	.50000	.18433	.22201
400.	.00	-118.62	40.87	27.05	.00237	.00316	.26599	.00063	.00084
450.	.00	-202.48	49.55	30.43	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	59.30	33.81	.00000	.00000	.06681	.00000	.00000

RANGE: (METERS)   BIAS   STANDARD DEVIATION   PROBABILITY OF HIT   PROBABILITY OF ESTIMATING RANGE   TOTAL HIT PROBABILITY

SIGMA AIM = 1.75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	25.59	7.83	7.61	.99462	.99462	1.00000	.99462	.99462
150.	.00	41.73	12.15	11.41	.61266	.61279	1.00000	.61266	.61279
200.	.00	42.52	16.94	15.21	.56030	.56476	.99379	.55682	.56125
250.	.00	49.13	22.34	19.02	.76283	.79787	.84134	.64180	.67129
300.	.00	.00	28.45	22.82	.84320	.84240	.50000	.42160	.47499
350.	.00	-45.12	35.37	26.62	.39664	.49240	.23753	.09421	.11696
400.	.00	-111.81	43.18	30.43	.00988	.01354	.10565	.00104	.00143
450.	.00	-192.13	51.97	34.23	.00001	.00001	.04779	.00000	.00000
500.	.00	-202.36	61.80	38.03	.00001	.00002	.02275	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	39.37	7.83	7.61	.77029	.77029	1.00000	.77029	.77029
150.	.00	61.02	12.15	11.41	.08014	.08014	1.00000	.08014	.08015
200.	.00	69.68	16.94	15.21	.05192	.05234	.99991	.05192	.05233
250.	.00	62.99	22.34	19.02	.16454	.17210	.97725	.16080	.16810
300.	.00	40.55	28.45	22.82	.51158	.57632	.79767	.40807	.45971
350.	.00	-.00	35.37	26.62	.72427	.89911	.50000	.34213	.44954
400.	.00	-58.66	43.18	30.43	.22936	.31430	.26599	.06101	.08360
450.	.00	-135.83	51.97	34.23	.00244	.00365	.13326	.00033	.00049
500.	.00	-202.36	61.80	38.03	.00001	.00002	.06681	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	8.15	7.83	7.61	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	15.24	12.15	11.41	.99524	.99545	1.00000	.99524	.99545
200.	.00	-8.94	16.94	15.21	.98310	.99093	.99379	.97700	.98478
250.	.00	-13.50	22.34	19.02	.90832	.95005	.84134	.76421	.79932
300.	.00	-48.94	28.45	22.82	.38234	.43077	.50000	.19119	.21534
350.	.00	-106.81	35.37	26.62	.01001	.01001	.23753	.00191	.00234
400.	.00	-180.04	43.18	30.43	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.48	51.97	34.23	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.48	61.80	38.03	.00001	.00001	.02275	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	19.57	7.83	7.61	.99958	.99958	1.00000	.99958	.99958
150.	.00	38.86	12.15	11.41	.70460	.70475	1.00000	.70460	.70475
200.	.00	39.25	16.94	15.21	.64210	.64730	.99991	.64213	.64724
250.	.00	25.08	22.34	19.02	.61492	.65236	.97725	.79638	.83297
300.	.00	-4.84	28.45	22.82	.83870	.84483	.79767	.66901	.75366
350.	.00	-48.15	35.37	26.62	.36065	.44772	.50000	.18033	.22386
400.	.00	-118.62	43.18	30.43	.00546	.00749	.26599	.00145	.00199
450.	.00	-202.48	51.97	34.23	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.48	61.80	38.03	.00001	.00001	.86681	.00000	.00000

RANGE	BIAS		STANDARD DEVIATION		PROBABILITY OF HIT		PROBABILITY OF	TOTAL HIT PROBABILITY	
(METERS)	X(INCHES)	Y(INCHES)	X(INCHES)	Y(INCHES)	(7.5 X 7.5)	(15.0 X 7.5)	ESTIMATING RANGE	(7.5 X 7.5)	(15.0 X 7.5)

SIGMA AIM = 2.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	P (7.5x7.5)	P (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	25.59	8.68	8.48	.98894	.98996	1.00000	.98896	.98894
150.	.00	41.73	13.38	12.72	.60098	.60144	1.00000	.60098	.60144
200.	.00	42.52	18.52	16.95	.54973	.55916	.99379	.54632	.55476
250.	.00	29.13	24.22	21.19	.77400	.77266	.84134	.60913	.65007
300.	.00	.00	30.58	25.43	.79290	.92020	.50000	.39645	.46010
350.	.00	-45.12	37.71	29.67	.38147	.48874	.23753	.09061	.11509
400.	.00	-91.81	45.70	33.91	.01648	.02321	.10565	.00174	.00245
450.	.00	-192.13	54.63	38.15	.00003	.00005	.04779	.00000	.00000
500.	.00	-202.36	64.57	42.39	.00005	.00009	.02275	.00000	.00000

SIGMA AIM = 2.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	P (7.5x7.5)	P (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	39.37	8.68	8.48	.74663	.74563	1.00000	.74663	.74663
150.	.00	61.02	13.38	12.72	.10386	.10394	1.00000	.10386	.10394
200.	.00	69.68	18.52	16.95	.07159	.07269	.99991	.07159	.07264
250.	.00	52.99	24.22	21.19	.18541	.19790	.97725	.18122	.19340
300.	.00	40.55	30.58	25.43	.48875	.56722	.79767	.38986	.45246
350.	.00	.00	37.71	29.67	.66801	.85585	.50000	.33401	.42792
400.	.00	-58.66	45.70	33.91	.23121	.32567	.26599	.06150	.08662
450.	.00	-135.83	54.63	38.15	.00509	.00778	.13326	.00068	.00104
500.	.00	-202.36	64.57	42.39	.00005	.00009	.06681	.00000	.00001

SIGMA AIM = 2.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	P (7.5x7.5)	P (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	8.15	8.68	8.48	.99999	.99999	1.00000	.99999	.99999
150.	.00	15.24	13.38	12.72	.98958	.99035	1.00000	.98958	.99035
200.	.00	8.94	18.52	16.95	.96773	.98255	.99379	.96172	.97647
250.	.00	-13.50	24.22	21.19	.86980	.92836	.84134	.73188	.78107
300.	.00	-48.94	30.58	25.43	.37646	.43590	.50000	.18823	.21845
350.	.00	-106.81	37.71	29.67	.01428	.01933	.23753	.00339	.00435
400.	.00	-150.04	45.70	33.91	.00002	.00003	.10565	.00000	.00000
450.	.00	-202.48	54.63	38.15	.00001	.00002	.04779	.00000	.00000
500.	.00	-202.48	64.57	42.39	.00005	.00009	.02275	.00000	.00000

SIGMA AIM = 2.00 MILS   VEL IN FPS = 950.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	P (7.5x7.5)	P (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	19.57	8.68	8.48	.99864	.99864	1.00000	.99864	.99864
150.	.00	38.86	13.38	12.72	.68482	.68535	1.00000	.68482	.68535
200.	.00	39.25	18.52	16.95	.63278	.63278	.99991	.62317	.63278
250.	.00	25.08	24.22	21.19	.82577	.82577	.97725	.75616	.80698
300.	.00	-4.84	30.58	25.43	.78631	.91487	.79767	.62881	.72977
350.	.00	-48.15	37.71	29.67	.35054	.44911	.50000	.17527	.22456
400.	.00	-118.62	45.70	33.91	.01010	.01423	.26599	.00269	.00379
450.	.00	-202.48	54.63	38.15	.00001	.00002	.13326	.00000	.00000
500.	.00	-202.48	64.57	42.39	.00005	.00009	.06681	.00000	.00001

STANDARD DEVIATION — PROBABILITY OF HIT / ESTIMATING RANGE / TOTAL HIT PROBABILITY

SIGMA AIM = 2.50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   CENTER   RANGE TO TARGET AIMPOINT = 300.

RANGE (METERS)	BIAS X (INCHES)	BIAS Y (INCHES)	STD DEV X (INCHES)	STD DEV Y (INCHES)	POH (7.5 x 7.5)	POH (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	25.59	10.44	10.27	.97060	.97062	1.00000	.97060	.97062
150.	.00	41.73	15.96	15.41	.58122	.58402	1.00000	.58122	.58402
200.	.00	42.52	21.85	20.54	.52642	.54802	.99379	.52315	.54402
250.	.00	29.13	28.22	25.68	.64891	.72872	.84134	.54595	.61311
300.	.00	.00	35.18	30.81	.68397	.84686	.50000	.34198	.42345
350.	.00	-45.12	42.83	35.95	.34805	.47504	.23753	.08267	.11283
400.	.00	-111.81	51.25	41.08	.03216	.04777	.10565	.00340	.00505
450.	.00	-192.13	60.54	46.22	.00040	.00063	.04779	.00002	.00003
500.	.00	-202.36	70.78	51.35	.00052	.00087	.02275	.00001	.00002

SIGMA AIM = 2.50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   CENTER   RANGE TO TARGET AIMPOINT = 350.

