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Techniques and Procedures to Improve 25mm Gunnery of the Bradley Fighting Vehicle

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October 1988

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U.S. ARMY RESEARCH INSTITUTE
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Research has been conducted to develop and evaluate procedures and techniques to improve 25mm gunnery of the Bradley Fighting Vehicle (BFV). The approach used for problem identification and development of solutions depended on the area of gunnery researched. This report summarizes research findings and products related to boresight equipment and procedures, zeroing procedures, firing control checks, battlesight gunnery, range estimation, aiming, and use of the auxiliary sight unit. Findings and products will be integrated into the BFV Gunnery field manual (FM 23-1), recommended as changes or additions to the turret technical manual (TM 9-2350-252-10-2), and used to indicate design and operational problems with fielded boresight equipment.

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25mm automatic gun, M242C	Backlash
7.62mm boresight kit	Range determination

Research Report 1520

Techniques and Procedures to Improve 25mm Gunnery of the Bradley Fighting Vehicle

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FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) has contributed to a program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with this mission, this report summarizes procedures, techniques, and job performance aids that have been developed, modified, and identified to improve the effectiveness of BFV gunnery, particularly the 25mm gun. Boresighting, zeroing, range estimation, aiming, and use of the auxiliary sight unit are addressed. This report is intended for BFV gunnery literature developers and administrators and senior instructors involved in BFV gunnery training.

ARI's Fort Benning Field Unit, a division of the Training Research Laboratory, monitored the research. ARI's mission is to conduct research on training and training technology using infantry combat systems and problems as mediums. The research task that supports this mission is titled "Advanced Methods and Systems for Fighting Vehicle Training" and is organized under the "Train the Force" program area. Sponsorship for this research effort is provided by a Memorandum of Understanding (effective 31 May 1983) between the U.S. Army Infantry School (USAIS), Training and Doctrine Command (TRADOC), Training Technology Agency, and ARI, which established how joint efforts to improve BFV tactical doctrine, unit, and gunnery training would proceed.

This work was conducted in close cooperation and coordination with the BFV gunnery proponent at USAIS and program managers associated with boresight equipment. Many of the modified and developed procedures and techniques described in this report will be integrated into the BFV Gunnery field manual (FM 23-1). Research in the area of boresight equipment has led program managers to recognize problems that were not previously reported.

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TECHNIQUES AND PROCEDURES TO IMPROVE 25MM GUNNERY OF THE BRADLEY FIGHTING VEHICLE

EXECUTIVE SUMMARY

Requirement:

To develop and evaluate procedures, techniques, and job performance aids to improve gunnery effectiveness of the Bradley Fighting Vehicle (BFV), with emphasis on those factors affecting first-round accuracy of the 25mm gun. This report summarizes research and developed or modified products in boresighting, zeroing, range estimation, aiming, and use of the auxiliary sight unit.

Procedure:

As appropriate to each problem, the methodology included literature review; observations of gunnery training and performance; interactions with students, instructors, and experts; development of procedural requirements; conduct of mathematical calculations and predictions; operational analysis of fielded equipment; and feasibility testing and validation of developed procedures and techniques.

Findings:

The findings and products of this research include:

- Identification of defective and inaccurate boresight equipment at Fort Benning;
- Preparation of quality deficiency reports (QDR) for defective and inaccurate boresight equipment;
- Procedures for testing the accuracy of the boresight telescope, the 25mm adapter, and the 25mm boresight kit;
- Modified procedures for boresighting the 25mm gun;
- Modified design of the close-in boresight panel;
- Modified procedures for using the close-in boresight panel;
- Procedures for conducting critical fire-control checks;

- A procedure to control for backlash between the sights and 25mm gun;
- A modified procedure for zeroing the 25mm gun with training ammunition;
- Score sheets for zeroing the 25mm automatic gun and 7.62mm coaxial machine gun;
- Trajectory curves for 25mm ammunition and expanded guidelines on range control settings for battlesight gunnery;
- A modified procedure for using the horizontal ranging stadia;
- A modified technique for estimating range with binoculars;
- A modified quick reference table for range estimation;
- A technique for estimating range using the integrated sight unit (ISU) lead lines;
- A technique to estimate maximum effective ranges for the 25mm gun and TOW missile system using the lead lines;
- A modified procedure for estimating range with the auxiliary sight unit;
- Procedures for zeroing and engaging targets with the auxiliary sight unit;
- Modified aiming rules for moving targets and firing while moving;
- A procedure for classifying target view as either frontal or flank for range estimation and application of lead rules.

Utilization of Findings:

The next version of the BFV Gunnery field manual (FM 23-1) will include the following developed or modified products: boresight equipment test procedures; the close-in boresight panel and procedures for using it; procedures for conducting fire-control checks; trajectory curves for 25mm ammunition and guidelines for battlesight gunnery; the technique for classifying target view; a quick reference table for range estimation; techniques for estimating range with the binoculars, the horizontal ranging stadia, and the auxiliary sight unit; and aiming rules. Where conflicts exist between the field manual and this report, the manual should take precedence. The developed/modified boresighting procedures and zeroing procedure for 25mm training ammunition were recommended (DA Form 2028-2) as additions or changes to the turret technical manual (TM 9-2350-252-10-2). The prepared QDRs for boresight equipment were submitted by a BFV unit to indicate the existence of design flaws in currently fielded equipment. The overall impact of implemented, or nearly implemented, research and use of developed products should improve the accuracy of 25mm gunnery.

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TECHNIQUES AND PROCEDURES TO IMPROVE 25MM GUNNERY OF THE BRADLEY FIGHTING VEHICLE

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SECTION 1. INTRODUCTION

Background

Since September 1983, Litton Computer Services (formerly Litton Mellonics) has been under contract to the Army Research Institute (ARI) Fort Benning Field Unit to conduct research and development on a wide scope of issues related to the Bradley Fighting Vehicle (BFV). Problem analysis of Bradley tactics, equipment, and training identified critical issues, deficiencies, and areas in need of improvement (Rollier et al.,1988b). This formed the basis for developing solutions to improve operational effectiveness of the BFV (Rollier et al.,1988a). Work in gunnery research and development focused on techniques and procedures to improve the gunner's capability to achieve first-round hits with the 25-mm gun (Perkins, 1987a).

The 25-mm gun often is referred to as a burst-on-target weapon system not designed to achieve first-round hits. Use of high-explosive incendiary with tracer (HEI-T) ammunition against area targets does not require first-round hits. However, the materiel need statement (Department of the Army, 1978) requires that the 25-mm weapon system have a high first-round hit capability when armor-piercing discarding sabot with tracer (APDS-T) ammunition is used against a BMP-sized target (about 2 meters high) at ranges of 0 to 1400 meters. Because of this requirement, further research was required to focus on techniques, procedures, and equipment to improve the gunner's capability to achieve first-round hits with the 25-mm gun.

Current Work

The current BFV research was divided into two major areas: gunnery (this report) and other operational issues (Rollier et al.,1988c). Major directives in the gunnery effort were to:

- Continue analysis to identify problem areas in BFV gunnery;
- Continue the development, modification, and identification of techniques, procedures, and job performance aids to improve gunnery performance;
- Conduct field tests of developed/modified techniques and procedures;
- Recommend equipment modifications and improvements.

Problem analysis and product development focused on areas of gunnery related to first-round hits: alignment of the sighting systems (i.e., during boresighting and zeroing), range estimation, aiming, and conduct of weapon accuracy checks (e.g., backlash). The remaining sections of this report cover the following areas of gunnery:

- Boresight equipment (Section 2),
- Backlash (Section 3),

- Boresighting procedures (Section 4),
- Close-in boresight panel (Section 5),
- Zeroing (Section 6),
- Range estimation (Section 7),
- Aiming (Section 8),
- Auxiliary sight unit (Section 9).

Each section is divided into Background and Findings and Products. The latter is a summary and highlighting of work in each content area. More information can be obtained from referenced reports and products. Content areas without supporting literature are covered in greater detail in this report. The summary section at the end of the report lists developed/modified products that will be implemented into gunnery literature.

This report is primarily intended for BFV gunnery literature developers and course administrators. The section on boresight equipment also will be of interest to product managers in that area.

SECTION 2. BORESIGHT EQUIPMENT

Background

Proper sight alignment increases the accuracy of the 25-mm weapon system. Boresighting aligns the sight with the aiming point of the gun bore at the range of the boresighting target. When possible, boresighting should be followed by zeroing to refine sighting accuracy. The criticality of accurate boresighting in combat is expressed by a BFV battalion commander.

> The quality of the boresight directly relates to the capability to achieve first-round hits during the zero procedure. In fact, combat situations may preclude zeroing, making boresighting the only means of achieving combat critical first-round hits...in combat this problem will result in fewer kills and an inversely greater friendly vehicle casualty rate (Department of the Army, 1987).

Accurate boresighting requires accurate boresight equipment. Observations of zeroing conducted at Fort Benning indicated that current equipment was inaccurate. Gunners missed the zeroing target by substantial margins after boresighting. Target misses led to excessive ammunition expenditure as the gunner attempted to adjust the sight to the point of impact (Perkins, 1988b).

A sample of boresight equipment at Fort Benning was tested. None of 18 25-mm boresight kits passed accuracy standards specified by the BFV Gunnery field manual in effect at the time of testing (FM 23-1, 1983). The typical 25-mm adapter was less accurate than the typical telescope; however, some telescopes were extremely inaccurate. Data indicate that telescope accuracy decreases with use and abuse of the equipment (Perkins & Wilkinson, 1988b).

Other boresight equipment problems identified by ARI (Perkins, 1987a) included:

- The telescope accuracy test presented in the turret technical manual (TM 9-2350-252-10-2, 1986) did not concur with the BFV Gunnery field manual (FM 23-1, 1983) and the standard presented by the Armament Munitions Chemical Command (AMCCOM, 1985),
- No accuracy standard existed for the adapter,
- No accuracy standard existed for the 25-mm boresight kit (i.e., combined action of the telescope and adapter),
- The originally fielded 25-mm boresight adapter had design flaws and there was no plan for replacement,
- Inaccurate or unserviceable boresight equipment was not being reported to indicate that a problem existed in the field.

Problems with boresight equipment are indicated from a user's perspective by a BFV battalion commander:

> The 25-mm adapter has no published specifications for serviceability which are available to using units; maintenance support units and calibration teams do not know how to inspect or classify it...We therefore do not have the information or procedures to replace 25-mm adapters...Instructions in the kit recommend that the entire kit be sent back to the factory annually for recalibration. This procedure is not practical for units in Europe. No spare kits are available and the 25-mm adapter does not appear to be calibrated under this plan. The absence of a working inspection, repair, and replacement procedure for the 25-mm adapter is currently limiting us from achieving the vehicle's accuracy potential (Department of the Army, 1987).

Findings and Products

The overall objective was to develop/modify techniques, procedures, and accuracy standards that allow soldiers to identify the good and bad boresight equipment in their units. Work in the area of boresight equipment included the following:

- Development of a test for the 25-mm boresight kit,
- Development of tests to screen telescopes and 25-mm adapters,
- Development of a procedure to form accurate 25-mm boresight kits,
- Development of a user's handbook describing boresight equipment tests,
- Preparation of a quality deficiency report (QDR) for defective boresight equipment at Fort Benning,
- Presentation of issues related to potential improvements in boresight equipment.

The developed tests for the 25-mm boresight kit, the 25-mm adapter, and the boresight telescope are described in a handbook entitled Boresight Equipment Testing Procedures (Perkins, 1988d). The kit test is conducted by the crew or squad during boresighting. Kits not meeting standard are reported to the battalion. Master gunners then test the telescopes and adapters of kits that failed standards. Accurate components are formed into kits. QDRs (Standard Form 368) are completed for inaccurate and non-operational equipment; the handbook provides a step-by-step description for completing the QDR. Completion of the QDRs by units is critical because it indicates that a problem exists with boresight equipment. Report of equipment problems is the first step toward equipment improvement and replacement.

Telescopes and 25-mm adapters were tested at Fort Benning during the development of the accuracy tests. An accuracy standard of 0.5 mils was used for both telescopes and adapters. QDRs were prepared for inaccurate and defective equipment. These QDRs then were signed and submitted by the 1st Battalion, 29th Infantry Regiment. Ninety-six of 118 (81%) 25-mm adapters were inaccurate. Of 108 telescopes, 35 (32%) were inaccurate while another 22 (20%) had operational problems. The most common problems were water inside the telescope and an improperly assembled eyepiece probably resulting from unauthorized tampering.

Extensive testing of BFV boresight equipment revealed the need for improvement in a number of areas. Boresight equipment considerations are discussed in Appendix A.

SECTION 3. BACKLASH

Background

As the 25-mm gun is elevated or depressed, the aiming point of the sight(s) should change with the gun. Backlash is a weapon-system error caused by an imprecise linkage between the sight and gun. Backlash is measured by taking the difference in the aim of the gun barrel after laying the integrated sight unit (ISU) reticle, first from low to high, then from high to low. Therefore, backlash causes a difference in the gun's aim following gun lays that end in elevation and depression. The maximum allowed backlash between the ISU and 25-mm gun is 2 mils (Department of Army, 1980).

Backlash is understood in the armor community. The adverse effects of backlash are controlled using a standardized gun-lay procedure called the G-pattern (e.g., FM 17-12, 1977); it always ends in elevation. This gun-lay procedure does not eliminate backlash, but backlash is controlled so that sighting accuracy is not affected during boresighting, zeroing, and target engagement. Unlike manuals for tanks, the BFV Gunnery field manual (FM 23-1, 1986) and the turret technical manual for the BFV (TM 9-2350-252-10-2, 1986) do not mention backlash and use of a standardized gun-lay procedure to control it.

Findings and Products

The following work was conducted in the area of backlash:

- Developed a test for the user to measure backlash,
- Tested backlash of the ISU and auxiliary sight,
- Described the theoretical effects of backlash,
- Described how and when to control backlash,
- Developed modified boresighting and zeroing procedures to control for backlash.

A User Test for Backlash

The details of the developed test procedure for backlash are presented in Appendix B. Figure 1 summarizes the procedure. As shown, the upper-left hand corner of a boresight panel is used as the aiming point. With a 25-mm boresight kit installed, the gun is elevated to the aiming point (Block 1). The ISU reticle then is adjusted to the same aiming point using the boresight adjustment knobs (Block 2). The gunner uses the elevation hand wheel to depress the sight (Block 3) and return it to the aiming point by ending the gun lay in elevation (Block 4). The aim of the gun is checked using the boresight reticle (Block 5). The gunner uses the gun elevation handwheel to

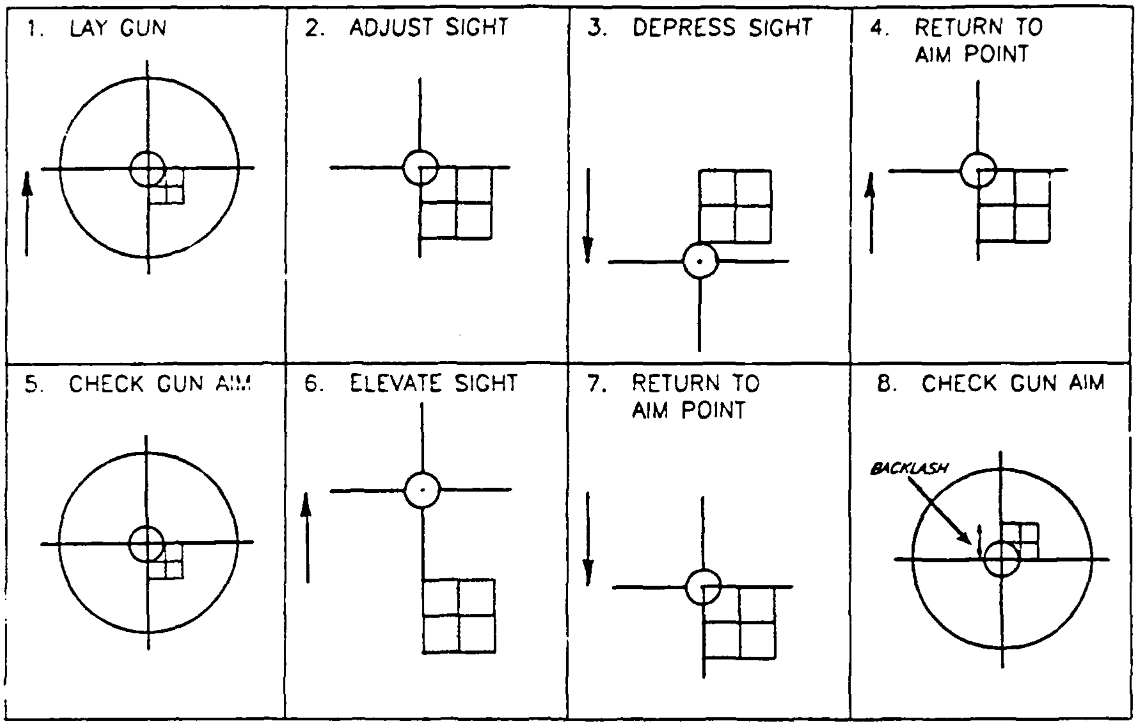


Figure 1. Procedure for testing backlash.

elevate the sight (Block 6) and then return it to the aim point using a gun lay ending in depression (Block 7). The aim of the gun is checked (Block 8) and compared to that previously observed (Block 5). The 2-mil circle of the boresight reticle is used to estimate the difference in the two aiming points of the gun; this is the measured backlash.

A specific backlash test procedure also was developed when using the close-in boresight panel described in the handbook Boresighting and Weapon Checks Using the Close-In Boresight Panel (Perkins & Roberson, 1988b). The backlash test should be conducted in the motor pool as one of several weapon checks in preparation for live fire.

Measured Backlash

Backlash was measured on eight ISUs and six auxiliary sight units on BFVs at Fort Benning. The testing procedure was similar to that just described. The distribution of backlash for these vehicles is presented in Table 1.

All ISUs had backlash that met the 2-mil standard. The average backlash was 0.53 mils while most ISUs (75%) had backlash of 0.5 mils or less. The average backlash for the auxiliary sight was 1.69 mils with backlash generally being between 1 and 2 mils; one sight was greater than 2 mils. Therefore, for the sample of vehicles tested, backlash requirements usually were met. However, backlash less than the standard can affect gunnery performance, so the following will discuss the effects of backlash on first-round accuracy and direct-fire adjustment.

Table 1

Number of ISUs and Auxiliary Sight Units Within a Given Range of Backlash

	Sight	
Backlash (mils)	ISU	Auxiliary
0.00 - 0.5	6	0
0.51 - 1.0	1	0
1.01 - 1.5	0	3
1.51 - 2.0	1	2
2.01 - 2.5	0	1

Theoretical Effects of Backlash

The direction of gun lay during sight alignment (i.e., boresighting or zeroing, whichever was performed last) affects first-round accuracy during target engagement. Table 2 presents the theoretical effects of backlash on first-round accuracy if backlash is present. The left column of Table 2 indicates the direction of gun lay during boresighting and/or zeroing. The second column describes the final direction of gun lay before target engagement. The third column shows the direction of round-impact error; it is assumed that the (a) correct range control setting is used and (b) ammunition dispersion is minimal.

Table 2

Direction of First-Round Error Based on Direction of Gun Lay During Sight Alignment and Target Engagement

Gun-lay direction before sight alignment	Gun-lay direction before target engagement	Direction of first-round error
UP	UP	NONE
UP	DOWN	LOW
DOWN	UP	HIGH
DOWN	DOWN	NONE

Table 2 indicates that if the direction of gun lay is the same during both sight alignment and target engagement (i.e., UP followed by UP or DOWN followed by DOWN), then backlash will not affect gunnery accuracy.

Table 3 shows how the direction of gun lay can affect direct-fire adjustment. This table is based on the need for adjustment because of a first-round miss, for any reason. As indicated by the table, there is no direct-fire adjustment error if both the initial and the adjusted gun-lay pattern are in the same direction.

Table 3

Direct-Fire Adjustment Error Based on Direction of Gun Lay During Firing of the First Round and the Adjusted Round

Gun-lay direction for the first round	Gun-lay direction for the adjusted round	Direction of error after adjustment
UP	UP	NONE
UP	DOWN	LOW
DOWN	UP	HIGH
DOWN	DOWN	NONE

How and When to Control Backlash

Tables 2 and 3 indicate that it is better to lay the gun in the same direction when aligning the sight, firing the sensing round, and adjusting fire. There are two possible directions to lay the gun, either up or down. Selection of one of these as the standardized direction for gun lay must consider the effects of accidently failing to lay the gun as intended.

If the sight is aligned using a gun-lay pattern ending in elevation, then accidental use of a gun lay ending in depression will produce low rounds. Alignment of the sight using a gun lay ending in depression followed by target engagement using a gun lay ending in elevation will produce high rounds. Since low rounds are easier to spot than high rounds, it is better to end the gun lay in elevation to control for backlash.

How far should the elevation be during the gun lay? The distance of elevation must be more than backlash so that all the slack or play is taken out of the system. Since the ISU is allowed 2 mils backlash, the recommended distance for the gun lay is 2.5 mils. This is the distance from the center dot of the ISU to the top of the center cross. Figure 2 illustrates the recommended gun-lay pattern. The same technique also can be used with the auxiliary sight because the upper arm of the center cross is also 2.5 mils long.

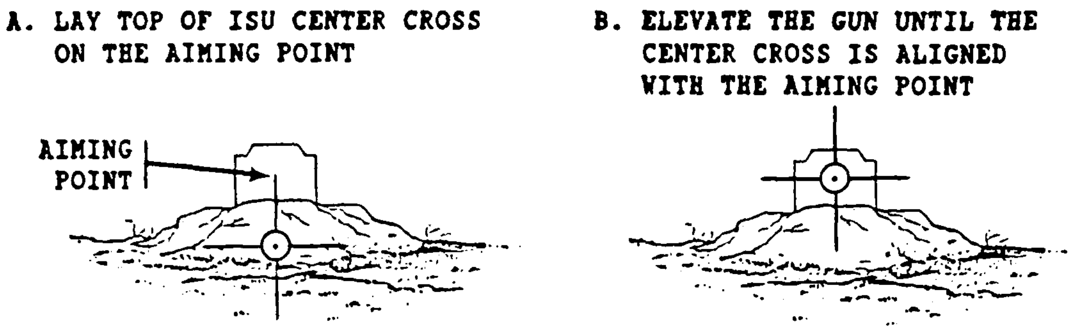


Figure 2. Recommended gun-lay pattern.

How much will backlash affect gunnery performance? As a general rule, if the same gun-lay pattern is not used during sight alignment and target engagement, then target hit probabilities will be dramatically reduced when the backlash (mils) is greater than one-half the exposed height of the target in mils. For example, more than 1 mil of backlash could cause target misses on a 2-mil high target. The following is an example of this.

A hypothetical example will illustrate the effect of 1.5 mils of backlash on direct-fire adjustment. Prior to target engagement, the weapon had been zeroed following a gun lay that ended in elevation. During target engagement, the gun lay ended in depression. As shown in Figure 3A, the first round hit the dirt about 1.5 mils below target center of mass. Consequently, the burst-on-target adjustment technique was applied (see Figure 3B) and the round passed the target about 1.5 mils above target center of mass. If direct-fire adjustment continued, rounds would hit 1.5 mils below and 1.5 mils above target center of mass on each successive firing, and the target would never be hit. This example illustrates that backlash under the 2-mil standard can affect gunnery accuracy.

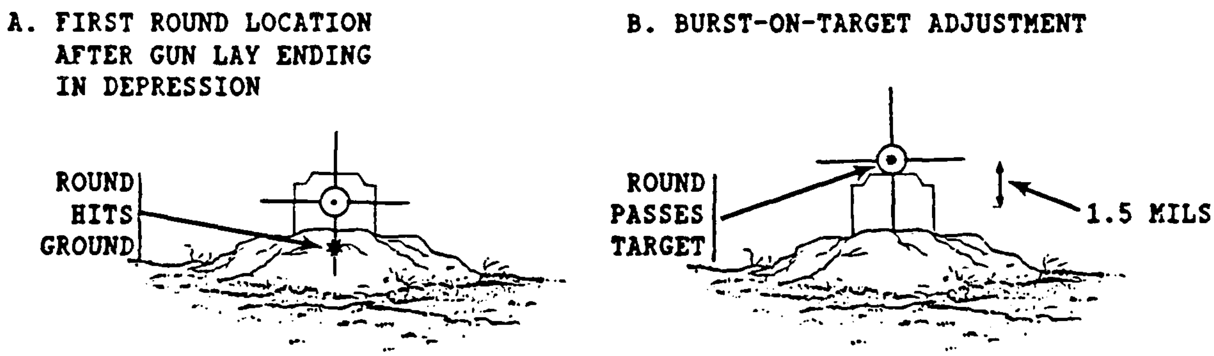


Figure 3. Effect of backlash on direct-fire adjustment.

As target range increases, it takes less backlash to affect accuracy because target size in mils decreases. Defilade targets have less exposed surface so even small amounts of backlash will affect gunnery performance. For these reasons, it probably is better to reinforce the practice of using a standardized gun-lay pattern under all conditions so that the gunner does not have to remember or calculate the conditions under which it should be used.

Controlling Backlash During Sight Alignment

Backlash is controlled by using a gun lay ending in elevation during sight alignment procedures (boresighting and zeroing) and target engagement. Developed modifications to boresighting and zeroing procedures are discussed in Sections 4 and 6, respectively.

SECTION 4. BORESIGHTING PROCEDURES

Background

As described in the turret technical manual (TM 9-2350-252-10-2, 1986), boresighting involves alignment of three turret weapons and four reticles. The primary tasks are to align:

- The ISU in day mode with the 25-mm gun,
- The auxiliary sight unit with the 25-mm gun,
- The coaxial machine gun with the ISU in day mode,
- The ISU in thermal mode with the 25-mm gun,
- The TOW launcher and TOW reticle.

An aiming point (e.g., a 90-degree corner) is selected as the common reference for aligning the sights and weapons. Boresighting is a two-man task. One crew member uses the boresight equipment to align the weapons while the other adjusts the sights from within the turret.

Analysis pinpointed problems related to boresighting techniques and procedures:

- The 25-mm boresight adapter frequently got stuck in the gun,
- The boresight telescope had parallax (i.e., change in the aim of the reticle when the user moved his head over the eyepiece),
- Only the telescope was tested for accuracy before boresighting,
- The gun-lay pattern prior to boresighting did not control for backlash,
- No procedure was available to re-focus the telescope when the crew member from the turret confirmed the aiming point of the gun.

Findings and Products

The following techniques and procedures were either developed, modified, or identified:

- Installation technique for the 25-mm adapter,
- Boresight telescope focusing procedure,
- Accuracy test for the boresight kit (telescope plus 25-mm adapter),

- Gun-lay procedure,
- Focusing procedure for aiming-point confirmation.

These developments were all incorporated into a proposed modification (using DA Form 2028-2) to the BORESIGHT WEAPON SYSTEMS task in the turret technical manual (TM 9-2350-252-10-2, 1986). The procedural modifications that were recommended are provided in Appendix C. The following summarizes the developments.

Installation Technique for the 25-mm Adapter

The turret technical manual says to "push 25-mm boresight adapter into 25-mm gun barrel until seated" (TM 9-2350-252-10-2, 1986, p. 2-207). Using this procedure may cause the adapter to stick or freeze in the gun barrel. Experience gained from extensive testing of boresight equipment revealed that the adapter did not stick if it was twisted while being slowly inserted (see step 1 of Appendix C).

Telescope Focusing Procedure

As shown in Figure 4, there are two focusing rings on the boresight telescope.

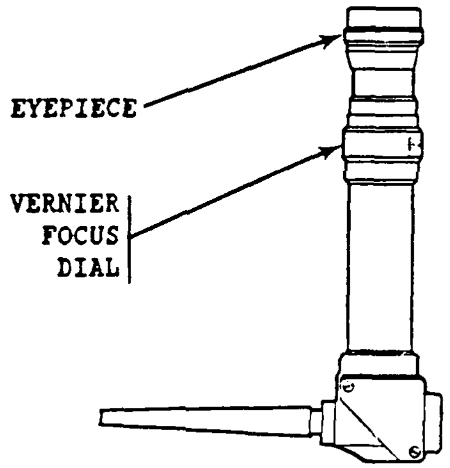


Figure 4. Focusing rings on the boresight telescope.

To focus the telescope, the turret technical manual says to:

(a) Look in eyepiece and move vernier focus dial up or down.

(b) Rotate eyepiece (TM 9-2350-252-10-2, 1986, p. 2-208).

Following this procedure may produce a clear, sharp picture, but parallax also may occur. For this reason, many telescopes have a label that provides different focusing instructions. The eyepiece is called the reticle focus while the vernier focus dial is called the target objective focus. The instructions read:

(a) Adjust reticle focus. Concentrate your eye totally on the reticle making the cross hairs clear and sharp.

(b) Now adjust target objective focus by rotating ring while looking at the reticle. Move your head slightly side to side until there is no apparent movement between the cross hair reticle and the target. Parallax is now eliminated.

Following this focusing procedure does eliminate parallax. Step 2 of Appendix C was written to concur with the thr label provided on the telescope. Step 2a was modified so that the user would hold the telescope to view the sky or some other evenly lit area. This keeps the user from focusing on objects other than the reticle.

Accuracy Test for the Boresight Kit

The turret technical manual describes a step in boresighting called CHECK ACCURACY OF BORESIGHT TELESCOPE; this is performed before sights and weapons are aligned. If the telescope fails the check, then another telescope is tried (TM 9-2350-252-10-2, 1986, p. 2-209).

The test procedure has three major problems. A telescope may fail the test because the 25-mm adapter does not fit properly with the telescope (Perkins & Wilkinson, 1988b). Secondly, the accuracy standard in the turret technical manual does not concur with that presented by AMCCOM (1985). More importantly, the test does not indicate the accuracy of the complete kit (Perkins & Wilkinson, 1988b). Accurate boresighting requires an accurate kit, not just an accurate telescope.

Figure 5 illustrates the test that was developed (see step 3 of Appendix C) to test the accuracy of the 25-mm boresight kit. With the eyepiece of the

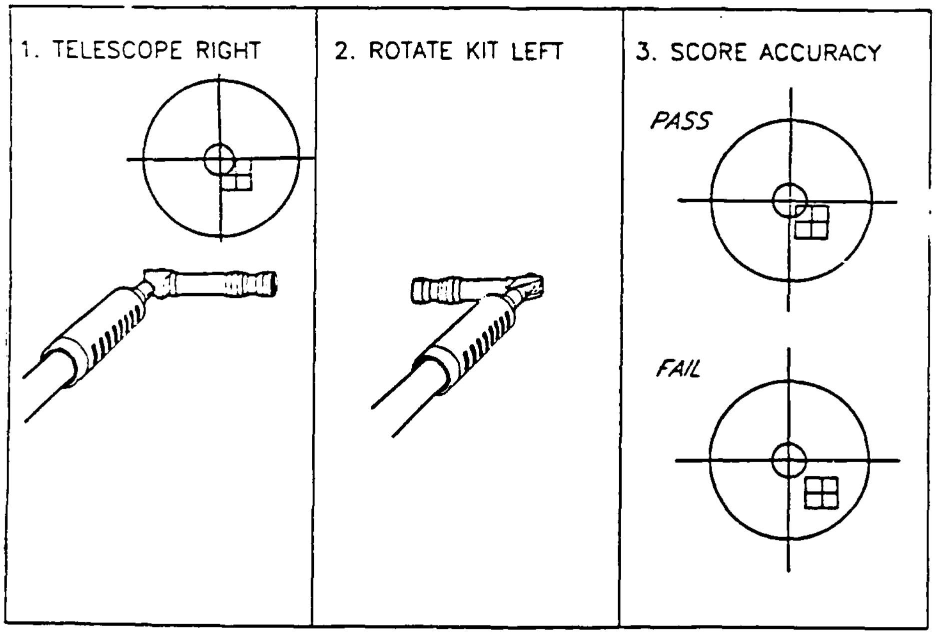


Figure 5. Accuracy test for the 25mm boresight kit.

telescope facing right, the boresight reticle cross hair is laid on the aiming point (e.g., upper left-hand corner of boresight panel). The entire kit is rotated 180 degrees. A pass is scored if the aiming point is on or within the 2-mil circle of the boresight reticle. The kit fails if the aiming point is outside the 2-mil circle.

Gun-Lay Pattern to Control Backlash

The turret technical manual does not specify the preferred direction of gun lay during boresighting. Figure 6 illustrates the developed procedure (step 4 of Appendix C) that requires the gun lay to end in elevation to control for backlash.

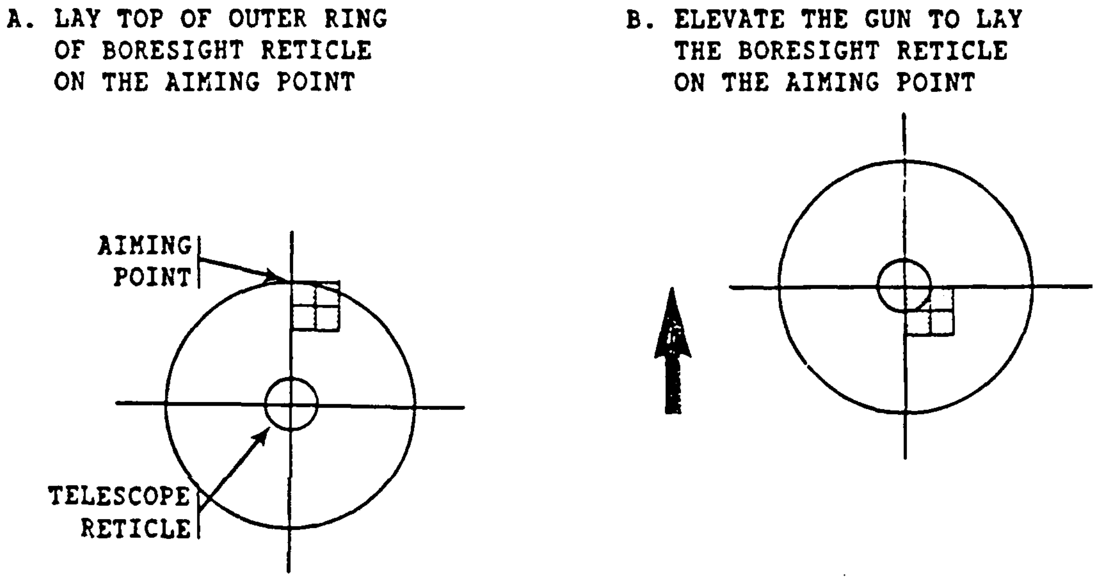


Figure 6. Boresight gun lay.

Confirm Aiming Point

After the 25-mm gun is laid on the aiming point, the gunner leaves the turret and confirms that the two crew members are using the same reference. This step is taught in BFV courses at Fort Benning, however, it is not included in the turret technical manual (TM 9-2350-252-10-2, 1986).

Step 5, Appendix C was developed to confirm the aiming point. If the telescope is out of focus during confirmation, then use the reticle focus knob to re-focus.

SECTION 5. CLOSE-IN BORESIGHT PANEL

Background

The BFV Gunnery field manual (FM 23-1, 1986) describes use of a close-in boresight panel (see Figure 7) to align turret weapons in a restricted or confined area like the motor pool. Use of this procedure would allow vehicles in Germany to be boresighted upon arrival at their general defensive position.