RANGE (METERS)	BIAS X (INCHES)	BIAS Y (INCHES)	STD DEV X (INCHES)	STD DEV Y (INCHES)	POH (7.5 x 7.5)	POH (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	39.37	10.44	10.27	.70821	.70822	1.00000	.70821	.70822
150.	.00	61.02	15.96	15.41	.14855	.14927	1.00000	.14855	.14127
200.	.00	69.68	21.85	20.54	.11024	.11476	.99971	.11023	.11479
250.	.00	62.99	28.22	25.68	.21499	.24144	.97725	.21010	.23594
300.	.00	40.55	35.18	30.81	.44327	.54484	.79767	.35358	.43770
350.	.00	.00	42.83	35.95	.55773	.76123	.50000	.27887	.38061
400.	.00	-58.66	51.25	41.08	.22567	.33516	.26599	.06003	.08915
450.	.00	-135.83	60.54	46.22	.01338	.02127	.13326	.00178	.00283
500.	.00	-202.36	70.78	51.35	.00052	.00087	.06681	.00003	.00006

SIGMA AIM = 2.50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   BOTTOM   RANGE TO TARGET AIMPOINT = 300.

RANGE (METERS)	BIAS X (INCHES)	BIAS Y (INCHES)	STD DEV X (INCHES)	STD DEV Y (INCHES)	POH (7.5 x 7.5)	POH (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	8.15	10.44	10.27	.99982	.99983	1.00000	.99982	.99983
150.	.00	15.24	15.96	15.41	.96855	.97323	1.00000	.96855	.97323
200.	.00	8.94	21.85	20.54	.91839	.95607	.99379	.91264	.95013
250.	.00	-13.50	28.22	25.68	.78130	.87740	.84134	.65735	.73820
300.	.00	-48.94	35.18	30.81	.35800	.44326	.50000	.17900	.22163
350.	.00	-106.81	42.83	35.95	.03022	.04124	.23753	.00718	.00980
400.	.00	-180.04	51.25	41.08	.00031	.00047	.10565	.00003	.00005
450.	.00	-202.48	60.54	46.22	.00018	.00028	.04779	.00001	.00001
500.	.00	-202.48	70.78	51.35	.00051	.00086	.02275	.00001	.00002

SIGMA AIM = 2.50 MILS   VEL IN FPS = 950.0   DRAG = T119E11   BOTTOM   RANGE TO TARGET AIMPOINT = 350.

RANGE (METERS)	BIAS X (INCHES)	BIAS Y (INCHES)	STD DEV X (INCHES)	STD DEV Y (INCHES)	POH (7.5 x 7.5)	POH (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	19.57	10.44	10.27	.99334	.99336	1.00000	.99334	.99336
150.	.00	35.86	15.96	15.41	.65170	.65485	1.00000	.65170	.65485
200.	.00	39.25	21.85	20.54	.58615	.61019	.99991	.58610	.61014
250.	.00	25.08	28.22	25.68	.69167	.77675	.97725	.67594	.75908
300.	.00	-4.84	35.18	30.81	.68002	.84197	.79767	.54243	.67162
350.	.00	-48.15	42.83	35.95	.32525	.44361	.50000	.16262	.22196
400.	.00	-118.62	51.25	41.08	.02265	.03364	.26599	.00602	.00895
450.	.00	-202.48	60.54	46.22	.00018	.00028	.13326	.00002	.00004
500.	.00	-202.48	70.78	51.35	.00051	.00086	.06681	.00003	.00006

RANGE — BIAS — STANDARD DEVIATION — PROBABILITY OF HIT — PROBABILITY OF ESTIMATING RANGE — TOTAL HIT PROBABILITY

RANGE (METERS)	BIAS X(INCHES)	Y(INCHES)	STD DEV X(INCHES)	Y(INCHES)	PROB OF HIT (7.5 x 7.5)	(15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	(15.0 x 7.5)

SIGMA AIM = 3.00 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

100.	.00	25.59	12.25	12.11	.94529	.94551	1.00000	.94529	.94551
150.	.00	41.73	18.63	18.16	.56247	.57145	1.00000	.56247	.57145
200.	.00	42.52	25.34	24.21	.49969	.54044	.99379	.49658	.53709
250.	.00	29.13	32.46	30.27	.57803	.68894	.84134	.48633	.57904
300.	.00	.00	40.09	36.32	.57934	.76521	.50000	.28967	.38261
350.	.00	-45.12	48.35	42.37	.31244	.45194	.23753	.07421	.10735
400.	.00	-111.81	57.30	48.43	.04727	.07359	.10565	.00499	.00777
450.	.00	-192.13	67.06	54.48	.00172	.00283	.04779	.00008	.00014
500.	.00	-202.36	77.70	60.53	.00203	.00350	.02275	.00005	.0000A

SIGMA AIM = 3.00 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

100.	.00	39.37	12.25	12.11	.67984	.67984	1.00000	.67884	.67900
150.	.00	61.02	18.63	18.16	.18588	.18885	1.00000	.18588	.18885
200.	.00	69.68	25.34	24.21	.14234	.15394	.99991	.14232	.15393
250.	.00	32.99	32.46	30.27	.23026	.27444	.97725	.22502	.26819
300.	.00	40.55	40.09	36.32	.39834	.52614	.79767	.31774	.41960
350.	.00	.00	48.35	42.37	.46124	.66718	.50000	.23062	.33350
400.	.00	-59.66	57.30	48.43	.21165	.32945	.26599	.05630	.08763
450.	.00	-135.83	67.06	54.48	.02354	.03879	.13326	.00314	.00517
500.	.00	-202.36	77.70	60.53	.00203	.00350	.06681	.00014	.00023

SIGMA AIM = 3.00 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

100.	.00	8.15	12.25	12.11	.99858	.99862	1.00000	.99858	.99862
150.	.00	15.24	18.63	18.16	.93400	.94891	1.00000	.93400	.94891
200.	.00	8.94	25.34	24.21	.84927	.91853	.99379	.84399	.91282
250.	.00	-13.50	32.46	30.27	.68779	.81975	.84134	.57866	.68969
300.	.00	-48.94	40.09	36.32	.33370	.44076	.50000	.16685	.22034
350.	.00	-166.81	48.35	42.37	.04675	.06742	.23753	.01110	.01606
400.	.00	-180.04	57.30	48.43	.00150	.00234	.10565	.00016	.00024
450.	.00	-212.48	67.06	54.48	.00096	.00157	.04779	.00005	.0000A
500.	.00	-202.48	77.70	60.53	.00202	.00348	.02275	.00005	.0000A

SIGMA AIM = 3.00 MILS   VEL IN FPS = 950.0   DRAG = T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

100.	.00	19.57	12.25	12.11	.98150	.98213	1.00000	.98190	.98213
150.	.00	38.86	18.63	18.16	.62243	.63236	1.00000	.62242	.63234
200.	.00	39.25	25.34	24.21	.54865	.59339	.99991	.54860	.59334
250.	.00	25.08	32.46	30.27	.61279	.73037	.97725	.59885	.71375
300.	.00	-4.84	40.09	36.32	.57634	.76125	.79767	.45973	.60723
350.	.00	-48.15	48.35	42.37	.29575	.42780	.50000	.14788	.21390
400.	.00	-118.62	57.30	48.43	.05626	.05645	.26599	.00965	.01501
450.	.00	-202.48	67.06	54.48	.00096	.00157	.13326	.00013	.00021
500.	.00	-202.48	77.70	60.53	.00202	.00348	.06681	.00013	.00023

203

SIGMA AIM = .50 MILS VEL IN FPS = 1000.0 DRAG = T119E11 RANGE TO TARGET AIMPOINT = 300. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	20.47	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	36.22	7.28	5.97	.92931	.92931	1.00000	.92931	.92931
200.	.00	38.58	10.87	7.96	.79000	.79003	.99379	.78510	.78513
250.	.00	26.38	15.27	9.95	.96624	.96935	.84134	.81294	.81554
300.	.00	.00	20.56	11.94	.97122	.99982	.50000	.48561	.49991
350.	.00	-40.94	26.78	13.93	.55756	.61417	.23753	.13243	.14585
400.	.00	-119.39	34.00	15.92	.00020	.00025	.10565	.00002	.00003
450.	.00	-176.39	42.24	17.91	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	51.56	19.90	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .50 MILS VEL IN FPS = 1000.0 DRAG = T119E11 RANGE TO TARGET AIMPOINT = 350. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	32.68	4.39	3.98	.99902	.99902	1.00000	.99902	.99902
150.	.00	53.54	7.28	5.97	.07629	.07629	1.00000	.07629	.07629
200.	.00	62.20	10.87	7.96	.01535	.01536	.99991	.01535	.01535
250.	.00	55.91	15.27	9.95	.13543	.13543	.97725	.13290	.13333
300.	.00	35.04	20.56	11.94	.77507	.79790	.79767	.61825	.63646
350.	.00	.00	26.78	13.93	.90599	.90799	.50000	.45300	.49899
400.	.00	-53.94	34.00	15.92	.23389	.28488	.26599	.06221	.07577
450.	.00	-161.02	42.24	17.91	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.36	51.56	19.90	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = .50 MILS VEL IN FPS = 1000.0 DRAG = T119E11 RANGE TO TARGET AIMPOINT = 300. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	5.91	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	7.28	5.97	1.00000	1.00000	1.00000	1.00000	1.00000
200.	.00	8.27	10.87	7.96	.99994	.99999	.99379	.99375	.99379
250.	.00	-9.94	15.27	9.95	.99650	.99979	.84134	.83847	.84117
300.	.00	-45.00	20.56	11.94	.48569	.49999	.50000	.24285	.25000
350.	.00	-93.31	26.78	13.93	.00024	.00026	.23753	.00006	.00006
400.	.00	-160.24	34.00	15.92	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.36	42.24	17.91	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	51.56	19.90	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .50 MILS VEL IN FPS = 1000.0 DRAG = T119E11 RANGE TO TARGET AIMPOINT = 350. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 X 7.5)	PROBABILITY OF HIT (15.0 X 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 X 7.5)	TOTAL HIT PROBABILITY (15.0 X 7.5)
100.	.00	20.08	4.39	3.98	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	34.65	7.28	5.97	.95851	.95851	1.00000	.95851	.95851
200.	.00	35.83	10.87	7.96	.87531	.87534	.99991	.87523	.87526
250.	.00	23.62	15.27	9.95	.98101	.98417	.97725	.95870	.96175
300.	.00	-3.54	20.56	11.94	.97111	.99971	.79767	.77463	.79744
350.	.00	-45.00	26.78	13.93	.45356	.49961	.50000	.22678	.24981
400.	.00	-100.79	34.00	15.92	.00019	.00023	.26599	.00005	.00006
450.	.00	-191.50	42.24	17.91	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.36	51.56	19.90	.00000	.00000	.06681	.00000	.00000