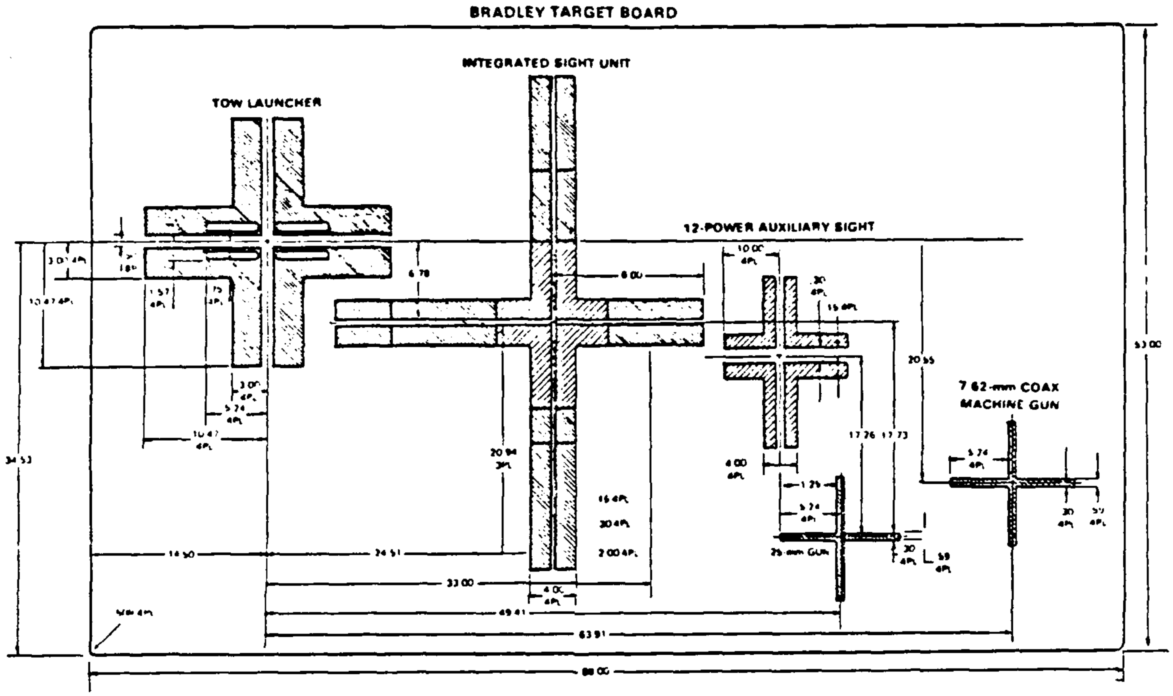


Figure 7. The close-in boresight panel (FM 23-1, 1986).

On the panel, each weapon and sight has a reference (aiming point) used for alignment. Problems identified with the close-in boresight panel include:

- Specification of target features and dimensions (see Figure 7) makes production difficult for units and training support units,
- Positioning of references on the panel does not allow convergence of the sight and weapon as with normal boresight procedures,
- No reference exists for the ISU in thermal mode,
- Illustration of auxiliary sight reference on panel is incorrectly positioned,
- No description of boresighting procedures is included for the thermal and auxiliary sights.

Findings and Products

Modifications in the design, use, and construction of the close-in boresight panel include:

- Redesigned reference points,
- A thermal reference point,
- Panel placement guidelines,
- Placement of references to allow convergence of the line of sight and weapon,
- Weapon accuracy checks,
- A handbook describing use and making of the panel.

On the modified panel, each sight and weapon has an aiming point or reference (see Figure 8). Reference crosses for the TOW launcher (TOW), 25-mm gun (25MM), ISU in the day mode (ISU), auxiliary sight unit (AUX), and coaxial machine gun (COAX) are labeled. The sixth reference is shaped like the letter "T" and made of metal to allow boresighting of the thermal sight.

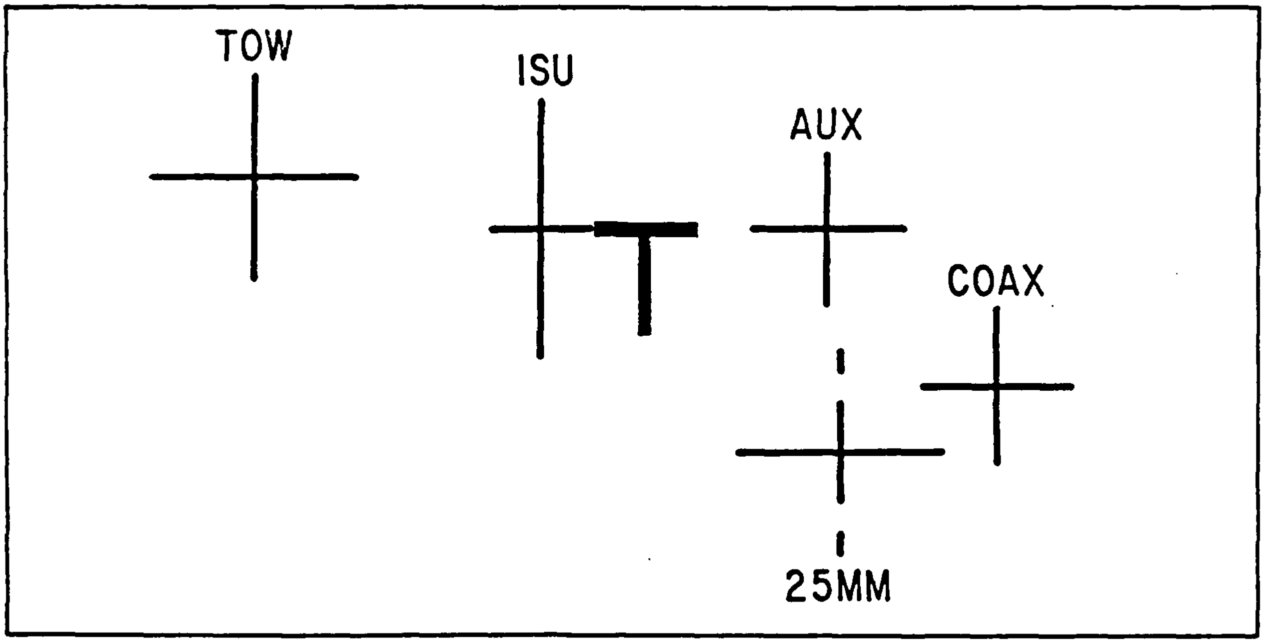


Figure 8. The modified close-in boresight panel.

The color of each reference provides good visual contrast with the reticle used to align the sight or gun. The TOW, 25MM, COAX, and AUX references are orange because they are viewed with a black reticle (boresight telescope). The ISU and "T" references are black.

Figure 9 shows an overhead view of the position of the panel and Bradleys during boresighting. Vehicles can be from 100 to 150 meters directly in front of the panel. BFVs also can be located to the right and left of the direct line of sight; 30 meters to the right or left for direct line distances from 100 to 120 meters and 50 meters in either direction for direct line distances from 120 to 150 meters. The panel can be placed from 0 to 25 meters above ground level. This allows placement on top of a building or on the side of a tower. Therefore, depending on the positioning of vehicles and the panel, it may be possible to boresight all vehicles within a battalion using only one panel.

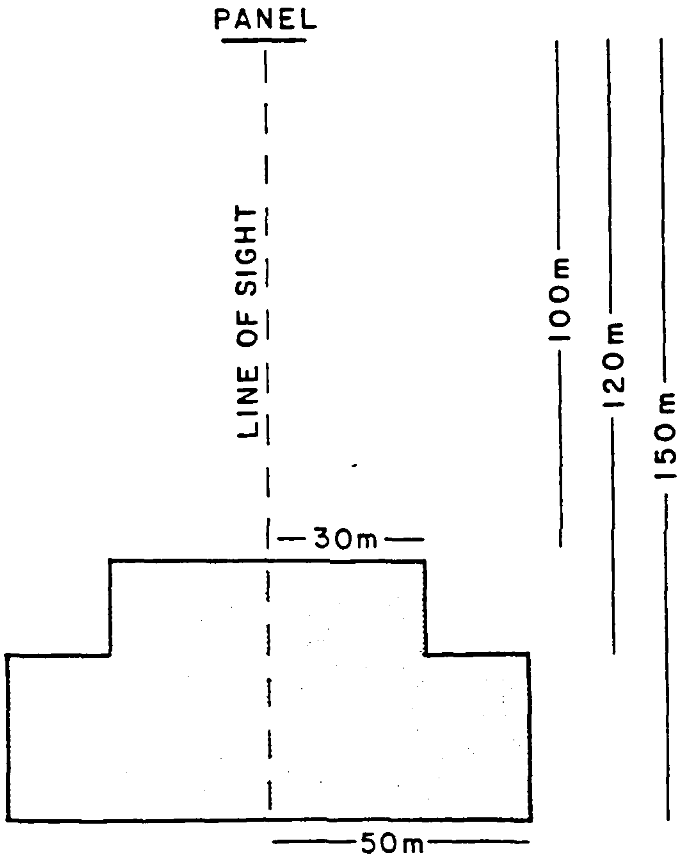


Figure 9. Positioning of vehicles (shaded area) and the close-in panel.

The panel was designed for use at distances of no less than 100 meters. Parallax (from head movement over the eyepiece causing aiming point changes) in the ISU may cause inaccurate boresighting at distances shorter than this.

The location of the references on the panel produces sight to weapon alignment (i.e., the lines of sight cross for the sight and weapon). Depending on the location of the vehicle in the designated vehicle area, the ISU and 25-mm gun will be aligned for ranges from 900 to 2000 meters. The coaxial machine gun and ISU will be aligned from 400 to 900 meters.

The alignment of the sights with the 25-mm gun applies only in the direction of deflection. For elevation, the ISU, "T", and AUX references have a line of sight that parallels that of the 25-mm gun (i.e., the line of sight for the sights remains higher than that of the gun). Because of "jump" of the gun when fired, use of this type of alignment procedure generally lessens the amount of sighting adjustment required during zeroing.

Procedures also were developed to conduct certain weapon checks using the close-in boresight panel. Checks are for backlash, equilibrator, drift, and boresight retention. It is recommended that these checks be conducted in the motor pool in preparation for live fire.

A handbook entitled Boresighting and Weapon Checks Using the Close-In Panel (Perkins & Roberson, 1988b) has been developed to describe panel placement procedures, boresighting procedures, weapon checks, and how to make the panel.

SECTION 6. ZEROING

Background

Zeroing aligns the sight and strike of the round at the range of the zeroing target. The BFV Gunnery field manual (FM 23-1, 1986) describes the following procedure for zeroing the 25-mm gun. After boresighting, zeroing is conducted on a 6-foot square, white panel at 1200 meters. The armor-piercing (AP) round is the preferred ammunition for zeroing because it is more accurate than the high-explosive (HE) and training (TP-T) ammunitions. A round is fired, and if a hit is observed in the 1-mil circle of the reticle, the weapon is zeroed. If the criterion is not met, a second and third round are fired with a check for accuracy after each round. If the weapon is not zeroed within three rounds, boresighting is repeated using a different boresight kit. A maximum of three more rounds are fired with a check of accuracy after each round. Organizational maintenance is notified if the weapon cannot be zeroed. If HE or TP-T is the only ammunition available, zeroing is conducted as described by AP ammunition (FM 23-1, 1986).

The turret technical manual (TM 9-2350-252-10-2, 1986) also describes a zeroing procedure for the 25-mm gun. Procedural differences compared to FM 23-1 are as follows. A truck is shown as the zeroing target. The round must strike in the center of the target, but no accuracy criterion is specified. Reboresighting is not recommended after firing of the first three rounds.

Previous (Perkins, 1987a) and current analysis and research indicated the following:

- Target design and placement did not optimize feedback of round impact,
- Alternative target distances were not recommended if one was not available at 1200 meters,
- Backlash was not controlled during gun-lay,
- Inaccurate boresight equipment led to excessive ammunition expenditure during zeroing,
- Reboresighting was not conducted after firing of three rounds,
- Zeroing was rarely conducted with six rounds or less and organizational maintenance was not notified,
- The zeroing criterion was too stringent for TP-T ammunition given its level of dispersion.

The bright 25-mm tracer is difficult to spot against the white background of the recommended target. The target also is positioned above ground level making it difficult to spot the precise location of short rounds. Boresight panels are not always located at 1200 meters.

Inaccurate boresight equipment often led to noticeable misses. As many as 6 to 15 rounds were expended, and frequently, the criterion was not met. This in part was due to the dispersion characteristics of TP-T ammunition. Figure 10 illustrates the 50 and 90 percent dispersion zones for AP and HE/TP-T ammunition when manufactured to maximum allowed levels of dispersion (Perkins, 1988c).

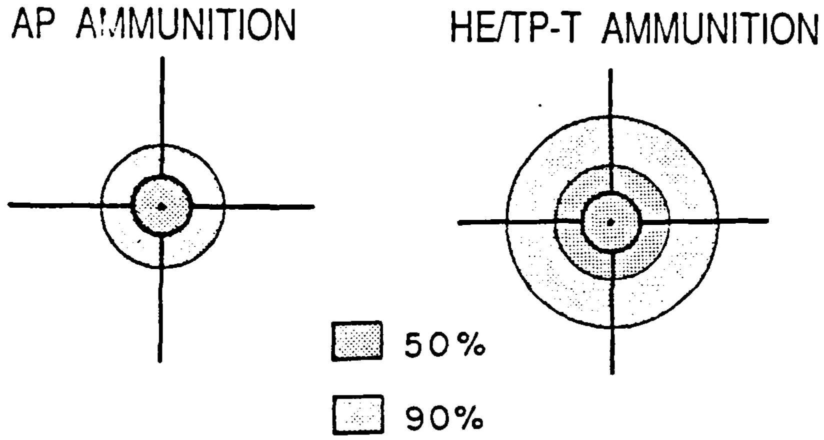


Figure 10. Dispersion zones for 25mm ammunition.

The dispersion zones are overlaid on an ISU reticle for purposes of illustration. The outer edge of the 50% dispersion zone marks the area where half of the rounds should hit. For TP-T ammunition, less than half of the rounds would hit within the 1-mil circle of the ISU indicating that the current accuracy standard is too stringent.

Findings and Products

The following were developed in the area of zeroing:

- Zeroing procedure for TP-T ammunition,
- Zeroing score sheet for TP-T ammunition,
- Weapon checks included as part of zeroing procedure,
- Concept of zeroing on a dirt berm,
- Zeroing score sheet for the coaxial machine gun.

Zeroing Procedure for TP-T Ammunition

Based on concepts developed in previous work (Perkins, 1987a), a procedure was developed for zeroing with TP-T ammunition. The procedure, included in Appendix D, has been recommended (using DA Form 2028) as an addition to the turret technical manual (TM 9-2350-252-10-2, 1986). A summary of the rationale for the developed procedure is as follows.

The recommended target is a frontal silhouette of a BMP (FM 25-7, 1985, p. B-33). The target is positioned at ground level and has sensors for recording target hits. This target design is recommended over the square white panel (FM 23-1, 1986) for the following reasons:

- Dark color (OD green) provides a better background for spotting bright tracers,

- Target placement at ground level allows short rounds to hit the dirt to provide feedback,

- Size of the target allows easy application of the developed accuracy criteria,

- The zeroing target is the same type of target engaged during training and qualification,

- BMP silhouettes usually are equipped with hit sensors.

During step 2 (Appendix D) of the developed procedure, the gun lay ends in elevation as a control for backlash (see Section 3). Zeroing is conducted with the turret and gun in power mode; however, firing is conducted using the trigger (manual) switch on the handwheel; this prevents accidental movement of the gun or turret during zeroing (step 3, Appendix D).

Because of the dispersion characteristics of TP-T ammunition (Perkins, 1988c), sighting adjustments are made using the center of a three-round shot group (Perkins, 1987a). Two criteria must be met before the weapon is zeroed.

- The shot-group center is located on or under the turret of the target,

- At least two of three target hits are obtained.

The size of the criterion zone used for the shot-group center is based on mathematical analysis of the accuracy of TP-T ammunition (Perkins, 1988c) and live-fire testing (Perkins, 1987b). The ideal criterion zone for zeroing is to have the shot-group center located in an imaginary 2-mil diameter circle surrounding the center dot of the ISU (Perkins, 1987a). This circle superimposed on the ISU and the recommended target are illustrated in Figure 11.

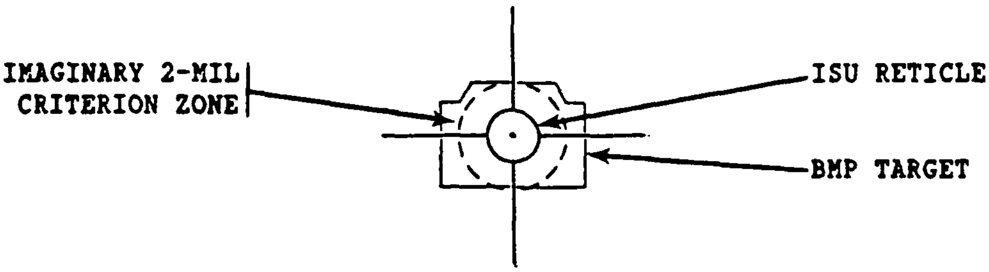


Figure 11. Ideal 2-mil criterion circle for TP-T zeroing.

Since the 2-mil circle is only imaginary, that portion of the target that closely matches its size (i.e., the turret and everything under it) was selected as the criterion zone of the target (see Figure 12).

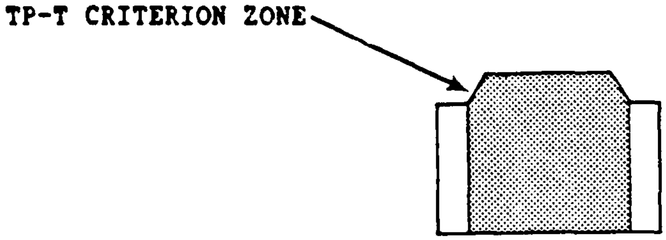


Figure 12. TP-T criterion zone (shaded) on a BMP target.

The requirement for two of three hits is a control for ammunition dispersion. The criterion is based on mathematical predictions of hits and misses based on ammunition dispersion (Perkins, 1988c) and live-fire data (Perkins, 1987b). As illustrated in Section A of Figure 13, it is possible to have the shot-group center in the criterion zone of the target but miss the target. Section B shows a shot-group center that meets both zeroing criteria.

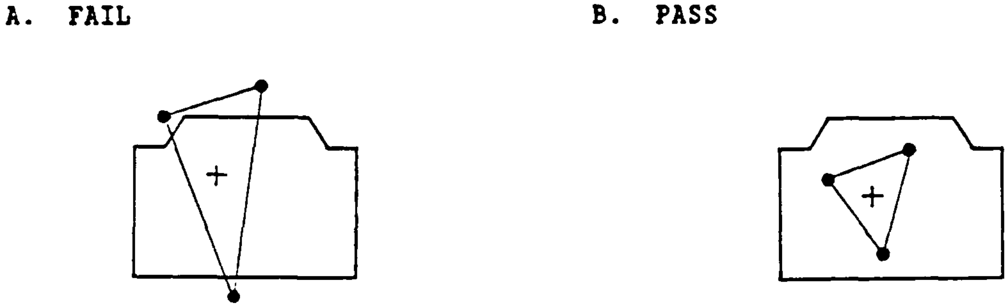


Figure 13. Sample shot groups.

Zeroing is conducted with TP-T ammunition using a standardized score sheet (see Appendix E). The score sheet (a) allows the gunner and commander to confirm their observation of round-impact location and (b) provides a record of weapon system and crew performance.

The score sheet is important for shot-group analysis when a vehicle fails to meet the two out of three hit requirement. Examination of shot groups from different vehicles can help diagnose the cause of failing the criterion. If all or most vehicles have wide shot groups, the ammunition probably has excessive dispersion. If one or a few vehicles have less than two hits when the shot-group center is in the criterion zone, then a weapon system problem (e.g., excessive barrel erosion) may exist; organizational maintenance must be notified.

The procedure allows the firing of two shot groups. Research indicates that with accurate boresighting, the BFV can be zeroed with TP-T ammunition using either one or two shot groups. A minimal sighting adjustment (usually 1 mil or less) is required after the first shot group, and in 90% of the cases, the weapon was zeroed on the second shot group (Perkins & Wilkinson, 1988a; Perkins, 1987b).

Zeroing on a Dirt Berm

Feedback on location of impact is critical for accurate zeroing. Steel-on-steel is the ideal feedback, but range restrictions often make it difficult to use steel targets. An alternative is dirt. A dirt berm produces a very clear signature when hit with a 25-mm round. One possible berm is 6 feet high with a 4 inch (or larger) light-colored object (e.g., rock, can) positioned about 2 feet from the bottom (see Figure 14). The object is used for aiming.

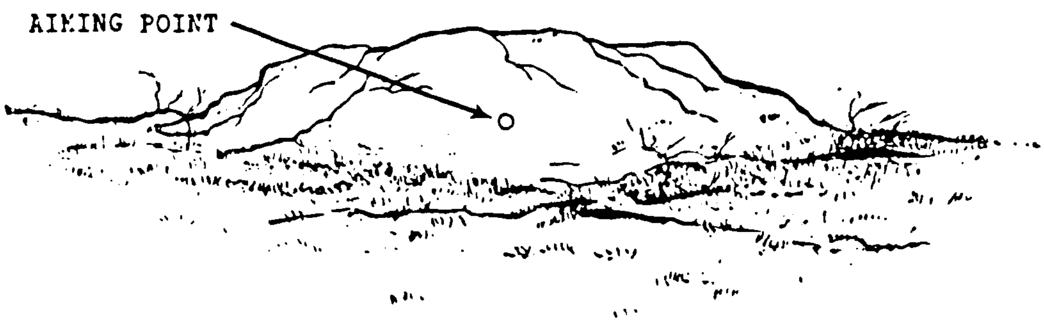


Figure 14. Dirt berm for zeroing.

Score Sheet for Zeroing the Coaxial Machine Gun

For the coaxial machine gun, knobs on the weapon are used to make elevation and deflection adjustments based on the location of the center of a burst. To do this, the crew must know (a) which way to turn the knobs and (b) the number of clicks. A score sheet was developed to facilitate this. Appendix E contains a blank score sheet while Figure 15 illustrates that portion used (a) to plot the center of burst and (b) to determine the type and direction of adjustment. The "X" marks a sample center of burst; the AZ KNOB must be turned 5 clicks clockwise and the EL KNOB must be turned 2 clicks counterclockwise.

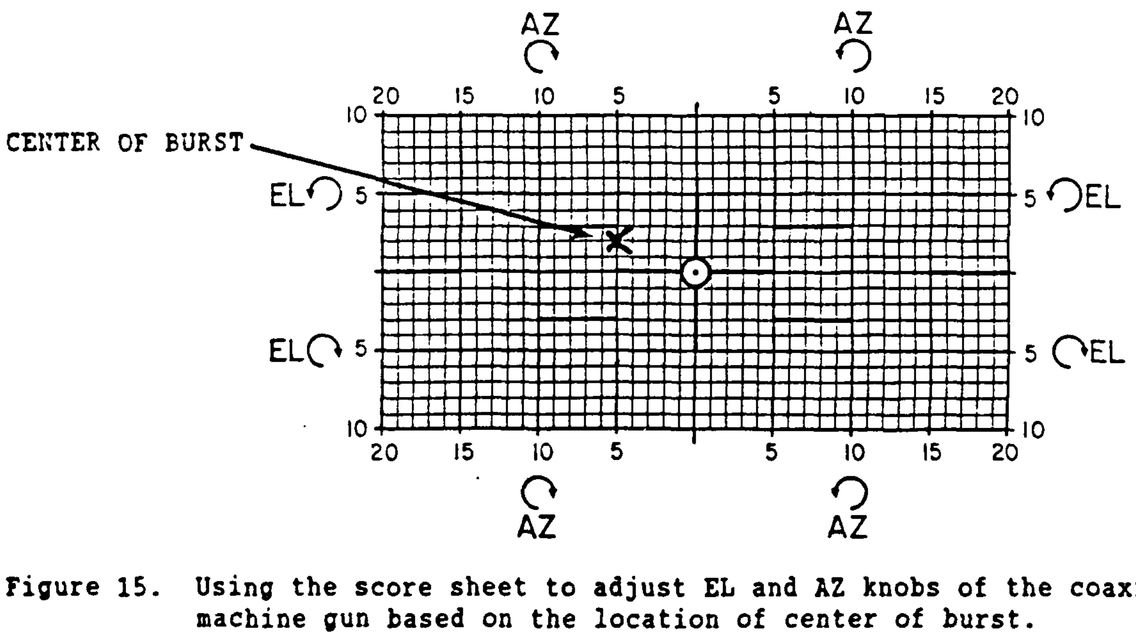


Figure 15. Using the score sheet to adjust EL and AZ knobs of the coaxial machine gun based on the location of center of burst.

SECTION 7. RANGE ESTIMATION

Background

When the ISU is used to engage targets with the 25-mm gun or the 7.62-mm coaxial machine gun, the gunner uses a range control knob to set target range into the fire-control system. Range can be set at 200-meter intervals from 0 through 3000 meters. The non-ballistic reticle then can be aimed at target center of mass (moving targets will require a lateral adjustment in aim).

Inaccurate range estimation will result in incorrect range control settings and target misses depending on factors including the amount of ranging error, height of target, and type of ammunition. The AP round has a flatter trajectory than HE ammunition. As a result, ranging errors will cause more high and low rounds with HE compared to AP ammunition. Figure 16 illustrates the trajectory curves for AP and HE ammunition when a center of mass aim is used on a 2-meter high target (shaded area). The circled number on each curve indicates the range control setting. A target hit occurs where the curve crosses the shaded area (Perkins, 1987a).

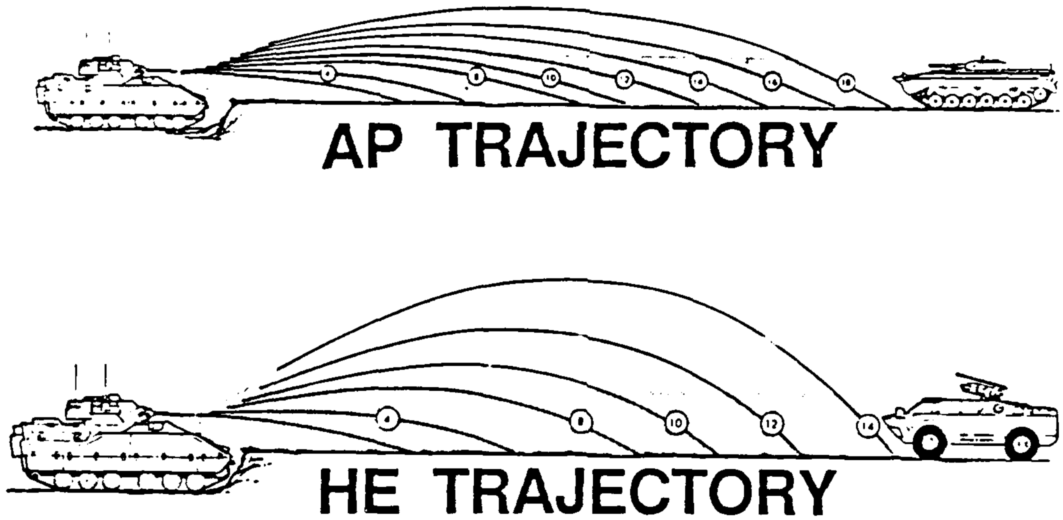


Figure 16. Trajectory curves for AP and HE/TP-T ammunition with varied range control settings (Perkins, 1987a).

As shown above, a range control setting of 12 for AP ammunition produces a high hit probability from 0 through 1400 meters. A setting of 16 allows a target hit from 1400 through 1750, approximately the range for tracer burn out. Therefore, two range control settings for AP ammunition usually will provide the correct elevation of the round from 0 meters through tracer burn out (Perkins, 1987a).

For HE ammunition, a range control setting of 8 provides target hits from 0 through 900 meters. Past 900 meters, range estimation must be within 100 meters to insure a high probability of first-round hits on vehicular targets (Perkins, 1987a).

Range does not have to be set in the fire-control system for the TOW missile system. The gunner aims target center of mass, fires, and maintains the aiming point until impact. However, it is critical to estimate maximum engagement ranges accurately for the TOW missile. Engagements beyond the maximum engagement range result in loss of control of the missile and unnecessary expenditure of the limited number of missiles stowed on a BFV.

The BFV Gunnery field manual (FM 23-1, 1986) classifies range estimation into unassisted (naked eye) and assisted (binoculars and stadia) methods. The unassisted technique is based on the soldier's ability to estimate range without the aid of special equipment. Past experience and training are critical factors in the accuracy of this technique. The three assisted techniques will be summarized below.

The ISU reticle has a horizontal ranging stadia used on BMP-sized targets. As shown in Figure 17 taken from the BFV Gunnery field manual (FM 23-1, 1986), the bottom of the target is positioned on the horizontal line. The sight is moved until the top of the BMP touches the slanted line of the stadia. Range is read or interpolated from the numbered scale (numbering is not shown in the figure).

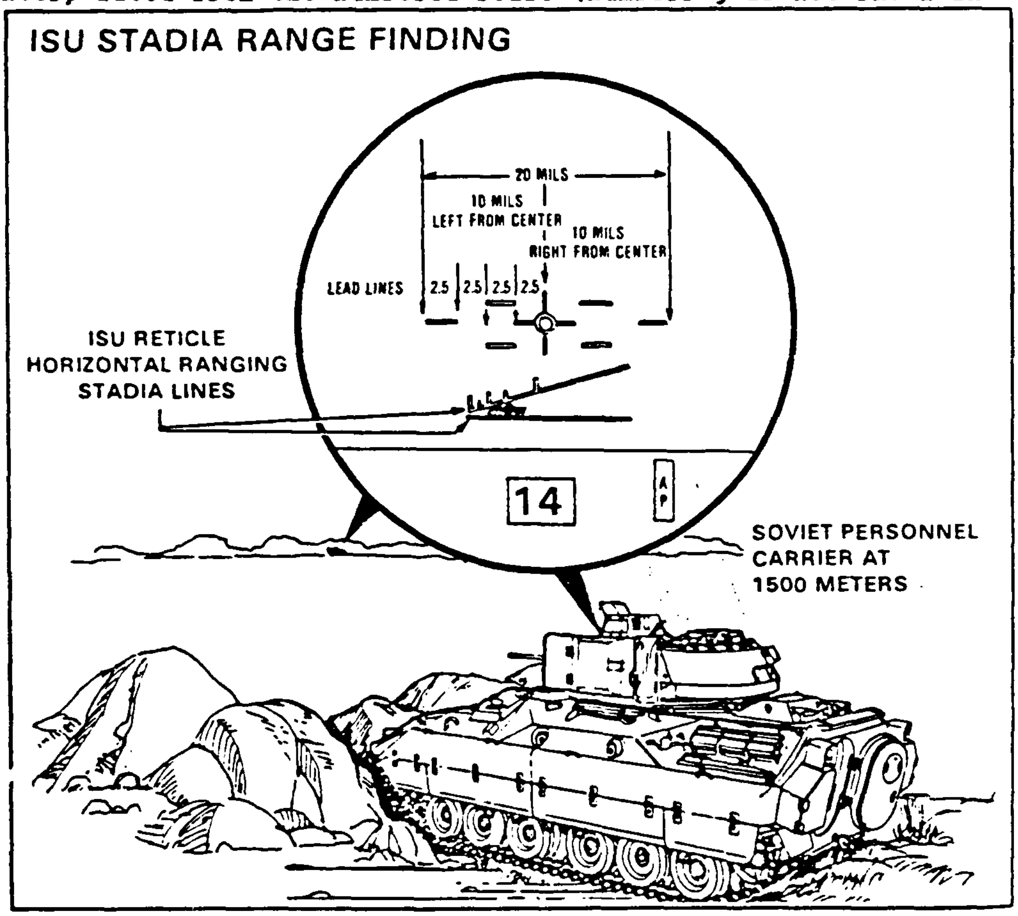


Figure 17. Use of the horizontal ranging stadia (FM 23-1, 1986, p. 4-10).

The second assisted method requires use of binoculars. Target size is measured using the mil-scale of the reticle. If target dimensions are known, the WORM formula (width over range times mils) can be used to calculate target range. Since it is difficult to remember target dimensions and the WORM formula, a quick reference table is included in the BFV Gunnery field manual (see Figure 18). Targets are categorized into four groups. After measuring target width, target group in the table is determined, and the range is read from the table.

NOTE: This table is a quick reference for determining the range of Threat vehicles at various ranges. The vehicles have been grouped and the sizes of the vehicles have been averaged.

GP 1 (BMP, BTR-152, BTR-60P, OT-62 & 64, MTLB & TAB 72)												
	6.5	6	5.5	5	4.5	4	3.5	3	2.5	2	1.5	1
FLANK 7.0 METERS	1000	1200	1200	1400	1600	1800	2000	2400	2800	3500	4700	7000
FRONT 2.8 METERS	0	0	0	0	0	0	800	1000	1200	1400	1800	2800
GP II (T-72, T-64, T—62, T—55, T-54, PT-76, ZSU 23-4)												
	6.5	6	5.5	5	4.5	4	3.5	3	2.5	2	2.5	1
FLANK 6.5 METERS	1000	1000	1200	1200	1400	1600	1800	2200	3600	3300	4300	6500
FRONT 3.35 METERS	0	0	0	0	0	0	1000	1000	1200	1600	2200	3350
GP III (BMD, BRDM)												
	6.5	6	5.5	5	4.5	4	3.5	3	2.5	2	1.5	1
FLANK 5.5 METERS	800	800	1000	1000	1200	1400	1600	1800	2200	2800	3650	5500
FRONT 2.35 METERS	0	0	0	0	0	0	600	800	1000	1200	1600	2400
GP IV (HIND-D HELICOPTER)												
	15	14	13	12	11	10	9	8	7	6	5	4.5
FLANK 17.25 METERS	1200	1200	1400	1400	1600	1800	2000	2200	2400	2800	3400	3800
	6.5	6	5.5	5	4.5	4	3.5	3	2.5	2	1.5	1
FRONT 6.9 METERS	1000	1200	1200	1400	1600	1800	2000	2400	2800	3400	4600	6900

Figure 18. Quick reference table for range estimation (FM 23-1, 1986, p. 4-9).

The auxiliary sight has a ballistic reticle that can be used to range to vehicular targets. The stadia uses the width of the target (frontal or flank angle) to estimate range. This will be discussed in Section 9.

Research (Perkins, 1987a; Perkins & Roberson, 1988a) indicated the following problems with the assisted methods/procedures used for range estimation:

- The horizontal ranging stadia is not calibrated as taught,
- Illustration on the use of the horizontal ranging stadia is not clear (see Figure 17),
- The scale on the binocular reticle makes it difficult to take accurate measurements,

- No technique exists to determine target angle (frontal or flank) when using the binoculars and auxiliary sight,

- Certain portions of the quick reference table in the BFV Gunnery field manual have range values of 0 meters.

Findings and Products

Work in the area of range estimation produced the following:

- Modified procedure for using the horizontal ranging stadia,

- Improved illustration on using the horizontal ranging stadia,

- Procedure for determining target angle (frontal or flank),

- Modified quick reference table for range estimation,

- Improved guidelines on ranging with the binocular reticle,

- Use of the ISU reticle to measure target size,

- Simplified guidelines for setting the range control knob (see Background; Perkins, 1987a).

Horizontal Ranging Stadia

If the stadia is used as recommended (FM 23-1, 1986), it should be possible to determine the range from the height of a BMP. The height of a BMP varies with the version and the weapon attached to the turret, but a commonly referenced height is 2.15 meters (DDB-1100-255-80, 1980: FM 100-2-3, 1984). Measurements taken of the stadia on vehicles indicates that it was designed for a target about 1.6 meters (5 feet, 3 inches) high (Perkins, 1987a; Perkins & Roberson, 1988b). As a result, use of the stadia as recommended in FM 23-1 (1986) would produce about a 25% underestimation of range.

Given the current design of the stadia, it was recommended (Perkins, 1987a) that the top of the hull be used as the reference for ranging to a BMP (see Figure 19) or similar sized object (a fully exposed soldier). The stadia can be used on frontal and flank angles of the target.

Determination of Target Angle

If the target is in defilade, the accuracy of the horizontal ranging stadia is reduced. In this case, it may be necessary either to (a) measure target width (in mils) with a reticle and use the quick reference table or (b) use the auxiliary sight (see Section 9). Use of either technique requires determination of target angle (frontal or flank). The previously developed technique (Perkins, 1987a; Perkins, 1988b) for determining target angle is illustrated in Figure 20.