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 x 7.5)	PROBABILITY OF HIT (15.0 x 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 x 7.5)	TOTAL HIT PROBABILITY (15.0 x 7.5)

SIGMA AIM = .75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5 x 7.5)	HIT (15.0 x 7.5)	EST. RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	20.47	4.53	4.90	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	36.22	6.79	7.97	.90201	.90201	1.00000	.90201	.90201
200.	.00	38.58	9.06	11.69	.76063	.76072	.89379	.75590	.75590
250.	.00	26.38	11.32	16.20	.94480	.95000	.94134	.79491	.79920
300.	.03	.00	13.59	21.56	.96223	.99904	.90000	.48112	.49952
350.	.00	-40.04	15.85	27.83	.53744	.60035	.53753	.12765	.14260
400.	.00	-100.39	18.11	35.08	.00089	.00110	.15565	.00009	.00012
450.	.00	-176.39	20.38	43.35	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	22.64	52.68	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5 x 7.5)	HIT (15.0 x 7.5)	EST. RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	32.68	4.53	4.90	.99673	.99673	1.00000	.99673	.99673
150.	.00	53.54	6.79	7.97	.10424	.10424	1.00000	.10424	.10424
200.	.00	62.20	9.06	11.69	.02851	.02882	.99991	.02881	.02882
250.	.30	55.91	11.32	16.20	.16666	.16758	.97725	.16287	.16377
300.	.00	35.04	13.59	21.56	.73986	.76816	.79767	.59017	.61274
350.	.00	.00	15.85	27.83	.69007	.89425	.50060	.44503	.49713
400.	.00	-53.94	18.11	35.08	.24876	.30758	.26599	.06617	.08181
450.	.00	-161.02	20.38	43.35	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.36	22.64	52.68	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5 x 7.5)	HIT (15.0 x 7.5)	EST. RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	5.91	4.53	4.90	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	6.79	7.97	1.00000	1.00000	1.00000	1.00000	1.00000
200.	.00	8.27	9.06	11.69	.99984	.99997	.99379	.99365	.99377
250.	.00	-9.84	11.32	16.20	.99358	.99905	.94134	.83595	.84055
300.	.00	-45.00	13.59	21.56	.48154	.49998	.50000	.24078	.24999
350.	.00	-93.31	15.85	27.83	.00103	.00115	.33753	.00024	.00027
400.	.00	-130.24	18.11	35.08	.00000	.00000	.15565	.00000	.00000
450.	.00	-202.36	20.38	43.35	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	22.64	52.68	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = .75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5 x 7.5)	HIT (15.0 x 7.5)	EST. RANGE	TOTAL (7.5 x 7.5)	TOTAL (15.0 x 7.5)
100.	.00	20.08	4.53	4.90	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	34.65	6.79	7.97	.93628	.93628	1.00000	.93628	.93628
200.	.00	35.83	9.06	11.69	.84416	.84425	.99991	.84409	.84419
250.	.00	23.62	11.32	16.20	.97053	.97053	.99725	.94326	.94845
300.	.00	.03	13.59	21.56	.96522	.99865	.79767	.76725	.79660
350.	.00	-45.00	15.85	27.83	.44706	.49939	.50000	.22353	.24969
400.	.00	-100.99	18.11	35.08	.00083	.00102	.26599	.00022	.00027
450.	.00	-181.50	20.38	43.35	.00000	.00000	.13326	.00000	.00000
500.	.00	-202.36	22.64	52.68	.00000	.00000	.06681	.00000	.00000

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 x 7.5)	PROBABILITY OF HIT (15.0 x 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 x 7.5)	TOTAL HIT PROBABILITY (15.0 x 7.5)

SIGMA AIM = 1.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE	X BIAS	Y BIAS	X STD	Y STD	HIT 7.5x7.5	HIT 15.0x7.5	EST RANGE	TOTAL 7.5x7.5	TOTAL 15.0x7.5
100.	.00	20.47	5.52	5.20	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	36.22	8.84	7.80	.86984	.86984	1.00000	.86984	.86984
200.	.00	38.58	12.76	10.40	.73118	.73149	.99379	.72664	.72694
250.	.00	46.38	17.41	13.00	.91497	.92397	.84134	.76980	.77735
300.	.00	.00	22.88	15.60	.94707	.99600	.50000	.47353	.49800
350.	.00	-40.94	29.23	18.20	.51551	.58704	.23753	.12245	.13944
400.	.00	-100.39	36.54	20.80	.00303	.00382	.10565	.00303	.00040
450.	.00	-117.39	44.85	23.40	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	54.21	26.00	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE	X BIAS	Y BIAS	X STD	Y STD	HIT 7.5x7.5	HIT 15.0x7.5	EST RANGE	TOTAL 7.5x7.5	TOTAL 15.0x7.5
100.	.00	32.68	5.52	5.20	.99109	.99109	1.00000	.99109	.99109
150.	.00	53.54	8.84	7.80	.13679	.13679	1.00000	.13679	.13679
200.	.00	62.20	12.76	10.40	.04906	.04909	.99991	.04905	.04908
250.	.00	55.91	17.41	13.00	.19871	.20067	.79767	.19419	.19610
300.	.00	35.04	22.88	15.60	.70208	.73835	.50000	.56003	.58894
350.	.00	-5.00	29.23	18.20	.86456	.94454	.26599	.43228	.49227
400.	.00	-53.94	36.54	20.80	.26089	.32907	.13326	.06939	.08753
450.	.00	-161.02	44.85	23.40	.00000	.00000	.06681	.00000	.00000
500.	.00	-202.36	54.21	26.00	.00000	.00000		.00000	.00000

SIGMA AIM = 1.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE	X BIAS	Y BIAS	X STD	Y STD	HIT 7.5x7.5	HIT 15.0x7.5	EST RANGE	TOTAL 7.5x7.5	TOTAL 15.0x7.5
100.	.00	5.91	5.52	5.20	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	8.84	7.80	.99997	.99997	1.00000	.99997	.99997
200.	.00	8.27	12.76	10.40	.99979	.99979	.99379	.99317	.99359
250.	.00	-9.84	17.41	13.00	.99684	.99557	.84134	.83329	.83846
300.	.00	-45.00	22.88	15.60	.47540	.49995	.50000	.23770	.24999
350.	.00	-93.31	29.23	18.20	.00396	.00396	.23753	.00083	.00094
400.	.00	-110.24	36.54	20.80	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.36	44.85	23.40	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	54.21	26.00	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE	X BIAS	Y BIAS	X STD	Y STD	HIT 7.5x7.5	HIT 15.0x7.5	EST RANGE	TOTAL 7.5x7.5	TOTAL 15.0x7.5
100.	.00	20.08	5.52	5.20	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	34.65	8.84	7.80	.90773	.90773	1.00000	.90773	.90773
200.	.00	35.83	12.76	10.40	.81070	.81104	.99991	.81063	.81097
250.	.00	23.62	17.41	13.00	.94072	.94998	.97725	.91932	.92836
300.	.00	-73.54	22.88	15.60	.94617	.99505	.50000	.75473	.79372
350.	.00	-45.00	29.23	18.20	.43814	.49896	.26599	.21908	.24944
400.	.00	-100.79	36.54	20.80	.00286	.00361	.13326	.00076	.00096
450.	.00	-181.50	44.85	23.40	.00000	.00000	.06681	.00000	.00000
500.	.00	-202.36	54.21	26.00	.00000	.00000		.00000	.00000

RANGE, BIAS, STANDARD DEVIATION, PROBABILITY OF HIT, PROBABILITY OF ESTIMATING RANGE, TOTAL HIT PROBABILITY

SIGMA AIM = 1.25 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	20.47	6.24	5.95	.99998	.99999	1.00000	.99998	.99999
150.	.00	36.22	9.85	8.93	.83724	.83725	1.00000	.83724	.83725
200.	.00	38.58	14.02	11.91	.70413	.70507	.99379	.69976	.70069
250.	.00	26.38	18.86	14.88	.87936	.89459	.84134	.73984	.75266
300.	.00	.00	24.48	17.86	.92300	.98802	.50000	.46150	.49401
350.	.00	-40.94	30.94	20.84	.49304	.57512	.23753	.11711	.13661
400.	.00	-100.39	38.34	23.82	.00761	.00984	.10565	.00080	.00104
450.	.00	-176.39	46.71	26.79	.00000	.00000	.04779	.00000	.00000
500.	.00	-282.36	56.11	29.77	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	32.68	6.24	5.95	.98080	.98080	1.00000	.98080	.98080
150.	.00	53.54	9.85	8.93	.16945	.16945	1.00000	.16945	.16945
200.	.00	62.20	14.02	11.91	.07435	.07425	.99991	.07424	.07434
250.	.00	55.91	18.86	14.88	.23172	.22777	.97725	.22259	.22649
300.	.00	35.04	24.48	17.86	.66449	.71129	.79767	.53004	.56739
350.	.00	.00	30.94	20.84	.82784	.96566	.50000	.41392	.48283
400.	.00	-53.94	38.34	23.82	.26863	.34701	.26599	.07145	.09230
450.	.00	-161.02	46.71	26.79	.00001	.00000	.13326	.00000	.00000
500.	.00	-282.36	56.11	29.77	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	5.91	6.24	5.95	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	9.85	8.93	.99974	.99976	1.00000	.99976	.99974
200.	.00	8.27	14.02	11.91	.99765	.99082	.99379	.99145	.99277
250.	.00	-9.84	18.86	14.88	.97394	.99062	.84134	.81942	.83362
300.	.00	-45.00	24.48	17.86	.46690	.49988	.50000	.23349	.24994
350.	.00	-93.31	30.94	20.84	.00873	.01018	.23753	.00207	.00242
400.	.00	-160.24	38.34	23.82	.00000	.00000	.10565	.00000	.00000
450.	.00	-202.36	46.71	26.79	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	56.11	29.77	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.25 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	20.08	6.24	5.95	.99999	.99999	1.00000	.99999	.99999
150.	.00	34.65	9.85	8.93	.87677	.87677	1.00000	.87677	.87677
200.	.00	35.83	14.02	11.91	.77833	.77933	.99991	.77823	.77926
250.	.00	23.62	18.86	14.88	.90887	.92461	.97725	.88819	.90358
300.	.00	-3.54	24.48	17.86	.92461	.98635	.79767	.73501	.78678
350.	.00	-45.00	30.94	20.84	.95635	.42704	.50000	.21354	.24909
400.	.00	-100.79	38.34	23.82	.49818	.00941	.26599	.00194	.00252
450.	.00	-181.50	46.71	26.79	.00728	.00000	.13326	.00000	.00000
500.	.00	-202.36	56.11	29.77	.00000	.00000	.06681	.00000	.00000

RANGE, BIAS, STANDARD DEVIATION, PROBABILITY OF HIT, PROBABILITY OF ESTIMATING RANGE, TOTAL HIT PROBABILITY

SIGMA AIM = 1.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	20.47	7.01	6.76	.99984	.99985	1.00000	.99986	.99986
150.	.00	36.22	10.96	10.14	.80669	.80572	1.00000	.80669	.80672
200.	.00	38.58	15.41	13.52	.68017	.68255	.99379	.67594	.67832
250.	.00	26.38	20.49	16.90	.84043	.86470	.84134	.70709	.72751
300.	.00	.00	26.30	20.28	.83874	.97290	.50000	.44437	.48645
350.	.00	-40.94	32.92	23.67	.47047	.56440	.23753	.11175	.13406
400.	.00	-106.39	40.42	27.05	.01491	.01777	.10565	.00157	.00206
450.	.00	-176.39	48.88	30.43	.00001	.00001	.04779	.00000	.00000
500.	.00	-202.36	58.35	33.81	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	32.68	7.01	6.76	.96581	.96581	1.00000	.96581	.96581
150.	.00	53.54	10.96	10.14	.19984	.19983	1.00000	.19983	.19984
200.	.00	62.20	15.41	13.52	.10130	.10165	.99991	.10129	.10164
250.	.00	55.91	20.49	16.90	.25200	.25528	.97725	.24627	.25338
300.	.00	35.00	26.30	20.28	.62836	.68785	.50000	.50122	.54869
350.	.00	.00	32.92	23.67	.78091	.93582	.79767	.39045	.46841
400.	.00	-53.94	40.42	27.05	.27202	.36076	.46599	.07235	.09596
450.	.00	-161.02	48.88	30.43	.00004	.00005	.13326	.00001	.00001
500.	.00	-202.36	58.35	33.81	.00000	.00000	.06681	.00000	.00000

SIGMA AIM = 1.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	5.91	7.01	6.76	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	10.96	10.14	.99892	.99896	1.00000	.99892	.99894
200.	.00	8.27	15.41	13.52	.99318	.99665	.99379	.98701	.99047
250.	.00	-9.84	20.49	16.90	.95314	.98066	.84134	.80192	.82507
300.	.00	-45.00	26.30	20.28	.45646	.49768	.50000	.22823	.24984
350.	.00	-93.31	32.92	23.67	.01709	.02050	.23753	.00406	.00487
400.	.00	-160.24	40.42	27.05	.00001	.00001	.10565	.00000	.00000
450.	.00	-242.36	48.88	30.43	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	58.35	33.81	.00000	.00000	.02275	.00000	.00000

SIGMA AIM = 1.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 X 7.5)	PROB OF HIT (15.0 X 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT (7.5 X 7.5)	TOTAL HIT (15.0 X 7.5)
100.	.00	20.08	7.01	6.76	.99989	.99989	1.00000	.99989	.99989
150.	.00	34.65	10.96	10.14	.84627	.84630	1.00000	.84627	.84630
200.	.00	35.83	15.41	13.52	.74857	.75119	.99991	.74850	.75115
250.	.00	23.62	20.49	16.90	.87187	.89705	.97725	.85203	.87664
300.	.00	-73.54	26.30	20.28	.80663	.97059	.50000	.70724	.77421
350.	.00	-45.00	32.92	23.67	.41412	.49680	.79767	.20706	.24846
400.	.00	-110.79	40.42	27.05	.01438	.01707	.26599	.00383	.00507
450.	.00	-181.50	48.88	30.43	.00000	.00000	.13326	.00000	.00000
500.	.00	-242.36	58.35	33.81	.00000	.00000	.06681	.00000	.00000

RANGE / BIAS / STANDARD DEVIATION / PROBABILITY OF HIT / PROBABILITY OF ESTIMATING RANGE / TOTAL HIT PROBABILITY

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 x 7.5)	PROBABILITY OF HIT (15.0 x 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 x 7.5)	TOTAL HIT PROBABILITY (15.0 x 7.5)

SIGMA AIM = 1.75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	PoH (7.5×7.5)	PoH (15.0×7.5)	Est. Range	Total (7.5×7.5)	Total (15.0×7.5)
100.	.00	20.47	7.83	7.61	.99937	.99937	1.00000	.99937	.99937
150.	.00	36.22	12.15	11.41	.77920	.77904	1.00000	.77904	.77920
200.	.00	38.58	16.92	15.21	.65835	.65424	.99379	.65424	.65940
250.	.00	26.38	22.27	19.02	.79990	.83607	.84134	.67299	.70342
300.	.00	.00	28.30	22.82	.84501	.94998	.50000	.42250	.47499
350.	.00	-40.94	35.10	26.62	.44800	.55420	.23753	.10643	.13164
400.	.00	-100.39	42.76	30.43	.02431	.03315	.10565	.00257	.00350
450.	.00	-176.39	51.34	34.23	.00004	.00006	.04779	.00000	.00000
500.	.00	-202.36	60.90	38.03	.00001	.00002	.02275	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	PoH (7.5×7.5)	PoH (15.0×7.5)	Est. Range	Total (7.5×7.5)	Total (15.0×7.5)
100.	.00	32.68	7.83	7.61	.94727	.94727	1.00000	.94727	.94727
150.	.00	53.54	12.15	11.41	.22704	.22709	1.00000	.22704	.22709
200.	.00	62.20	16.92	15.21	.12805	.12806	.99991	.12804	.12905
250.	.00	35.91	22.27	19.02	.27085	.28310	.97725	.26469	.27666
300.	.00	35.04	28.30	22.82	.59377	.66754	.79767	.47364	.53248
350.	.00	.00	35.10	26.62	.72741	.89966	.50000	.36370	.44987
400.	.00	-53.94	42.76	30.43	.27155	.37033	.26599	.07223	.09850
450.	.00	-161.24	51.34	34.23	.00022	.00032	.13326	.00003	.00004
500.	.00	-202.36	60.90	38.03	.00001	.00002	.06681	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	PoH (7.5×7.5)	PoH (15.0×7.5)	Est. Range	Total (7.5×7.5)	Total (15.0×7.5)
100.	.00	5.91	7.83	7.61	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	12.15	11.41	.99668	.99689	1.00000	.99668	.99689
200.	.00	8.27	16.92	15.21	.98414	.99190	.99379	.97803	.98574
250.	.00	-9.94	22.27	19.02	.92394	.96572	.84134	.77735	.81250
300.	.00	-45.00	28.30	22.82	.44406	.49722	.50000	.22203	.24961
350.	.00	-93.31	35.10	26.62	.02783	.03442	.23753	.00661	.00818
400.	.00	-162.36	42.76	30.43	.00005	.00007	.10565	.00001	.00001
450.	.00	-202.36	51.34	34.23	.00000	.00000	.04779	.00000	.00000
500.	.00	-202.36	60.90	38.03	.00001	.00002	.02275	.00000	.00000