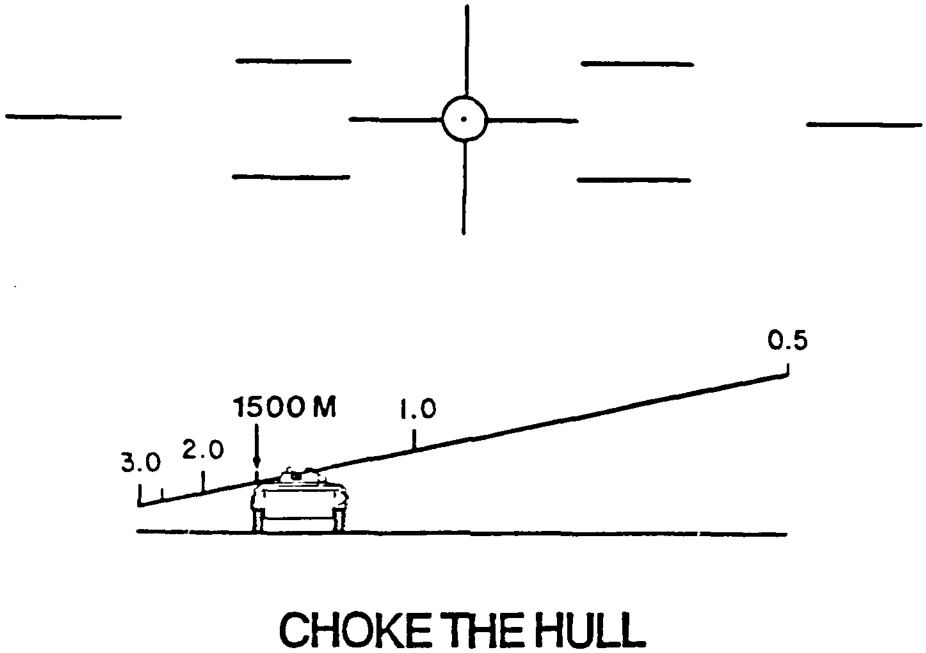


Figure 19. Recommended technique for using the horizontal ranging stadia.

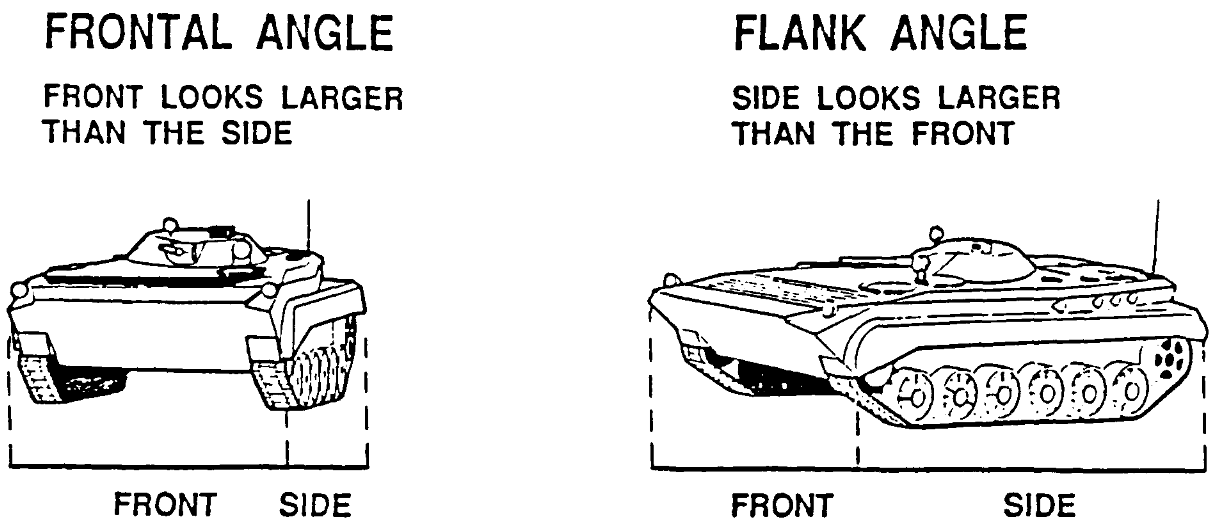


Figure 20. Determination of target angle.

Target angle is determined by comparing how much of the front and side of the vehicle is seen. A target is a frontal angle if its front looks larger than the side. For a flank angle, the side looks larger than the front (Perkins, 1987a).

When measuring the size of frontal angles of a target, measure only the front slope (i.e., front portion of the vehicle). Measure the entire width of the vehicle for flank angles. These measuring techniques are illustrated later in this section.

The Quick Reference Ranging Table

The table was modified (see Figure 21). Comparison of Figures 18 and 21, indicate that all zeros have been eliminated in the modified version. It also combined Group I and Group II vehicles into a single group called Group I. The dimensions of the target in the modified Group I (3 meters wide, 6.75 meters long) are intermediate to the dimensions included in the original Group I (2.8 meters wide, 7 meters) and Group II (3.35 meters wide, 6.5 meters long). The modified Group dimensions are very similar to those of a BMP (2.94 meters wide, 6.74 meters long) while at the same time providing a good representation of other vehicular targets in the group.

NOTE: This table is a quick reference for determining the range of Threat vehicles at various ranges. The vehicles have been grouped and the sizes of the vehicles have been averaged.

GP 1 (BMP, TANK, BTR, ZSU, OT, MT-LB & TAB)									
TARGET WIDTH (MILS)	5	4.5	4	3.5	3	2.5	2	1.5	1
FLANK 6.75 METERS	1400	1600	1800	2000	2300	2800	3400	4600	6900
FRONT 3.0 METERS	600	700	800	900	1000	1200	1600	2000	3000
GP 2 (BMD & BRDM)									
TARGET WIDTH (MILS)	5	4.5	4	3.5	3	2.5	2	1.5	1
FLANK 5.5 METERS	1200	1300	1400	1600	1800	2200	2800	3800	5500
FRONT 2.35 METERS	400	500	600	700	800	1000	1200	1600	2400
GP 3 (HIND-D HELICOPTER)									
TARGET WIDTH (MILS)	22.5	20	17.5	15	12.5	10	7.5	5	2.5
FLANK 17.25 METERS	800	900	1000	1200	1400	1800	2400	3600	7000
TARGET WIDTH (MILS)	5	4.5	4	3.5	3	2.5	2	1.5	1
FRONT 6.9 METERS	1400	1600	1800	2000	2400	2800	3600	4600	6900

Figure 21. Modified quick reference table for range estimation.

The flank data of Group IV (Hind-D Helicopter) also was modified. Increments of measurement were changed from 1 mil to 2.5 mils. The ISU reticle, and the auxiliary sight reticle have lead lines divided into 2.5 mil intervals. This modification allowed estimation of longer distances for helicopters.

Improved Use of the Binocular Reticle

When measuring target size using the binoculars, the currently recommended technique is to use that portion of the reticle marked at 10-mil increments (FM 23-1, 1986). Measuring targets to the nearest 0.5 mil requires the soldier to break the 10-mil increment into 20 imaginary parts. This is difficult to do for targets that are only several mils wide.

There are gaps in the horizontal line of the binocular reticle that can be used to obtain accurate measurements of target size. The drawing of the binocular reticle in FM 23-1 does not show these gaps, so a scaled illustration of the reticle was produced. Figure 22 shows two gaps in the horizontal line of the reticle near the "cross hair".

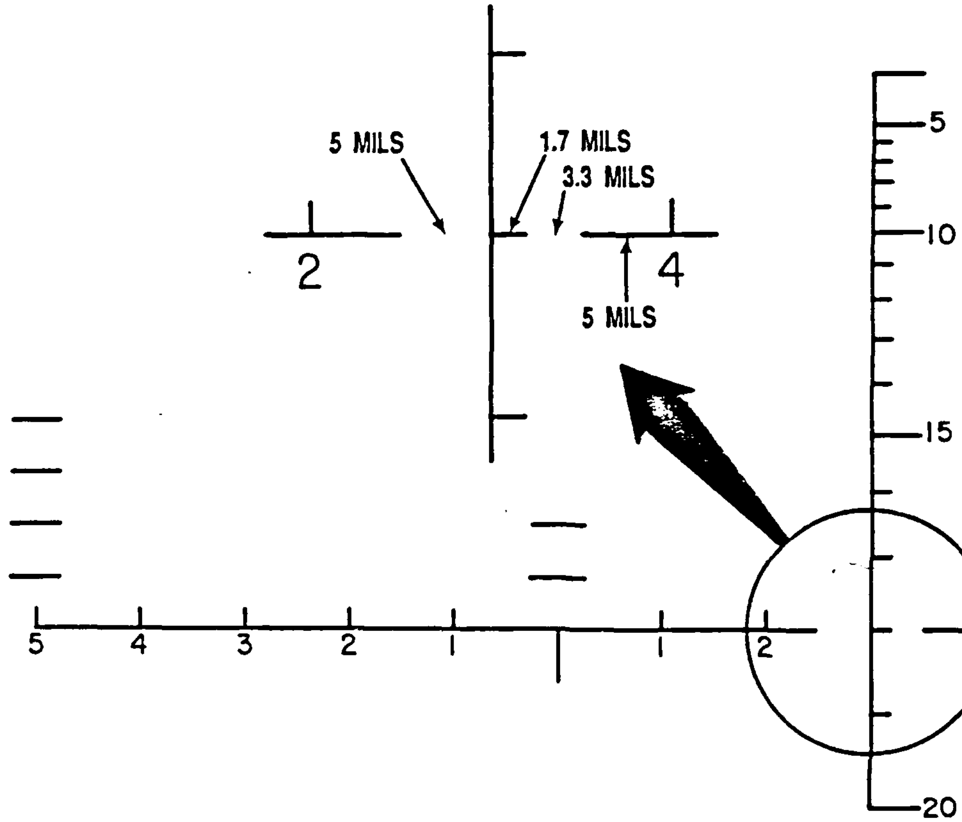


Figure 22. Improved illustration of the binocular reticle.

Figure 23 shows a possible technique to measure the size of frontal and flank angles of a BMP. The 5-mil gap to the left of the cross hair is used. Note that measurements for frontal angles include only the front slope of the vehicle.

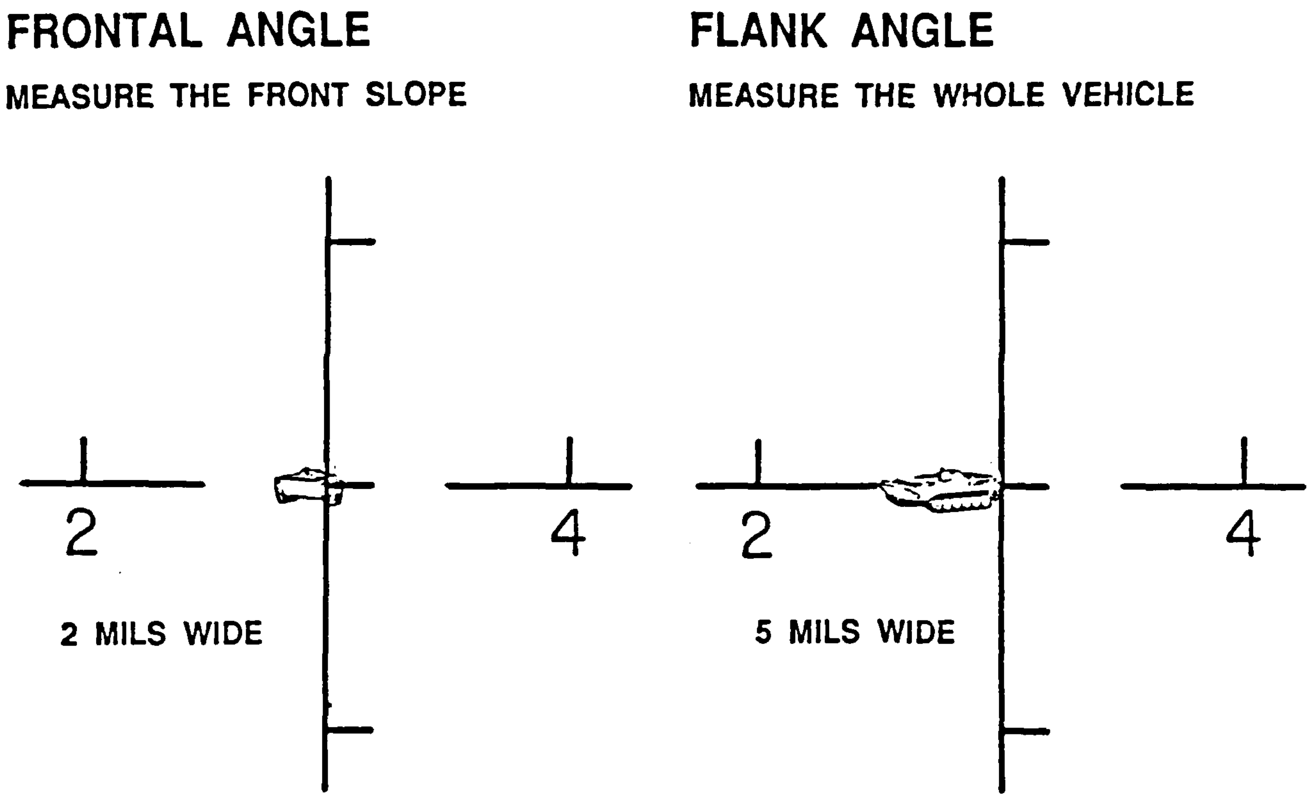


Figure 23. Range estimation on frontal and flank angles with the binoculars.

Range Estimation with the ISU Reticle

The center cross of the ISU reticle also can be used to measure target width for purposes of range estimation. The ISU has several advantages over the binocular reticle: (a) higher magnification, (b) mil markings with smaller increments, (c) easier to hold steady, and (d) only minor aiming adjustments must be made for target engagement after ranging.

The center cross of the ISU is 5 mils wide (see Figure 24). After target width is measured, the quick reference table is used to estimate range.

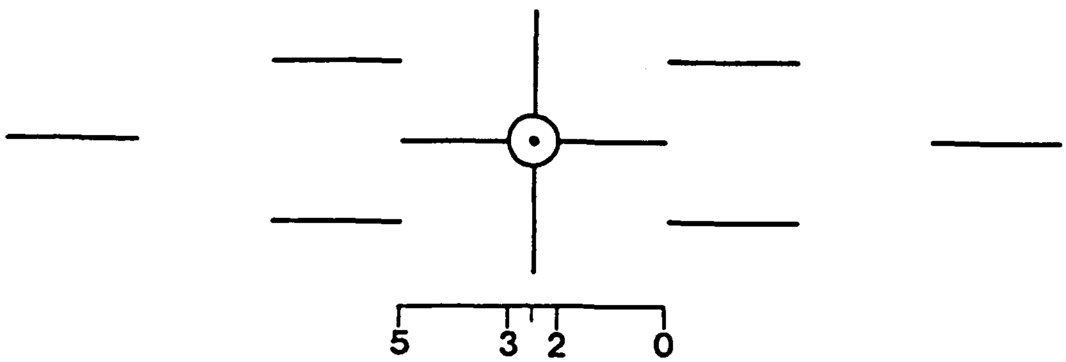
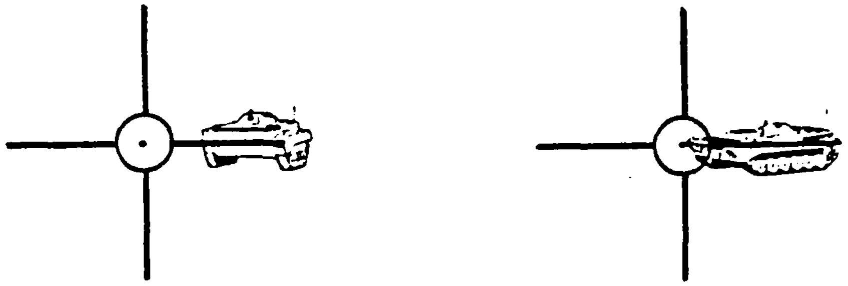


Figure 24. Distance in mils across the ISU center cross.

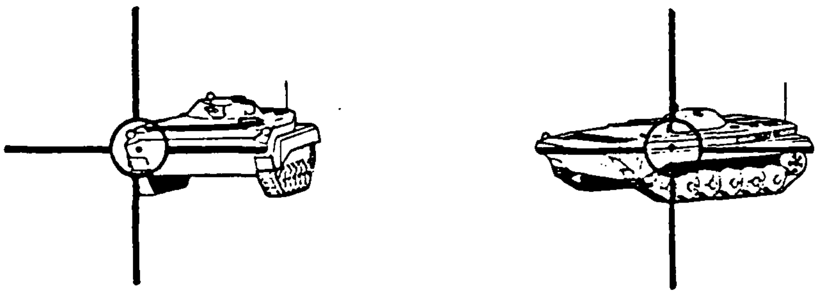
For frontal angles of a vehicle, measure only the front slope (see Figure 25). As indicated by Group I data of the quick reference table (see Figure 21), the BMP at a frontal angle in Figure 25 is at a range of 2000 meters. For flank angles, measure the entire width of the target (see Figure 25).



FRONTAL (1.5 MILS) FLANK (2.5 MILS)

Figure 25. Measuring target width with the ISU.

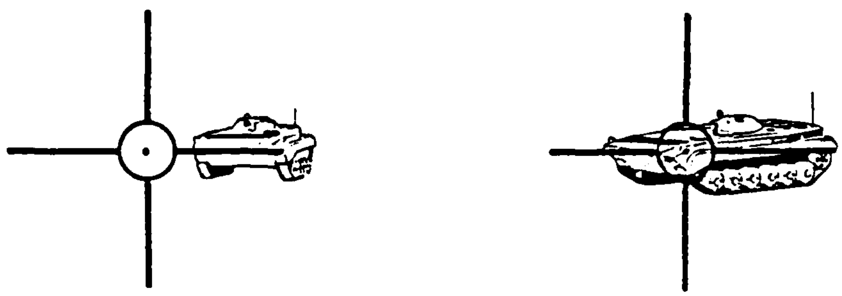
The ISU reticle can be used to determine critical target ranges for BFV gunnery. There is a high probability of obtaining a first-round hit on a BMP at 0 through 1400 meters when a range control setting of 12 is used. The size of frontal and flank angles of a BMP at 1400 meters are shown in Figure 26.



FRONTAL (2 3/4 MILS) FLANK (5 MILS)

Figure 26. Size of a BMP at 1400 meters.

Figure 27 shows the size of a BMP at the range of tracer burn out for AP ammunition.



FRONTAL (1 3/4 MILS) FLANK (4 MILS)

Figure 27. Size of a BMP at 1800 meters.

The ISU reticle can be used to estimate maximum effective range for the TOW 2 (see Figure 28). For frontal angles of a target, position the bottom of the tank on the bottom on the center circle of the ISU. To be within maximum effective range, the target must be 0.75 mils (i.e., the top of the target is between the center dot and the top of the circle) or higher as shown in Figure 28. For flank angles, position the rear of the target on the end of the center cross, and measure to the front edge of the hull. The target is within maximum effective range when the target is 2 mils or longer. Since the 25-mm reticle is not available for a vehicle that has the TOW missile system selected, a "buddy" or section vehicle could estimate the range using the ISU and communicate the information to the TOW-ready vehicle.

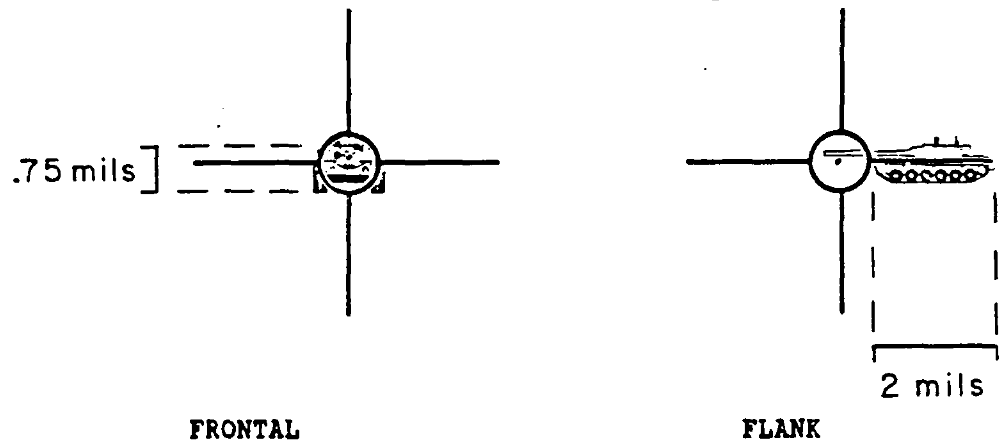


Figure 28. Size of a tank within maximum effective range (3750 meters) for the TOW 2.

SECTION 8. AIMING

Background

In a modern, fast moving battlefield, moving targets and firing on the move will be the norm rather than the exception. If either the BFV or the target is moving, the aiming point must be offset from target center of mass to increase the probability of first-round hits with the 25-mm gun.

When a stationary BFV engages a moving target with AP ammunition, the BFV gunnery field manual (FM 23-1, 1986) recommends use of a 2.5-mil lead from target center of mass. A 5-mil lead is recommended for HE ammunition. Small vertical adjustments in aim are made when the target is approaching or moving away from a stationary BFV. When the target is approaching, aim at the center base of visible mass, and if the target is fleeing, aim at the top of target, center of mass.

When the BFV is firing over its flank (side), movement of the vehicle affects the projectile as it leaves the muzzle. If the target is stationary, the aiming point is the leading edge of the target opposite the direction of travel of the Bradley (see Figure 29).

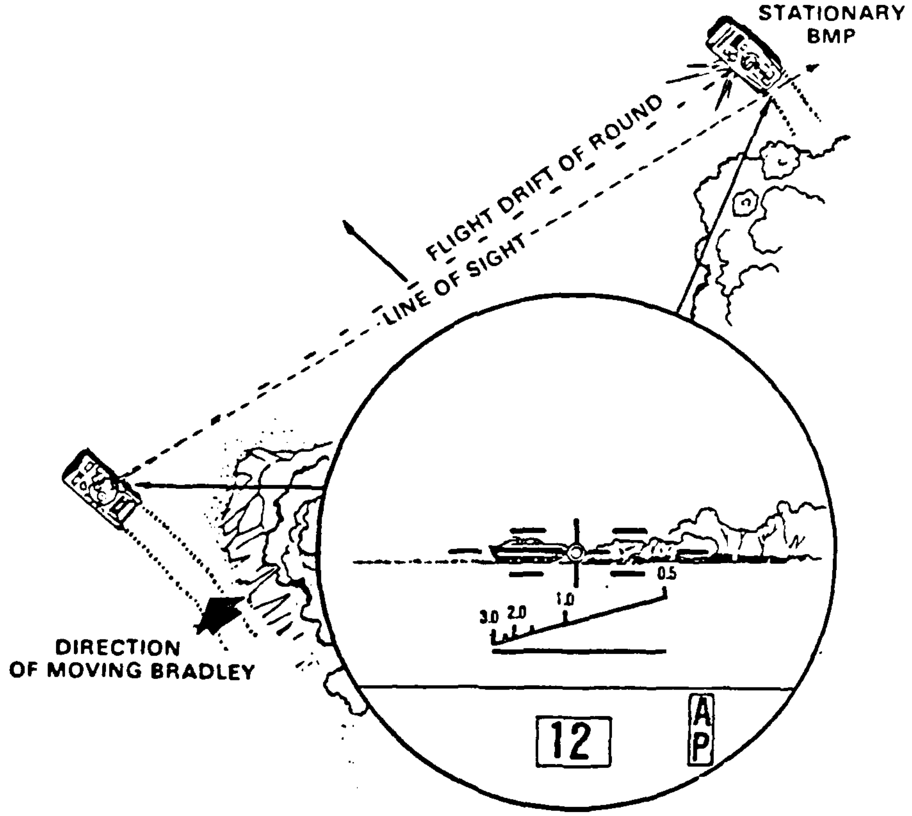


Figure 29. Aiming rule for firing over the flank at a stationary target (FM 23-1, 1986, p. 5-14).

If both the BFV and target are moving parallel to each other and in the same direction, a center of mass aim is used. If the BFV and target are moving parallel but in opposite directions, normal target lead plus lateral motion (caused by BFV movement) must be considered when aiming (FM 23-1, 1986).

Mathematical analysis (Perkins, 1988a; 1987a) indicated the following problems with recommended aiming rules:

- The 2.5 mil AP-lead rule for moving targets underestimates the required lead,
- The 5 mil HE-lead rule for moving targets underestimates the required lead,
- The aiming rule when firing over the flank at the stationary target underestimates the requirements,
- There is insufficient guidance on aim when the BFV and target are traveling parallel but in opposite directions.

Findings and Products

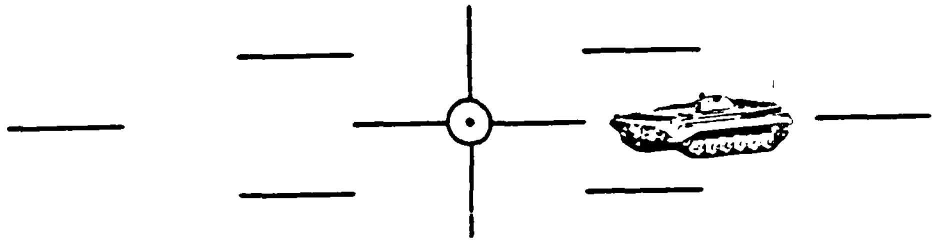
Three aiming rules were developed for target engagement with the 25-mm gun (see Figure 30) based on mathematical predictions on the amount of lead required against moving targets (Perkins, 1988a). Developed rules are expressed as short, simple, and common terms that describe the sight picture. The most commonly used rule is called GAP LEAD because the target is centered in the gap of the ISU reticle. Gap lead is equal to a 5-mil lead from target center of mass. The other two rules are used under special circumstances discussed latter. For FAR LEAD, the farthest lead line of the reticle is centered over the target. For NOSE LEAD, the center dot of the reticle is aimed at the leading edge of the target.

Findings and products in the area of aiming are divided into (a) fundamental aiming rules and (b) advanced principles and techniques. The former covers fundamental aiming rules that all gunners should know before firing the 25-mm gun. Advanced principles and techniques presents important information for instructors, and experienced gunners and crews.

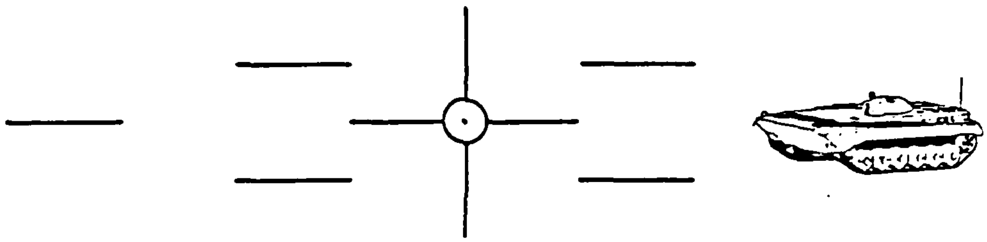
Fundamental Aiming Rules

When engaging a target that is moving perpendicular to the gun, the gunner must aim in front of (i.e., lead) the target. The amount of lead depends on flight time of the round, target speed, and the angle of approach by the target (Perkins, 1988a). Lead rules are applied for moving targets classified as flank angles (the side appears larger than the front of the target). When using AP ammunition against a moving target, use GAP LEAD (see Figure 30A). (GAP LEAD was called BOX LEAD in previous reports (Perkins, 1988a; 1987a).

A. GAP LEAD



B. FAR LEAD



C. NOSE LEAD

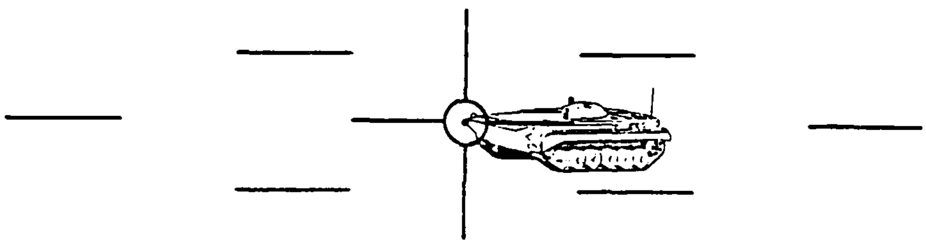


Figure 30. Aiming rules applied on a flank angle of a BMP.

Moving target engagements with HE ammunition require greater lead than with AP because of a longer flight time for HE ammunition. Figure 31 shows FAR LEAD applied on a BRDM engaged with HE ammunition (Perkins, 1988a; 1987a).

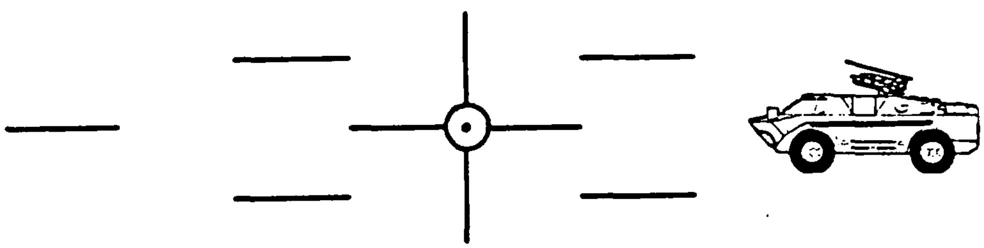


Figure 31. FAR LEAD applied on a BRDM engaged with HE ammunition.

When a moving BFV is firing over its side at a stationary target (e.g., the BFV is ambushed), the motion of the vehicle pulls the round away from the line of sight. The gunner should use GAP LEAD for both AP and HE ammunition. When firing over the left side of the Bradley, aim 5 mils to the left of target center of mass (see Figure 32) (Perkins, 1988a; 1987a).

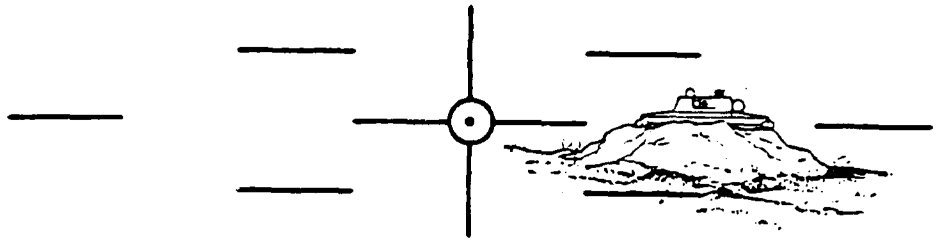


Figure 32. GAP LEAD applied when the Bradley fires over its left flank at a stationary BMP.

If the the BFV is moving and engaging a target moving parallel but in the opposite direction, then apply FAR LEAD (see Figure 33).

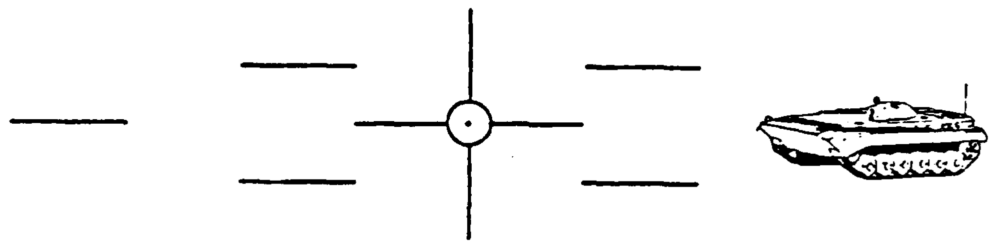


Figure 33. FAR LEAD applied when the target and Bradley are moving in parallel and opposite directions. The BFV is firing over its left flank.

Advanced Aiming Principles and Techniques

Firing on the move. One of the most difficult concepts to teach is the aiming rule for firing over the flank while moving. The following will describe the principles of aiming while firing on the move. A full understanding probably will occur only after practical exercise.

Firing over the flank of a moving BFV at a stationary target is similar to using a lead rule on a moving target from a stationary Bradley. When the target is moving left relative to a stationary BFV, the gunner must traverse left, and aim with the ISU center dot 5 mils to the left of target center of mass (i.e., gap lead as shown in Figure 30). Therefore, the gunner must traverse left and lead left.

When the BFV is moving forward and firing over its left flank at a stationary target, the gunner must traverse left to maintain a steady aim on the target. To hit the target, the gunner must also lead to the left (i.e, gap lead as shown in Figure 32). Therefore, the gunner must lead left while traversing left.

In summary, the direction of lead is the same as the direction of turret movement. When traversing left, lead left. When traversing right, lead right. If in doubt about the amount of lead to use, apply gap lead.

Improving first-round hits on moving targets. Direct-fire adjustment for stationary targets usually is in the direction of elevation. Moving target engagement may require adjustment in both elevation and deflection. Adjustment for moving targets would be simplified if correction was limited to only one direction. This can be done by minimizing the requirement for an elevation correction. Engage targets at 1400 meters or less with a range control setting of 12.

The ISU reticle can be used to quickly determine target ranges of 1400 meters or less (see Figure 34). To determine when the target is at 1400 meters or closer, apply GAP LEAD on a flank angle of a moving target. Do not fire unless the target fills the gap of the reticle (i.e., BMP is 5 mils wide).

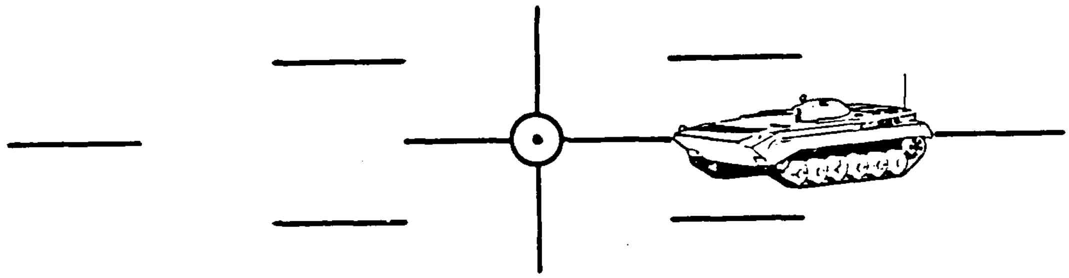


Figure 34. A flank angle of a BMP at 1400 meters fills the gap.

Aiming, direct-fire adjustment, and fire commands. The lead rules for AP and HE were developed based on a target speed of 20 miles per hour (32 km/hr). Targets may move slower or faster than this, so direct-fire adjustment in deflection may be required when recommended lead rules are used.

The adjustment technique recommended in the BFV Gunnery field manual (FM 23-1, 1986) is to give the deflection correction in mils. This may be an acceptable technique for minor adjustments, if the gunner can remember the mil relationship of the reticle. The following is a possible way to make quicker and larger changes in aim. It involves use of common aiming points. If gap lead is applied on a moving target and rounds hit behind the target, then apply far lead. If gap lead is applied and rounds hit in front of the target, apply nose lead (see Figure 30C).

The lead rule when firing on the move was based on a BFV speed of 20 miles per hour. Nose lead and far lead can be used when the BFV is moving slower or faster than 20 miles per hour, respectively. NOSE LEAD applied while firing over the left flank is shown in Figure 35.

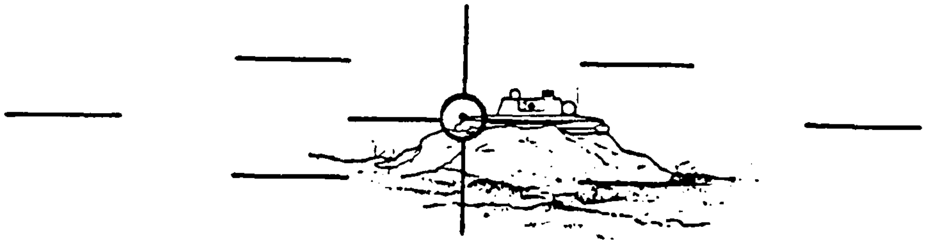


Figure 35. NOSE LEAD applied when firing over the left flank of a slow moving Bradley.

SECTION 9. AUXILIARY SIGHT

Background

The auxiliary sight unit is used to engage targets with the 25-mm and 7.62-mm guns when the ISU is inoperative. The sight is mounted with a pivotal eyepiece to permit use by either the gunner or commander. The 6-power sight has a ballistic reticle designed for both AP and HE ammunition (see Figure 36).