SIGMA AIM = 1.75 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	PoH (7.5×7.5)	PoH (15.0×7.5)	Est. Range	Total (7.5×7.5)	Total (15.0×7.5)
100.	.00	20.08	7.83	7.61	.99947	.99947	1.00000	.99947	.99947
150.	.00	34.65	12.15	11.41	.81765	.81782	1.00000	.81765	.81782
200.	.00	35.83	16.92	15.21	.72102	.72671	.99991	.72096	.72665
250.	.00	23.52	22.27	19.02	.83170	.86931	.97725	.81278	.84953
300.	.00	-73.54	28.30	22.82	.84260	.84728	.79767	.67212	.75591
350.	.00	-45.00	35.10	26.62	.39980	.49947	.50000	.19990	.24724
400.	.00	-100.79	42.76	30.43	.02361	.03219	.26599	.00628	.00856
450.	.00	-181.50	51.34	34.23	.00002	.00003	.13326	.00000	.00000
500.	.00	-202.36	60.90	38.03	.00001	.00002	.06681	.00000	.00000

RANGE / BIAS / STANDARD DEVIATION / PROBABILITY OF HIT / PROBABILITY OF ESTIMATING RANGE / TOTAL HIT PROBABILITY

SIGMA AIM = 2.00 MILS — VEL IN FPS = 1000.0 — DRAG = T119E11 — RANGE TO TARGET AIMPOINT = 300. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL (7.5 X 7.5)	TOTAL (15.0 X 7.5)
100.	.00	20.47	8.68	8.48	.99809	.99809	1.00000	.99809	.99809
150.	.00	36.22	13.37	12.72	.75440	.75499	1.00000	.75440	.75499
200.	.00	38.58	18.50	16.95	.63786	.64757	.99379	.63389	.64355
250.	.00	26.38	24.15	21.19	.75930	.30969	.84134	.63883	.68123
300.	.00	.00	30.45	25.43	.79446	.92032	.50000	.39723	.46014
350.	.00	-40.94	37.47	29.67	.42558	.54352	.23753	.10109	.12910
400.	.00	-100.39	45.30	33.91	.03477	.04878	.10565	.00367	.00515
450.	.00	-176.39	54.03	38.15	.00017	.00026	.04779	.00001	.00001
500.	.00	-242.36	63.71	42.39	.00005	.00009	.02275	.00000	.00000

SIGMA AIM = 2.00 MILS — VEL IN FPS = 1000.0 — DRAG = T119E11 — RANGE TO TARGET AIMPOINT = 350. CENTER

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL (7.5 X 7.5)	TOTAL (15.0 X 7.5)
100.	.00	32.68	8.69	8.48	.92686	.92686	1.00000	.92686	.92686
150.	.00	53.54	13.38	12.72	.25079	.25099	1.00000	.25079	.25099
200.	.00	62.20	18.50	16.95	.15279	.15511	.99991	.15277	.15510
250.	.00	55.91	24.15	21.19	.28439	.30326	.97725	.27792	.29636
300.	.00	35.04	30.45	25.43	.56067	.64949	.79767	.44723	.51808
350.	.00	.00	37.47	29.67	.67061	.85645	.50000	.33530	.42823
400.	.00	-93.00	45.30	33.91	.26786	.37576	.26599	.07126	.09995
450.	.00	-151.02	54.03	38.15	.00070	.00107	.13326	.00009	.00014
500.	.00	-202.36	63.71	42.39	.00005	.00009	.06681	.00000	.00001

SIGMA AIM = 2.00 MILS — VEL IN FPS = 1000.0 — DRAG = T119E11 — RANGE TO TARGET AIMPOINT = 300. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL (7.5 X 7.5)	TOTAL (15.0 X 7.5)
100.	.00	5.91	8.68	8.48	1.00000	1.00000	1.00000	1.00000	1.00000
150.	.00	13.78	13.38	12.72	.99218	.99218	1.00000	.99218	.99284
200.	.00	8.27	18.50	16.95	.96929	.98404	.99379	.96327	.97793
250.	.00	-9.94	24.15	21.19	.88754	.94644	.84134	.74674	.79630
300.	.00	-45.00	30.45	25.43	.43010	.49824	.50000	.21505	.24912
350.	.00	-93.31	37.47	29.67	.03985	.05089	.23753	.00946	.01209
400.	.00	-160.24	45.30	33.91	.00023	.00032	.10565	.00002	.00003
450.	.00	-202.36	54.03	38.15	.00001	.00002	.04779	.00000	.00000
500.	.00	-202.36	63.71	42.39	.00005	.00009	.02275	.00000	.00000

SIGMA AIM = 2.00 MILS — VEL IN FPS = 1000.0 — DRAG = T119E11 — RANGE TO TARGET AIMPOINT = 350. BOTTOM

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB HIT (7.5 X 7.5)	PROB HIT (15.0 X 7.5)	PROB ESTIMATING RANGE	TOTAL (7.5 X 7.5)	TOTAL (15.0 X 7.5)
100.	.00	20.08	8.68	8.48	.99835	.99835	1.00000	.99835	.99835
150.	.00	34.65	13.38	12.72	.79144	.79209	1.00000	.79148	.79209
200.	.00	35.83	18.50	16.95	.69516	.70575	.99991	.65510	.70564
250.	.00	23.62	24.15	21.19	.79030	.84274	.97725	.77232	.82357
300.	.00	-3.54	30.45	25.43	.79200	.91747	.79767	.63175	.73184
350.	.00	-45.00	37.47	29.67	.38419	.49066	.50000	.19209	.24533
400.	.00	-100.79	45.30	33.91	.03394	.04761	.26599	.00903	.01266
450.	.00	-181.50	54.03	38.15	.00010	.00016	.13326	.00001	.00002
500.	.00	-202.36	63.71	42.39	.00005	.00009	.06681	.00000	.00001

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STANDARD DEVIATION X(INCHES)	STANDARD DEVIATION Y(INCHES)	PROBABILITY OF HIT (7.5 x 7.5)	(15.0 x 7.5)	PROBABILITY OF ESTIMATING RANGE	TOTAL HIT PROBABILITY (7.5 x 7.5)	(15.0 x 7.5)

SIGMA AIM = 2.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   CENTER

RANGE	X BIAS	Y BIAS	X STD	Y STD	PHIT 7.5	PHIT 15.0	P EST RANGE	TOTAL 7.5	TOTAL 15.0
100.	.00	20.47	10.44	10.27	.99153	.99154	1.00000	.99153	.99154
150.	.00	36.22	15.96	15.41	.71214	.71558	1.00000	.71214	.71558
200.	.00	38.58	21.83	20.54	.59822	.62265	.99379	.59450	.61872
250.	.00	26.38	28.17	25.68	.67901	.76201	.84134	.57128	.64111
300.	.00	.00	35.06	30.81	.68528	.84709	.50000	.34264	.42354
350.	.00	-40.94	42.61	35.95	.38045	.51794	.23753	.09037	.12302
400.	.00	-100.39	50.89	41.08	.05522	.08176	.10565	.00583	.00864
450.	.00	-176.39	60.00	46.22	.00122	.00194	.04779	.00006	.00009
500.	.00	-202.36	70.00	51.35	.00052	.00087	.02275	.00001	.00002

SIGMA AIM = 2.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   CENTER

RANGE	X BIAS	Y BIAS	X STD	Y STD	PHIT 7.5	PHIT 15.0	P EST RANGE	TOTAL 7.5	TOTAL 15.0
100.	.00	32.68	10.44	10.27	.88484	.88485	1.00000	.88484	.88485
150.	.00	53.54	15.96	15.41	.28833	.28973	1.00000	.28833	.28973
200.	.00	62.20	21.83	20.54	.19324	.20118	.99991	.19327	.20116
250.	.00	55.91	28.17	25.68	.29844	.33496	.79725	.29169	.32734
300.	.00	35.04	35.06	30.81	.49808	.61569	.50000	.39730	.49111
350.	.00	.00	42.61	35.95	.55970	.76197	.26599	.27985	.38099
400.	.00	-53.94	50.89	41.08	.25303	.37461	.13326	.06730	.09964
450.	.00	-161.02	60.00	46.22	.00330	.00522	.06681	.00044	.00072
500.	.00	-202.36	70.00	51.35	.00052	.00087		.00003	.00006

SIGMA AIM = 2.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300.   BOTTOM

RANGE	X BIAS	Y BIAS	X STD	Y STD	PHIT 7.5	PHIT 15.0	P EST RANGE	TOTAL 7.5	TOTAL 15.0
100.	.00	5.91	10.44	10.27	.99991	.99993	1.00000	.99991	.99993
150.	.00	13.78	15.94	15.41	.97384	.97855	1.00000	.97384	.97855
200.	.00	8.27	21.83	20.54	.92075	.95834	.99379	.91503	.95230
250.	.00	-9.94	28.17	25.68	.79922	.89691	.84134	.67242	.75461
300.	.00	-45.00	35.06	30.81	.39895	.49315	.50000	.19947	.24657
350.	.00	-93.31	42.61	35.95	.06342	.08634	.23753	.01506	.02051
400.	.00	-160.24	50.89	41.08	.00157	.00232	.10565	.00017	.00025
450.	.00	-202.36	60.00	46.22	.00018	.00029	.04779	.00001	.00001
500.	.00	-202.36	70.00	51.35	.00052	.00087	.02275	.00001	.00002

SIGMA AIM = 2.50 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350.   BOTTOM

RANGE	X BIAS	Y BIAS	X STD	Y STD	PHIT 7.5	PHIT 15.0	P EST RANGE	TOTAL 7.5	TOTAL 15.0
100.	.00	20.08	10.44	10.27	.99234	.99238	1.00000	.99236	.99238
150.	.00	34.65	15.94	15.41	.74540	.74909	1.00000	.74549	.74909
200.	.00	45.83	21.83	20.54	.64592	.67230	.99991	.64586	.67224
250.	.00	23.62	28.17	25.68	.70625	.79257	.79725	.69018	.77454
300.	.00	-3.54	35.06	30.81	.68316	.84447	.50000	.54494	.67361
350.	.00	-45.00	42.61	35.95	.35018	.47673	.26599	.17509	.23836
400.	.00	-100.79	50.89	41.08	.05426	.08033	.13326	.01443	.02137
450.	.00	-191.50	60.00	46.22	.00086	.00136	.06681	.00011	.00018
500.	.00	-202.36	70.00	51.35	.00052	.00087		.00003	.00006