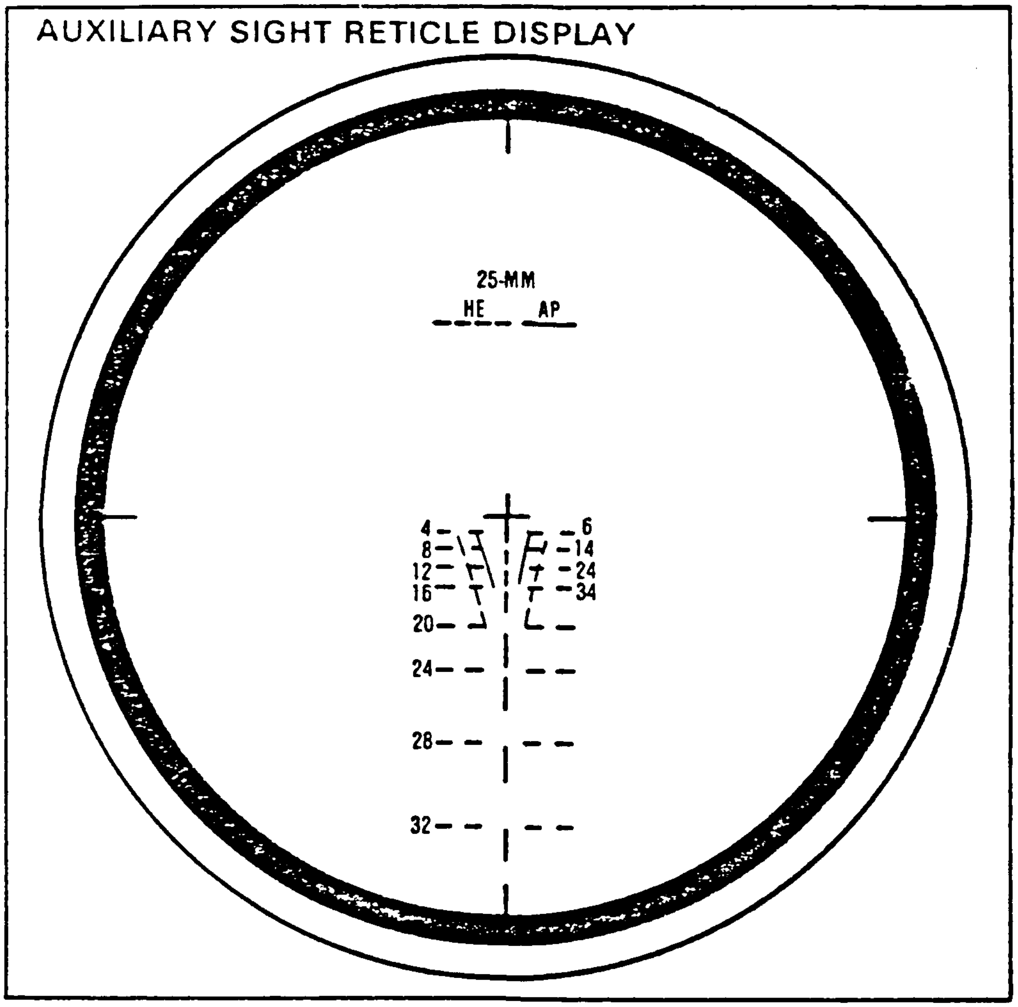


Figure 36. Auxiliary sight reticle display (FM 23-1, 1986, p. 4-11).

The BFV Gunnery manual describes how to range frontal and flank angles of vehicular targets using the HE and AP ranging stadia on the reticle (FM 23-1, 1986). The turret technical manual describes how to boresight the auxiliary sight unit with the 25-mm gun (TM 9-2350-252-10-2, 1986).

Analysis of literature available to the user on the auxiliary sight unit indicated that:

- Illustrations of the sight were inaccurate and features were unlabeled,
- Ballistic characteristics of the reticle were not explained,
- No zeroing procedure was mentioned,
- No description was given on how to engage targets with the 25-mm gun,
- Recommended procedure providing ballistic corrections for firing the coaxial machine gun was inaccurate.

Findings and Products

Work in the area of the auxiliary sight unit developed the following:

- A scaled drawing of the reticle to use as the basis for constructing training aids and materials,
- A 4-foot by 4-foot square wooden mock up of the reticle with transparent targets to illustrate ranging and aiming,
- Description of the reticle,
- Ranging and aiming procedures,
- Zeroing procedures.

Developed techniques for using the auxiliary sight will be described. This information will be included in a handbook that will be developed.

The Reticle

Parts of the auxiliary sight reticle are labelled in Figure 37. The boresight cross is used to align the reticle and gun during boresighting. The stadia (AP and HE), range scales (AP and HE), and range lines are used on BMP-sized targets (a) to estimate range and (b) to provide the correct gun elevation for target engagement.

Figure 38 shows the ranges indicated by the reticle. The HE range scale is marked every 400 meters from 0 through 3200 meters; each range mark represents 200 meters and the distance between each mark also is 200 meters. For AP ammunition, each range line and the distance between each line represents more than 200 meters (see the figure for the exact distance).

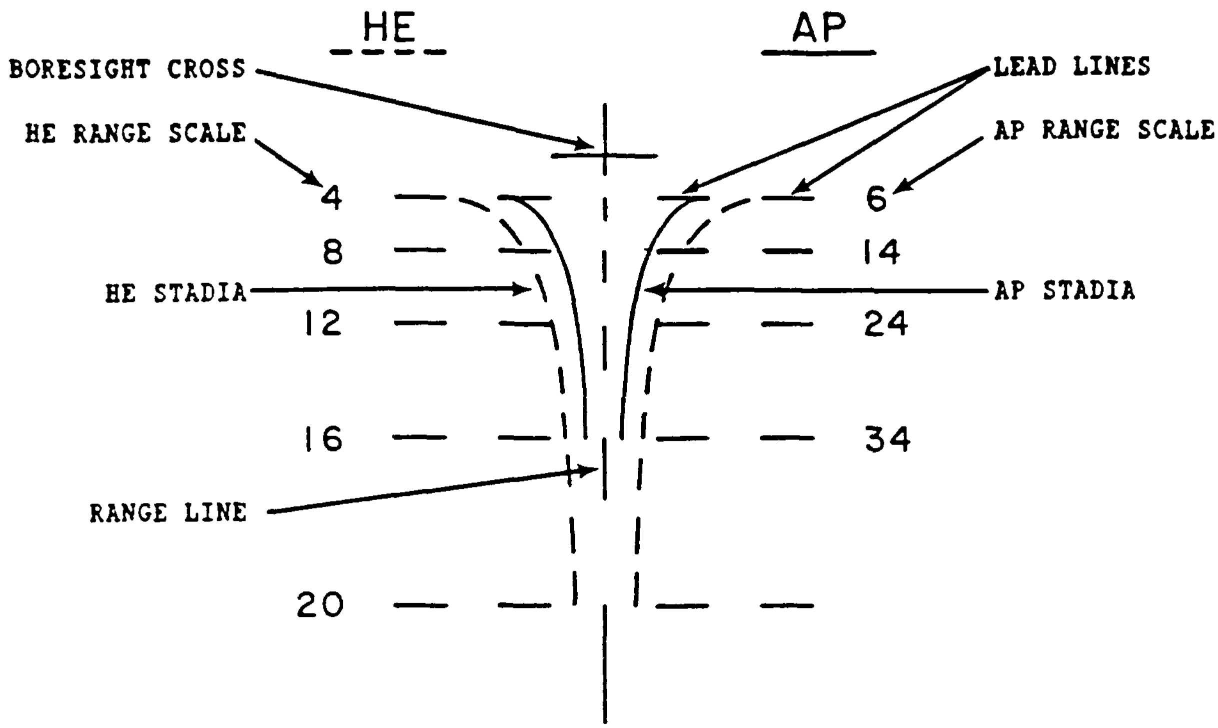


Figure 37. Features of the auxiliary sight reticle.

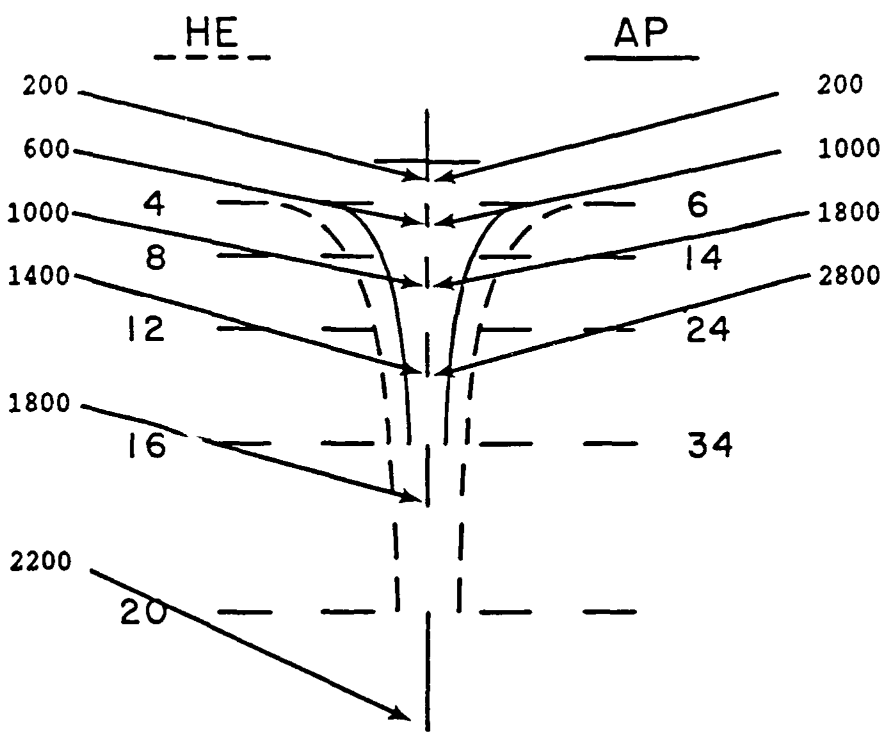


Figure 38. Range indicated at the bottom of range lines for HE and AP ammunition. (Note: HE range lines from 2200 through 3400 meters have been omitted.)

Target Engagement

Using the ranging stadia for target engagement. The round begins to drop when it leaves the barrel, so to hit a target, the gun must be elevated above direct line of sight. For a target the width of a BMP, correct elevation of the gun can be applied using the stadia of the auxiliary sight reticle.

Figure 39 shows how to engage a frontal angle of a BMP with AP ammunition. Turret and gun controls are used to position the edge of the target against a range line (Step A). Then elevate the gun (to control for backlash) to choke the front slope of the target between the reticle centerline and the AP stadia (Step B); the gun now has the correct elevation. Check target range using the range lines and AP range scale. If the target is within 1800 meters, traverse to center the target between the two solid stadia lines (Step C). Fire and adjust.

Engaging a flank angle of a BMP with AP ammunition would be conducted as shown in Figure 40. Turret and gun controls are used to center the target on the vertical line of the boresight cross (Step A). The gun is elevated until each edge of the target touches the two solid stadia lines (Step B). If the target is at 1800 meters or less, traverse to apply a 5-mil lead (Step C). Fire and adjust.

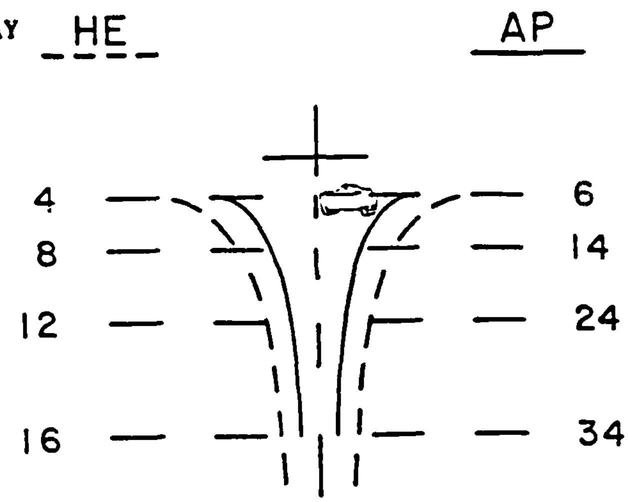
Engagements with HE ammunition are conducted as for AP except that the HE ranging stadia is used. The aiming point for flank angles of the target is far lead as shown in Figure 41.

Engagements not using the stadia. Range to troop targets cannot be estimated with the stadia. It also is difficult to use it on vehicular targets under poor visibility conditions. In these cases, range estimation must be conducted using other techniques, like the range card. Once range is known, the range scales and range lines must be used to apply the correct gun elevation for target engagement.

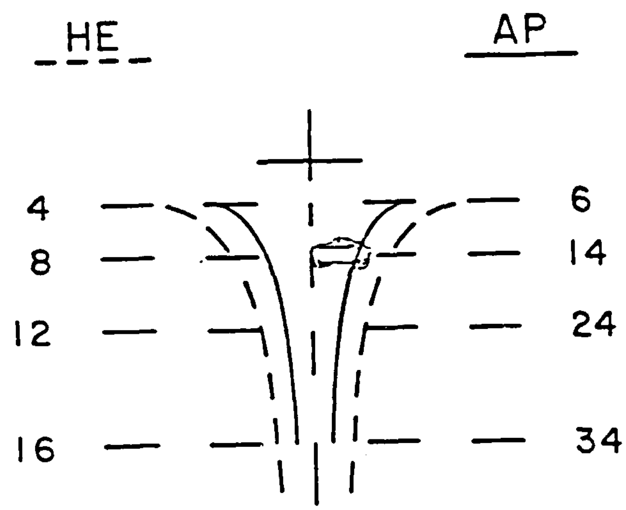
Engagements with the coaxial machine gun. It also may be necessary to fire the coaxial machine gun using the auxiliary sight unit. The BFV Gunnery field manual (FM 23-1 (C1), 1986) recommends use of the HE ranging scale to provide the correct elevation for the coaxial machine gun.

Examination of the ballistic data for HE and 7.62-mm ammunition indicates that the latter requires about twice the superelevation (Department of the Army, 1980, Table V). Figure 42 shows the reticle markings that provide the most accurate ballistic correction for the coaxial machine gun. As shown, 200-meter increments in range are indicated by the bottom of successive range lines. The following technique could be used for setting the correct gun elevation for target engagement. For a target at 600 meters, the gunner first aims the boresight cross at the target. The gun is elevated as the gunner counts 2, 4, and 6 (meaning 200, 400, and 600 meters) until the bottom of the third range line is aiming at the target. Fire and adjust.

A. INITIAL GUN LAY



B. RANGE



C. AIM

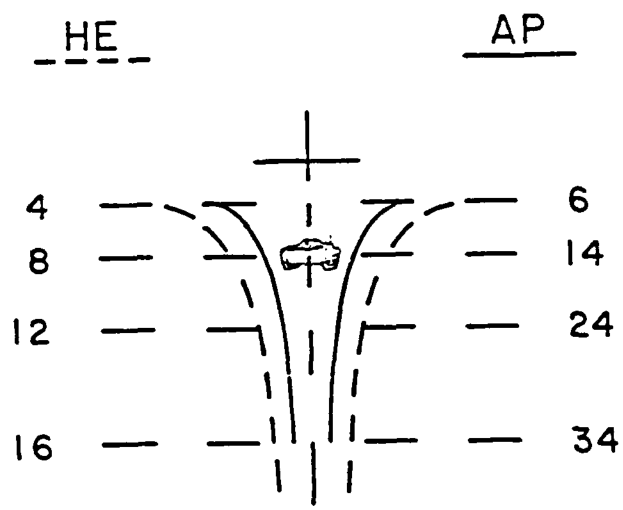
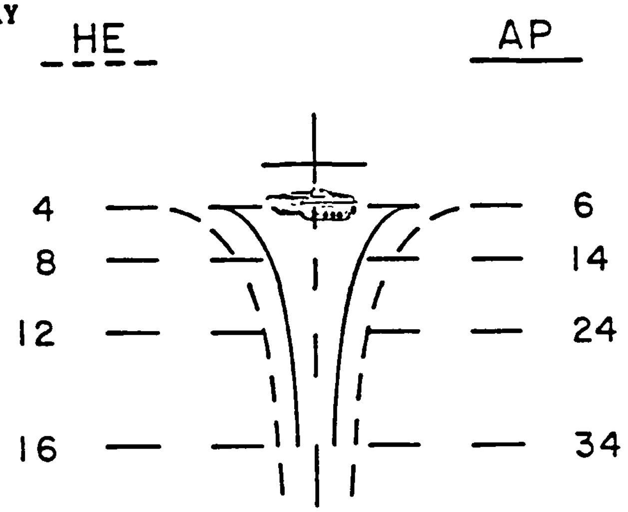
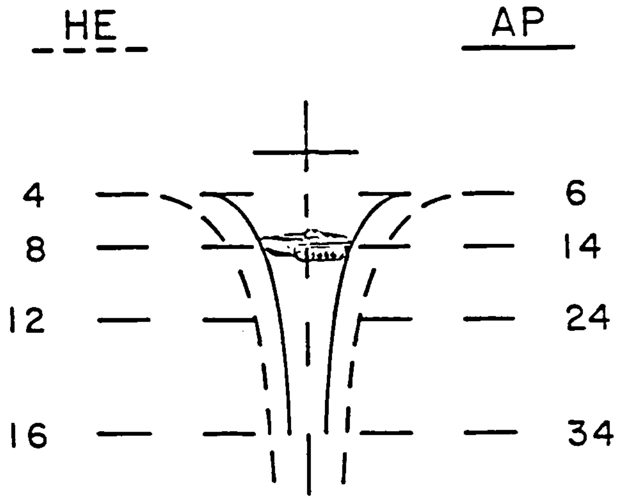


Figure 39. Engaging a frontal angle of a BMP with AP ammunition.

A. INITIAL GUN LAY



B. RANGE



C. AIM

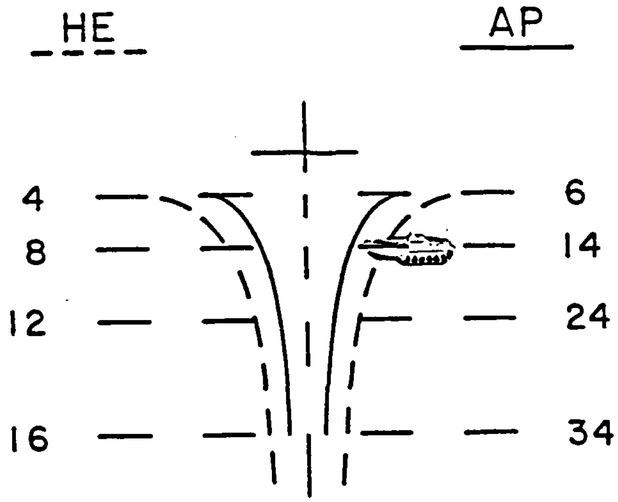


Figure 40. Engaging a flank angle of a BMP with AP ammunition.