RANGE (METERS)	BIAS X(INCHES)	BIAS Y(INCHES)	STD DEV X(INCHES)	STD DEV Y(INCHES)	PROB OF HIT (7.5 x 7.5)	PROB OF HIT (15.0 x 7.5)	PROB OF ESTIMATING RANGE	TOTAL HIT PROB (7.5 x 7.5)	TOTAL HIT PROB (15.0 x 7.5)

SIGMA AIM = 3.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300. CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5x7.5)	HIT (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	20.47	12.25	12.11	.97834	.97860	1.00000	.97836	.97860
150.	.00	36.22	18.63	18.16	.67484	.68562	1.00000	.67484	.68562
200.	.00	38.58	25.32	24.21	.55865	.60405	.99379	.55518	.60031
250.	.00	26.38	32.41	30.27	.60252	.71762	.84134	.50693	.60377
300.	.00	.00	39.99	36.32	.58027	.76549	.20000	.29014	.38275
350.	.00	-40.94	48.15	42.37	.33599	.48506	.23753	.07981	.11521
400.	.00	-100.39	56.99	48.43	.07130	.11074	.10565	.00753	.01170
450.	.00	-176.39	66.57	54.48	.00396	.00652	.04779	.00019	.00031
500.	.00	-202.36	76.98	60.53	.00205	.00352	.02275	.00005	.00008

SIGMA AIM = 3.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350. CENTER

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5x7.5)	HIT (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	32.68	12.25	12.11	.84530	.84550	1.00000	.84530	.84550
150.	.00	53.54	18.63	18.16	.31407	.31909	1.00000	.31407	.31908
200.	.00	22.20	25.32	24.21	.22068	.23862	.99991	.22066	.23860
250.	.00	55.91	32.41	30.27	.29963	.35687	.97725	.29281	.34875
300.	.00	35.04	39.99	36.32	.43948	.57977	.79767	.35056	.46246
350.	.00	.00	48.15	42.37	.46264	.66795	.50000	.23133	.33397
400.	.00	-53.94	56.99	48.43	.23164	.35982	.26599	.06162	.09571
450.	.00	-161.02	66.57	54.48	.00828	.01361	.83326	.00110	.00181
500.	.00	-202.36	76.98	60.53	.00205	.00352	.06681	.00014	.00024

SIGMA AIM = 3.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 300. BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5x7.5)	HIT (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	5.91	12.25	12.11	.99912	.99935	1.00000	.99912	.99936
150.	.00	13.78	18.63	18.16	.94157	.95660	1.00000	.94157	.95660
200.	.00	8.27	25.32	24.21	.85190	.92114	.99379	.84661	.91542
250.	.00	-9.94	32.41	30.27	.70330	.83765	.84134	.59172	.70475
300.	.00	-45.00	39.99	36.32	.36488	.48135	.50000	.18244	.24067
350.	.00	-93.31	48.15	42.37	.08226	.11876	.23753	.01954	.02821
400.	.00	-160.24	56.99	48.43	.00494	.00767	.10565	.00052	.00081
450.	.00	-282.36	66.57	54.48	.00097	.00159	.04779	.00005	.00008
500.	.00	-202.36	76.98	60.53	.00205	.00352	.02275	.00005	.00008

SIGMA AIM = 3.00 MILS   VEL IN FPS = 1000.0   DRAG =T119E11   RANGE TO TARGET AIMPOINT = 350. BOTTOM

RANGE	BIAS X	BIAS Y	STD X	STD Y	HIT (7.5x7.5)	HIT (15.0x7.5)	EST RANGE	TOTAL (7.5x7.5)	TOTAL (15.0x7.5)
100.	.00	20.08	12.25	12.11	.97996	.98020	1.00000	.97996	.98020
150.	.00	34.65	18.63	18.16	.70439	.71563	1.00000	.70439	.71563
200.	.00	35.83	25.32	24.21	.59827	.64690	.99991	.59822	.64685
250.	.00	23.62	32.41	30.27	.62484	.74420	.97725	.61062	.72727
300.	.00	93.54	39.99	36.32	.57866	.76337	.79767	.46158	.60892
350.	.00	-45.00	48.15	42.37	.31406	.45341	.50000	.15703	.22676
400.	.00	-100.79	56.99	48.43	.07035	.10926	.26599	.01871	.02906
450.	.00	-231.50	66.57	54.48	.00305	.00502	.83326	.00041	.00067
500.	.00	-202.36	76.98	60.53	.00205	.00352	.06681	.00014	.00024

APPENDIX I

SIGHT-PERFORMANCE EVALUATION BASED ON HIT PROBABILITIES
(Provided by the U. S. Army Ballistic Research Laboratories)

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The attached document, "Evaluation of SMAWT Sighting" is a copy of the evaluation submitted to Mr. Jerome Frankle, SMAWT Program Coordinator, 27 December 1973.

ROBERT T. GSCHWIND

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EVALUATION OF SMAWT SIGHTING

As part of the SMAWT program the Human Engineering Laboratories conducted an evaluation of stadiametric range finders. The major portion of this evaluation consisted of a field test conducted in two phases. Five sights were used in each phase. The sights and the test plan are described in the HEL Draft Report on SMAWT dated April 1973. The results of test are still being analyzed by HEL; however, enough work has been done to reach some conclusions with respect to the Phase I sights.

These sights include a rifle type peep and post sight for aiming errors, the M72 type stadia based on a 475 foot per second projectile. The other three used the same type of stadia/ballistic reticle as the M72 but they were based on a 1200 foot per second projectile. One was a three power telescope, another was an M202 type of reflecting sight, and the last one was an M72 type of sight but with the high velocity reticle.

The most recent tabulation of results from Phase I was received on December 14, 1973. These tables have been reduced in size by combining the results for the three target aspects. This procedure causes the change in apparent target width to affect the standard deviation of error rather than the bias and, fortunately, it contributes approximately the same amount of error as an aspect chosen at random from the full 360°, i.e., about eight percent of width. These results are shown in the table for both stationary and 7 mph targets. The column titled elevation is a close approximation of the design goal for superelevation. These numbers are needed to compare to the Mean aim point for each sighting condition. Each data entry on the table represents approximately 60 observations with the exception of Sight #5 data which represents 90 observations. Sight #5 was modified and retested but the results were so similar they have been combined on this table.

The results in the Table lead to a lot of observations and conclusions: a) Moving targets cause a slight increase in superelevation error with the stadiametric sights but the biases do not appear to be affected. No further analyses of moving targets has been made at this time. b) All of the sights have a component of error of perhaps a quarter meter at the target which causes the angular error to increase to a couple of milliradians at short range. c) The peep and post iron sight has an insignificant bias and a standard deviation approaching one milliradian at long range. This finding is consistent with the LAW workshop estimate of one milliradian aiming at 500 meters for a good supported firing position and adequate time to aim (five seconds or more). Much larger aiming errors are attributed to iron sights when they are used with rifles from a standing or unsupported firing position and when they are used under time stress as against pop up targets. d) The accuracy of the stadia sights is influenced by the projectile velocity and hence the reticle shape. This dependence is clearly shown when comparing the M72 type sights that were designed for different velocities. Although there is definitely a dependence, there has not been a model developed which can functionally relate sight and weapon parameters to accuracy. This evaluation will postulate a component of error equal to ten percent of the required superelevation. Some assumption is necessary to adjust the error for changes in velocity and the ten percent component seems to fit all the data pretty well. The procedure looks like the following:

$$SD_2^2 = (SD_1)^2 - (Elevation_1/10)^2 \times (1 - (Vel_1/Vel_2)^4)$$

This procedure uses the approximation that superelevation is inversely proportional to the velocity squared. e) A comparison of the mean elevation with the design elevation reveals that all the stadia sights were biased low during the test. The bias varies from two milliradians at

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mid-range to four to eight milliradians at maximum range. Some sources of bias are identified in the HEL report but these sources do not account for much of the bias. Furthermore, although biases can usually be designed out of a weapon, in this instance a change in the stadia design to increase the superelevation will also increase the standard deviation. Also, there is always the possibility the bias is an occasion to occasion error that could not be completely removed. In any case, attempts to remove this bias would need to be tested before the potential benefits could be relied upon. f) The three power stadia sight out-performed both of the non magnifying stadia sights.

The results of the HEL test become most meaningful when applied to hit probability calculations. The attached figure shows hit probability against a 7½ x 7½ target for a 950 foot per second projectile with one milliradian dispersion. The azimuth probabilities were generated by assuming the iron sight aiming error to be circular and RSSing the one milliradian dispersion. This same azimuth hit probability was assumed to apply to the stadia sights as well. The iron sight verticle dispersion is the RSS of the aiming error, one milliradian dispersion, 20 percent range estimation error, and a 35 meter range error arising from a sight working in 100 meter increments. The three power stadia and the M202 verticle dispersions were calculated two ways. Both ways used the adjusted standard deviation and the one milliradian dispersion. The optimistic predictions did not include the bias or any additional error for variability in vehicle dimensions. The conservative predictions included the bias and a ten percent standard deviation in vehicle dimensions. Other curves show the grazefire predictions contained in an AMSAA letter dated 19 November 1973. The aiming errors for the grazefire curve were taken from the iron sight test condition. The higher curve is the probability of hitting given a shot. The lower curve is penalized for the percentage of times the gunner estimates the target is out of range and therefore doesn't shoot.

The hit probability curves show that stadiametric sights offer promise of improving performance over a conventional iron sight if the biases can be removed and if they are designed for the target being fired on. However, the performance of stadia sights in the test was more like the conservative curves because of the large biases. Therefore the current state-of-art of stadia performance isn't much different from the performance achieved with iron sights and human range error.

The grazefire curves are shown even though the technique was not tested as part of the SMAWT Program. Grazefire performance exceeds iron sight performance at certain ranges for two reasons pointed out in BRL Memorandum Report No. 2315; namely, the bottom aim technique and the method of evaluating weapons against true range rather than estimated range. Bottom aim does offer some advantage with any sighting system if it does not confuse the gunner to aim at the bottom of the target when he has been accustomed to aiming at center of mass. Grazefire would not be suitable as the only sighting method available because of the complete loss in capability over 300 meters even though the range might be known from some other source.

The SMAWT sighting effort was supposed to determine if an iron sight could be used to accurately aim at a tank and to determine if some form of stadiametric range finding sight could do better than human range estimation. The iron sight aiming performance was nicely described by the HEL test. The demonstrated error of approximately 1.3 milliradians is adequate for a short-range weapon. The stadiametric sights' performance was not so neatly described because of the large biases in the data. The test methodology appears sound but there is just something about the way gunners use stadiametric sights which causes biases. Furthermore, the biases cannot simply be designed out because changes in stadia shape will cause changes in aiming performance. Therefore, although the optimistic view of the stadia data shows significant

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improvement over conventional ranging and aiming, the technology program has not proven that this performance can be achieved without further reticle design and subsequent testing. The three power stadia sight looks particularly promising in that it had smaller biases and standard deviations than either of the other stadia types tested in Phase I such that even the conservative estimate was better than conventional aiming. The other stadias in Phase I appear to be worse than conventional aiming when the biases are included.

Obviously this effort does not lead to any firm position regarding the ultimate sight for LAW type weapons. However, the most appropriate immediate solution appears to be some form of simple sight to be issued as part of the weapon with provision built into the weapon to accept a high performance sight as a reusable accessory when it is developed and if it is available to the gunner when he needs it. The simple sight could be a grazefire sight if there was assurance that the high performance sight would be readily available; or better still, the simple sight could have an adjustable superelevation capability to give it a long range capability especially when the range is known. The provision for a high performance sight would be some form of bracket or dovetail. This bracket could be used for mounting a night sight (individual weapon sight), some form of improved stadiametric rangefinder sight, and/or a laser-rangefinder sight. The feasibility of the laser-rangefinder sight will be established in the next few months as a by-product of the ECOM effort on the Mini Rangefinder for the 40mm Grenade Launcher. The stadiametric sight will require something like a validation test to see if the biases can be removed when the sight is designed for the appropriate trajectory of the new LAW. This test would be similar to the Phase 1 sighting study.

HEL SMAWT SIGHT TEST

Elevation error, combined aspects

	Sight	Range meters	Elevation mrad	Stationary Mean mrad	S.D. mrad	Moving 7-mph Mean mrad	S.D. mrad
#1	Peep	130	0	0.4	1.5	-0.1	1.6
	&	210	0	-0.1	1.5	-0.3	1.4
	Post	290	0	0.0	1.3	-0.5	1.2
		370	0	-0.1	1.3	-0.1	1.4
		450	0	-0.3	1.2	-0.6	1.4
#2	M72	130		—	—		
	475	210	56	54.8	5.0	55.5	6.0
	FPS	290	84	75.3	7.1	76.5	10.1
		370	114	96.0	12.2	93.6	12.4
		450		—	—		
#3	3 Power	130	5.2	2.8	2.1	3.3	2.9
	Stadia	210	9.4	7.7	1.8	7.5	2.2
	1200	290	14	11.9	1.6	11.7	1.8
	FPS	370	19	15.9	1.8	16.2	2.1
		450	24	20.6	2.7	19.4	2.7
#4	M202	130	5.2	2.2	2.3	1.9	2.8
	Stadia	210	9.4	7.1	1.8	7.1	2.7
	1200	290	14	10.1	2.2	10.2	2.1
	FPS	370	19	13.8	2.6	13.7	3.2
		450	24	16.8	2.6	15.7	3.2
#5	M72	130	5.2	0.5	2.2	0.0	2.5
	1200	210	9.4	6.6	2.4	6.5	2.5
	FPS	290	14	10.6	2.8	9.8	2.6
		370	19	14.0	2.7	13.5	2.9
		450	24	16.9	3.4	16.5	3.5

APPENDIX J

SOURCES OF RANGE-MEASUREMENT ERRORS USING STADIA

There are many sources of range-measurement error with stadia. The sources of error described here can be separated into three categories; the first is shown in Figure 1K, and the other two are shown in Figure 2K.

Three components of range-measurement error, which shall be called "components of normal range-measurement error," are shown in Figure 1K. The left side of the figure shows full-stadia ranging to side-on targets, and the right side of the figure shows half-stadia ranging to head-on targets. At the top of the figure, there is a stationary tank target with a two-to-one length-to-width ratio, and stadia lines with an infinitesimal line thickness. The target shown here is correctly positioned in the stadia at a range, "a". The stadia lines, however, have a finite thickness and, although the stadia are designed assuming that a gunner fits the target to the centers of the lines, Army doctrine requires the gunner to fit the target to the inside edges of the lines. This source of error, labelled "component 1" in the figure, causes the gunner to underestimate the target's range. As shown, the range-measurement error is greater for head-on targets than for side-on targets.

For a hand-held weapon, there is a component of aiming error (sometimes called "holding error") caused by the gunner's unsteadiness. This unsteadiness, shown as "component 2" in the figure, appears to reduce the separation between the stadia lines—which, in turn, causes the gunner to underestimate target range. Because reducing the separation between the stadia lines is equivalent to increasing the stadia-line thickness, the figure shows that this error component is greater for head-on than for side-on targets.

Target movement causes a third component of error, which is similar to component 2. For a side-on target, the gunner's unsteadiness is greater because he must track the target. Also, dirt clouds and exhaust fumes mask the rear of the target, making it seem larger than it really is. There is a similar effect for head-on targets; but usually there is less unsteadiness and target obscuration than for a side-on target. However, because of components 1 and 2, the range-measurement error for a head-on target is more sensitive to changes in the apparent separation of the stadia lines than if the target were side-on. Thus, quite likely, both head-on and side-on target motion can have identical effects.

There are also other range-measurement errors, in addition to the three "normal" components, arising from misuse of the stadia or because targets are not at exactly side-on or head-on aspects. These range-measurement errors are shown in Figure 2K where, as before, full-stadia ranging is shown on the left, and half-stadia ranging is shown on the right. Illustrations "I" and "II" show the effect of errors in selecting full- or half-stadia, which lead to gross underestimates of range for a side-on target, and to similar large overestimates of range for a head-on target. Of the two possible errors, misplacing the head-on target in the full-stadia occurs more frequently. Illustration IV shows another error gunners can make when positioning head-on targets in the stadia. Here, the gunner mistakenly uses the base of the target to measure target range (as A*); he should use the midsection of the target, as shown at "A" in "I" and "IV".

In a real encounter with a tank target, it is quite unlikely that the target will be exactly head-on or side-on. For this condition, if the target's length appears greater than its width, the gunner should use the full-stadia to measure the target's range, and he should fit the entire target, within the stadia as shown in "III." This results in underestimating the target range when the target is correctly positioned in the stadia at A. Such decision processes are more difficult for targets that are nearly head-on than for those that are nearly side-on. Here, if the target appears wider than it is long, the gunner should use the half-stadia to measure the target's range. But, unlike previous procedures, only the frontal portion of the target should be fitted into the half-stadia. Placing the target correctly, as shown in "V," results in overestimating target range. However, it is quite likely that gunners will place the target at either A*, shown in "V," or at A*, shown in "II," depending on whether the target appears to be more nearly head-on or more nearly side-on.

The overall errors for those conditions, shown in Figure 2K, can be determined by adding the errors shown in Figure 1K. If the target's size differs from the one assumed in designing the stadia, or if the target's length-to-width ratio is not 2 to 1, still other errors will obviously occur.

① TRUE TARGET RANGE ②

③ COMPONENT 1
Caused by Stadia Line Thickness
$b \cdot a < b' \cdot a$ ④

⑤ COMPONENT 2
Caused by Gunner's Unsteadiness
$c \cdot b < c' \cdot b'$ ⑥

⑦ COMPONENT 3
Caused by Movement of Target
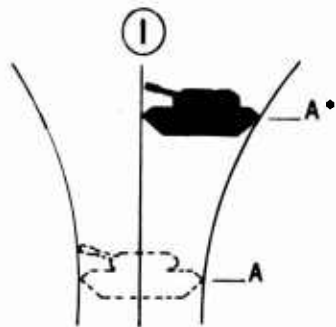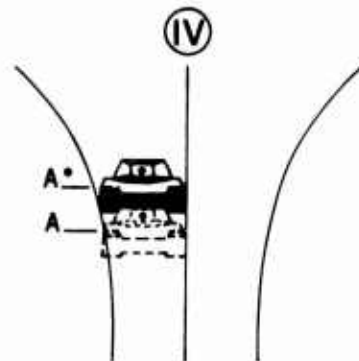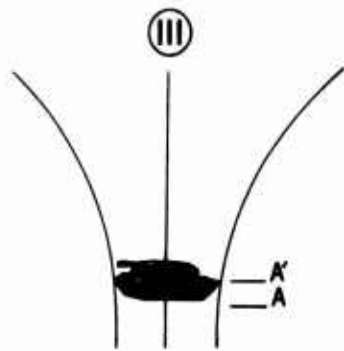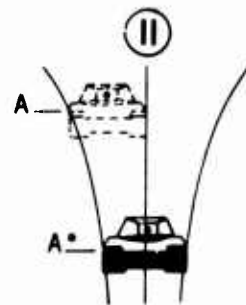$d \cdot c \overset{?}{=} d' \cdot c'$ ⑧
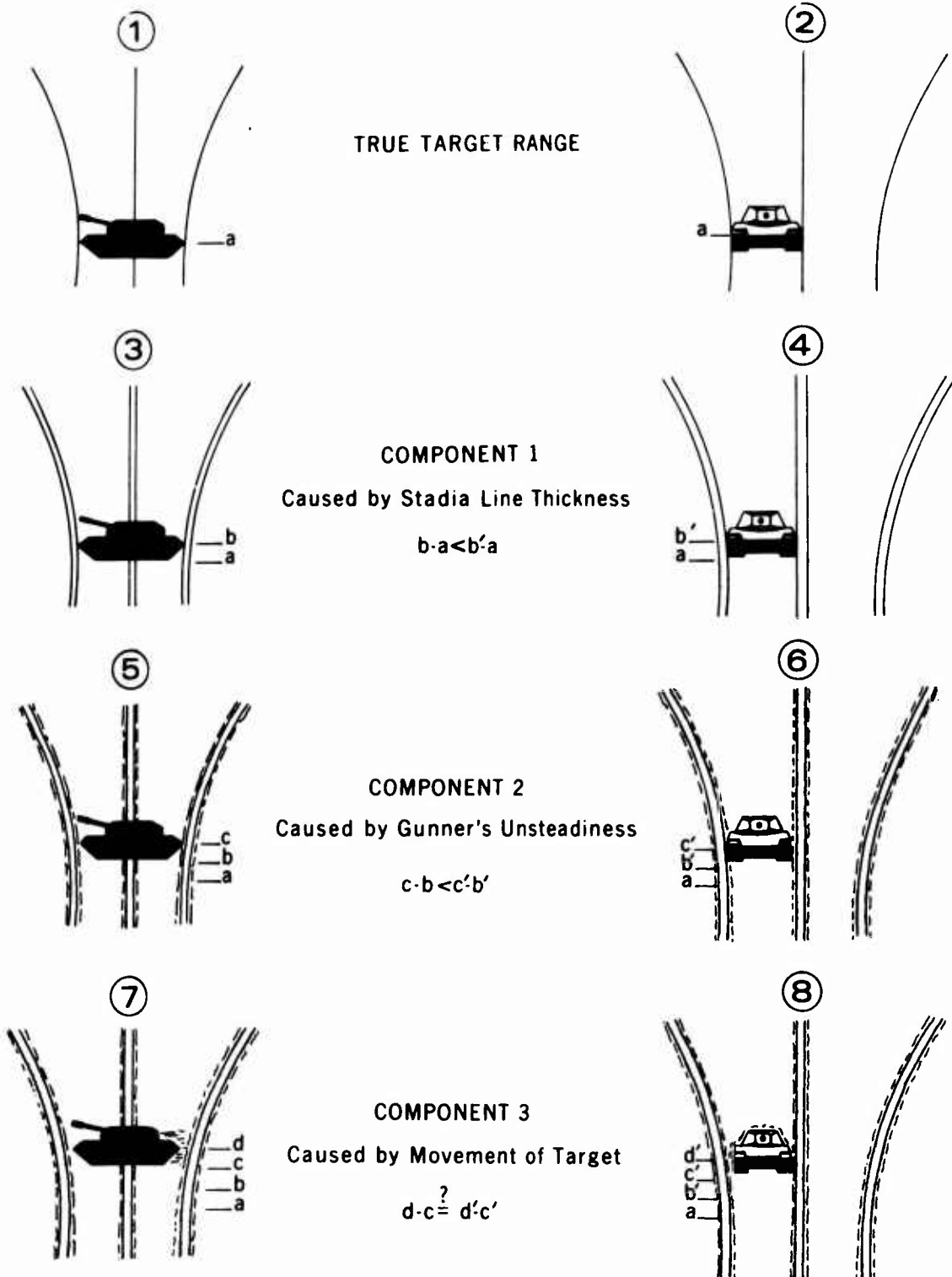
Fig. 1J. Components of "normal" range measurement error using stadia.

FULL-STADIA RANGING

HALF-STADIA RANGING

LEGEND

A = True target range

A• = Incorrect range resulting when the target
is incorrectly placed in the stadia

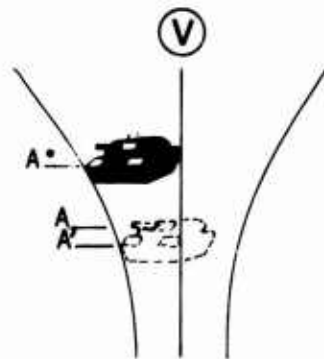A' = Incorrect range resulting when the target
is correctly placed in the stadia

Fig. 2J. Range measurements errors resulting from (1) misuse of stadia and
(2) targets at aspects other than head-on or side-on.

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APPENDIX K

HYPOTHESES OF POSSIBLE CAUSES OF SUPERELEVATION AND RANGE-FINDING BIASES

As an explanation for possible causes of reduced superelevations for the conventional length/width stadia sights, the following hypotheses have been formulated:

1. The gunner's holding error for the firing position used in the experiment is on the order of 0.5 mils. When the gunner is attempting to touch the edges of a stationary target to the stadia lines, the reticle is moving both horizontally and vertically in relation to the target. This motion could cause the stadia separation to appear smaller or, with similar results, could cause a "circle of confusion" about the edges of the target, causing the gunner to fit an apparently larger target into the stadia. For an error of fixed-mil size (or stadia separation), either error source would reduce superelevation increasingly for smaller or more distant targets. With moving targets which the gunner must track, increasing the sight's relative motion would tend to reduce superelevation still further.

2. For oblique targets, the tank's horizontal extremes (or ranging points) are pointed and relatively easy to locate and frame in the stadia lines. But for head on targets, the ranging points are located in the upper portion of the rectangular hull, and difficult for the gunner to discriminate. If the prescribed ranging points are poorly defined and the gunner places the bottom of the tank in the stadia lines, a reduced superelevation, inversely proportional to target range, would be incurred.

3. Target emplacement at the three aspects was controlled in the experiment by using surveyed-in locator stakes. However, small variations from the nominal target aspects were expected. Examination of how changing the target's aspect affects its size (Figure 20) shows the effect of an error in positioning the target. At the 0- and 62.4-degree aspects, either a plus or a minus angular error in target emplacement would reduce the apparent target size and thus increase (rather than decrease) superelevation. For example, an error as large as plus-or-minus 5 degrees would cause a range overestimation of less than 1 percent. The same emplacement error at the 90-degree aspect would cause a range underestimation of about 4 percent.

4. For head-on targets, gunners who placed the horizontal extremes of the target in the stadia, would reduce the apparent target range. A 5-degree target-placement error would increase target size approximately 16 percent which, in turn, would reduce superelevation progressively for farther ranges. For moving targets, where smoke and dust obscure the target's edges, superelevation would be reduced even more.

Although these are only hypotheses, the first one would explain why reduced superelevation is directly related to target range, and inversely related to nominal target size. The second and fourth hypotheses explain why head-on targets cause additional reductions in superelevation.

For the modified M72 sight, the reduction in superelevation compared to the unity and three-power optical sights (which are designed for the same muzzle velocity) cannot be completely explained by the sight-radius error. Non-optical sights may reduce superelevation more than optical sights do, because the reticle and target cannot both be in focus simultaneously. The "fuzzy" edges of an out-of-focus reticle (or target) would tend to decrease the apparent separation of the stadia lines (or, equivalently, increase the apparent target size), thus reducing superelevation.

For the turret stadia sight, the reduction in crossover range between QE's is equivalent to an apparent increase in stadia separation, or to a decrease in target size—a seeming contradiction to the (previous) hypotheses that holding error reduces superelevation. However, the stadia in this sight are two sets of parallel lines, rather than curved continuous lines used in conventional length/width stadia. Here, rather than seeking to match stadia separation and target size, the gunner superimposes one set of lines on the target and determines only whether or not the target is narrower than the pair of lines. If the gunner's holding error moves the sight horizontally, an edge of the target will alternately appear to be inside and outside of the gate. Since the gunner cannot readily average this phenomenon over time, he may match the target to a larger gate or, equivalently, estimate a smaller turret size. Additionally, if the stadia line obscures the edge of the turret, the turret could appear smaller than it really is.

In the pretest range-estimation training for the experiment, there was negligible bias in the gunners' estimates of target range (mean error = -2 percent of range). Yet during the main test of the experiment, both groups of gunners overestimated the range of close targets when using the rifle sights (Figure 17), thus classifying an inordinate percentage of near targets as midrange. One possible cause is the terrain features of the test area. A more likely explanation is that, when the gunners were unsure of the target range, they tended to select the middle of the three range classifications, rather than either extreme.