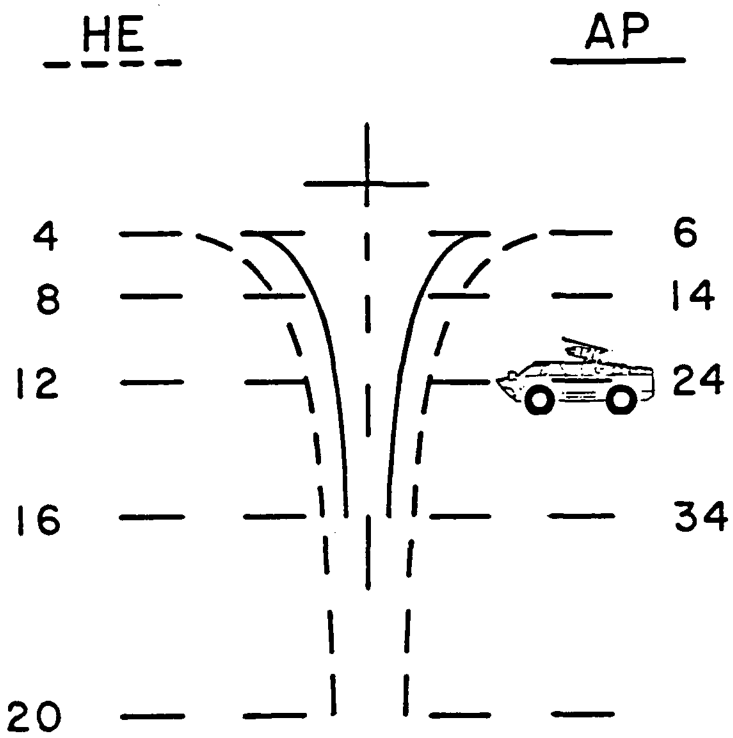


Figure 41. FAR LEAD when engaging flank angles of moving targets with HE ammunition.

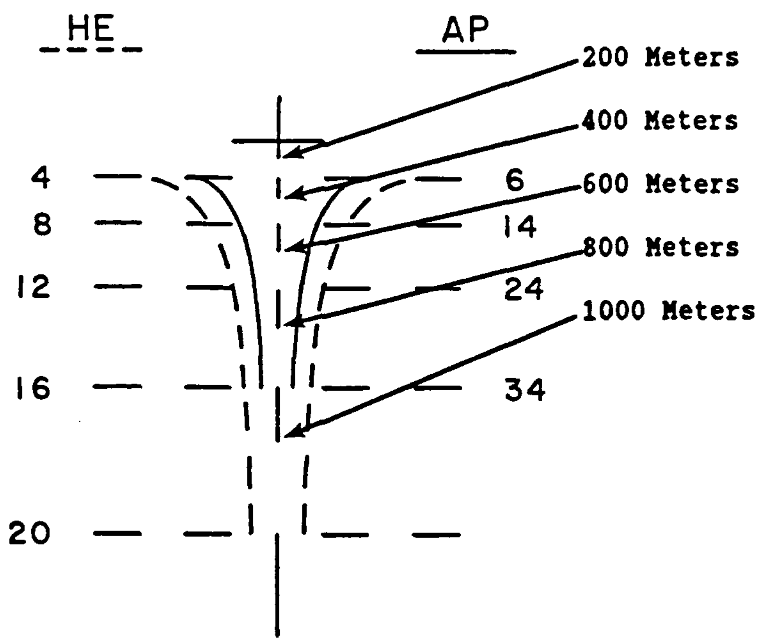


Figure 42. Range indicated by range lines when using the coaxial machine gun.

Range Estimation

The stadia can be used for range estimation without target engagement. The AP and HE stadia, when used only for range estimation, have advantages and disadvantages. The AP stadia extends to 3400 meters while the HE stadia only goes to 2000 meters. Furthermore, the HE stadia allows estimation to the nearest 200 meters, while intervals for the AP stadia are greater. Therefore, the HE stadia is more accurate up to 2000 meters while the AP stadia allows range estimation for distances beyond that of the HE stadia. The following technique is recommended for range estimation, without engaging, with the stadia. The sample target is oriented at a flank angle to the gunner.

- Traverse and end the gun lay in elevation to position the target above the stadia,
- Elevate the gun until each end of the target touches an AP stadia line,
- Read the range on the AP range scale,
- If the range is 2000 meters or less, then greater accuracy can be obtained by elevating the gun until the target is choked in the HE stadia,
- Read range on the HE range scale.

Zeroing

Aligning the sight with a zeroed ISU and 25-mm gun. Boresighting the auxiliary sight unit provides a preliminary alignment between the sight and gun. If the ISU and 25-mm gun have been zeroed, then the auxiliary sight reticle can be referenced to that of the ISU in order to increase the accuracy of sight alignment. After the ISU and 25-mm gun are zeroed, align the auxiliary sight as outlined below.

- Set range control knob of ISU to 0,
- Traverse and end gun lay in elevation to align the ISU reticle on an aiming point at the distance used for zeroing,
- Use the azimuth and elevation knobs of the auxiliary sight unit to align the boresight cross of the reticle with the aiming point.

Zeroing the auxiliary sight unit and the 25-mm gun. If the ISU is inoperative, the auxiliary sight unit will have to be zeroed with the 25-mm gun. In this case, the auxiliary sight reticle will be aligned based on firing using the sight.

When zeroing, it is critical to know (a) target range and (b) where that range is represented on the reticle. Zeroing is conducted as described in Section 6 (and Appendix D) using the appropriate range line to aim. Figure 43 shows the correct aim when zeroing is conducted at 1200 meters with TP-T ammunition (HE range scale is used).

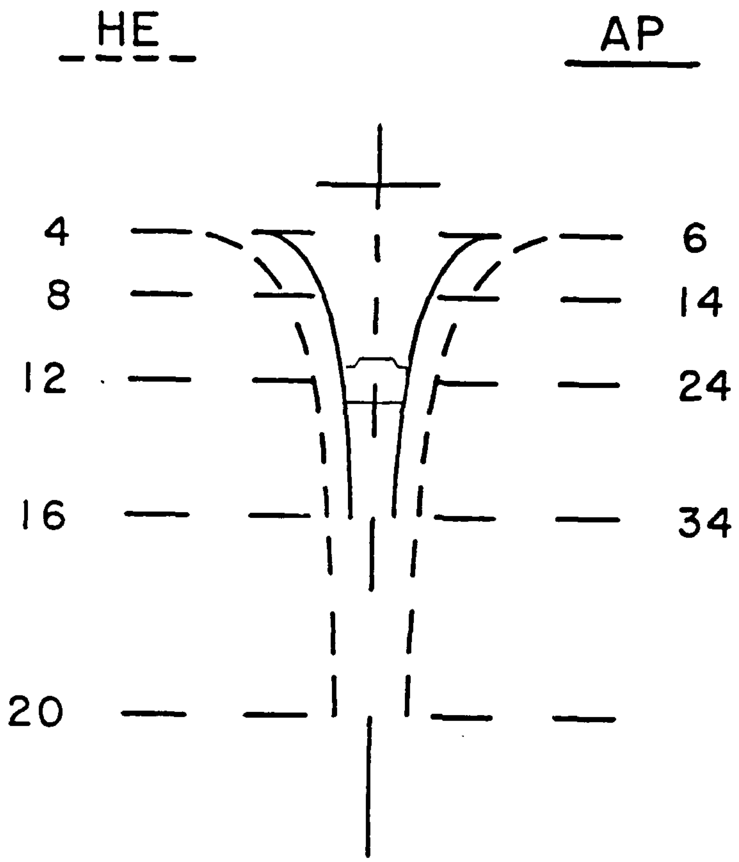


Figure 43. Sight picture when zeroing with TP-T ammunition at 1200 meters.

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SECTION 10. SUMMARY

The primary goal of this work was to develop, modify, and identify procedures and techniques to improve the gunner's capability to achieve first-round hits with the 25-mm gun. The next version of the BFV Gunnery field manual will include many of the techniques and procedures described in this report. The following summarizes developed/modified techniques and procedures and their status for implementation.

The developed handbook, Boresight Equipment Testing Procedures (Perkins, 1988d), will be Appendix B of the gunnery manual. These test procedures for the 25-mm kit, the 25-mm adapter, and the boresight telescope were not previously included in the gunnery manual. Tests will allow the unit to test the accuracy of their 25-mm boresight kit before boresighting. Kits not passing standard will receive further testing conducted at battalion level to determine whether the telescope or adapter or both contributed to inaccuracy. Accurate components can be used to form accurate kits to be used for boresighting. Inaccurate boresight equipment can be reported as deficient using the QDR (Standard Form 368).

The developed handbook, Boresighting and Weapon Checks Using the Close-In Panel (Perkins & Roberson, 1988b), will be presented as Appendix C in the gunnery manual. Developed material, which replaces a previous appendix in the manual, provides a description of how to make the panel, where to place the panel in the motor pool, how to boresight all turret weapons and sights, and how to conduct weapon checks. The portion on weapon checks describes test procedures (e.g., backlash, equilibrator, and boresight retention) not previously available to the user. Use of the panel allows boresighting and conduct of weapon checks before the vehicle leaves the motor pool.

Boresighting and zeroing procedures for the 25-mm gun are described in the turret technical manual (TM 9-2350-252-10-2, 1986). Recommended changes based on developments described in this report have been submitted using DA Form 2028-2. Recommended changes to boresighting include adapter installation, telescope focusing procedures, a kit accuracy test, gun-lay procedure, and aiming-point confirmation (see Appendix C). The recommended modification to zeroing involves use of three-round shot groups to zero with TP-T ammunition (see Appendix D) and a specially developed score sheet (see Appendix E).

A number of developments in range estimation will be included in the next version of the BFV Gunnery field manual. A summary of these developments is presented below along with where they were discussed in this report. Referenced figures will be included in the BFV Gunnery field manual.

- AP and HE trajectory curves (see Section 7, Figure 16),
- Battlesight range control settings for AP and HE ammunition (see Section 7),
- Technique to determine frontal and flank angles of targets (see Section 7; Figure 20),

- Modified quick reference table for range estimation (see Section 7, Figure 21),

- Modified procedure for measuring the width of frontal angles of vehicular targets (see Section 7, Figure 25),

- Technique for using the ISU lead lines to estimate range (see Section 7; Figures 24 and 25),

- Determining critical target ranges for 25-mm and TOW engagements using the ISU reticle (see Section 7; Figures 26, 27, and 28),

- Modified technique for using the horizontal ranging stadia (see Section 7; Figure 19).

Inclusion of trajectory curves is new to the manual. These curves are used (a) to illustrate differences in the trajectory of AP and HE ammunition with varied range control settings and (b) possible battlesight range control settings for AP and HE ammunition. A technique was developed that allows determination of target angle (frontal and flank). Use of this technique is required to estimate range when using the binoculars, the ISU center cross, and the auxiliary sight. Use of the ISU lead lines to estimate range will be new in the manual. As part of using this technique, the manual will illustrate the target size at critical target ranges for 25-mm and TOW gunnery.

The developed fundamental aiming rules (Figures 30A, 31, 32, and 33) will replace those previously shown in the BFV Gunnery field manual (FM 23-1, 1986). The newly developed rules require a greater amount of aiming point offset than the original rules.

Revision of the BFV Gunnery field manual was completed before the following materials and products were completed.

- Advanced aiming principles and techniques (see Section 8),

- Improved use of the binocular reticle for range estimation (see Section 7),

- Zeroing score sheets for TP-T ammunition and the coaxial machine gun (see Appendixes E and F, respectively),

- Use of the dirt berm for zeroing (see Section 6),

- Zeroing, ranging, and aiming procedures for the auxiliary sight (see Section 9).

These products should be reviewed by USAIS for possible inclusion in gunnery literature and training.

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Appendix A

BORESIGHT EQUIPMENT CONSIDERATIONS

Introduction

Inaccurate fielded boresight equipment is partly due to absence of operational performance standards for the 25-mm adapter and 25-mm boresight kit. Equipment also is inaccurate because of design flaws. Furthermore, telescopes that have operational problems or do not meet accuracy requirements are not turned in or reported on a regular basis. The user (i.e., USAIS and TRADOC) needs to consider boresight equipment modification and/or redesign. The following will discuss recommended requirements and considerations related to boresight equipment for the BFV.

Packaged as a Kit

Boresight equipment for the BFV includes a boresight telescope, a 25-mm adapter, a 7.62-mm adapter, a red safety flag, and a container box. All equipment fits into the container box except the 25-mm adapter. The 25-mm adapter has received unnecessary abuse and exposure to moisture because of the lack of a container for it. The original design of the adapter is not rust-proof and the modified one has only portions that are chromium plated and rust-proof. Fielded adapters also do not have serial or identification numbers that allow the user to insure that the same adapter is always used with the same telescope.

It is recommended that all BFV boresight equipment be enclosed in a single container (a) for protective purposes and (b) to allow all equipment to be stowed in the same location within the vehicle. Each piece should be marked with a serial or identification number that allows all pieces of equipment in the kit to be kept together.

Establish Accuracy Standards for Each Weapon

Separate user testable standards should not exist for individual components of the kit (i.e., telescope and adapter) required to boresight a particular weapon. A soldier is not required to test individual components of his rifle and then put them together to see if the rifle passes a standard. The soldier should not be expected to test components of his boresight equipment in an effort to form accurate kits.

Boresighting requirements exist for the 25-mm gun, TOW missile system, and coaxial machine gun. There are unique considerations for all three weapons. From an operational standpoint, it is recommended that there be only one accuracy standard for each weapon boresighted on the BFV.

A boresighting accuracy standard of 0.5 mils or less for the 25-mm gun has been proven effective (Perkins & Wilkinson, 1988a; Perkins, 1987b). Accurate boresighting produced a 60% hit rate for training ammunition on a 1200-meter target the approximate size of a frontal silhouette of a BMP. This can be considered a moderate level of first-round hit potential for a weapon system that is often purported not to have that capability.

The 7.62-mm machine gun usually is referred to as an area-fire weapon so there has been a general opinion that accurate boresighting is not important. In discussing the characteristics of an area-fire weapon, it is important to distinguish between (a) the sighting accuracy of the weapon and (b) the capability to deliver a large volume of fire over a large area. If the BFV is ambushed while on the move, then a quick and accurate delivery of fire is required. It should be emphasized that an area-fire weapon does not have to have inaccurate sighting capabilities. For example, the coax machine gun of the M1 tank has a high level of sighting accuracy (Personal communication, PM Boresight Office, AMCCOM, October, 1986).

Despite the frequently mentioned statement that the coax machine gun is an area-fire weapon, the gunnery field manual (FM 23-1, 1986) states that the coax machine gun is primarily an offensive weapon used to destroy unarmored <u>area</u> and <u>point</u> targets, to suppress enemy positions, and to conduct reconnaissance by fire. If the coax machine gun is primarily an offensive weapon that will be used against point targets (e.g., an ambush by an RPG while the BFV is moving), then there will be situations in which target hits or suppression will be required very quickly. In this situation, the coax machine gun will need a high level of sighting accuracy. Sighting accuracy requires accurate boresighting particularly in situations that preclude zeroing.

In addition to the 25-mm and 7.62-mm guns, there is a unique boresight receptacle for the TOW missile system. The original TOW receptacle was straight tubular design. The tapered telescope stem was inserted into this receptacle. Because of the difference in shape of the TOW boresight receptacle and telescope stem, there was an imprecise fit between the telescope and TOW launcher. The boresight receptacle was redesigned so that it was tapered much like the telescope stem. A receptacle with this modified design is placed only on new vehicles and no retrofitting has occurred.

Boresight equipment modifications or redesign must consider the type of mount that will be used on the TOW launcher. Only the telescope is currently used to boresight the TOW. Another possible configuration would be use of a 7.62-mm female receptacle in the TOW launcher.

<u>Equipment Design Supports a Field Test of Accuracy</u>

The soldier must be able to test boresight equipment accuracy. This is done using a 180-degree kit rotation test (see Section 4). It is possible, but tedious, to perform a kit rotation test with current equipment. For the rotation test to provide a valid test of equipment accuracy, the optical part (i.e., the telescope) must not move within the adapter as it is rotated in the gun barrel. Current equipment does not allow the telescope to lock on to the adapter.

The requirement to use a kit rotation test to verify equipment accuracy implies that the telescope should be attached to the adapter(s). The attachment would probably have to be temporary so that the same telescope or optical system could be used with more than one adapter type for the BFV.

Collimating the Telescope

The boresight telescope has a precisely aligned optical system. Use of such a system can result in optical misalignment. A collimation feature is one that allows adjustment of the reticle in the telescope so that optical alignment errors are eliminated or minimized. The collimation feature if utilized by the soldier can allow on the spot adjustments in the accuracy of the equipment.

The collimation procedure itself is not complicated. Actual adjustment requires the use of two screws that adjust the telescope reticle in direction of deflection and elevation. Collimation is not significantly different from adjusting the ISU reticle with the boresight knobs, adjusting the auxiliary sight, and adjusting the coaxial machine gun. If the gunner can perform these tasks, then he can probably collimate the boresight kit. This was demonstrated using four students in a BFV Commander Course. Each student was tested on his ability to collimate a boresight kit (manufactured by Wild Heerbrugg Instruments Inc.). On their first attempt, all students collimated the reticle to achieve 0.5 mil accuracy or better after the kit had been intentionally misaligned by 3 to 5 mils.

The current tendency is to keep inaccurate boresight equipment in the unit: equipment which has been turned in for repair is often difficult to replace. Therefore, giving the gunner or master gunner the collimation capability allows him to correct inaccuracies in his own equipment and increases the probability that accurate boresight equipment will be maintained throughout the unit.

Optical Features of the Boresight Telescope

The reticle must be designed to support the requirements of boresighting. The current boresight telescope has 2-mil and 10-mil diameter circles with horizontal and vertical cross hairs. The 2-mil circle can be easily used to test accuracy of the kit as described in Section 4. The gun is laid with the cross hairs on the corner of a target with the telescope eyepiece facing right. The entire kit (i.e., telescope and adapter) is rotated to the left (180 degrees) and the original aiming point must stay within the 2-mil circle of the telescope to pass standards (a 1-mil change in aiming point allowed).

The recommended reticle for the boresight telescope is illustrated below. The cross hairs of this reticle do not extend into the center 2-mil circle. This prevents "clutter" in the sight picture during conduct of the kit rotation test. Mil markings along the cross hairs facilitates the collimation procedure.

The telescope should be able to focus from 100 meters to infinity. A range of 1200 meters is recommended for boresighting the 25-mm gun using normal procedures but the close-in boresight panel can be used at ranges as short as 100 meters.

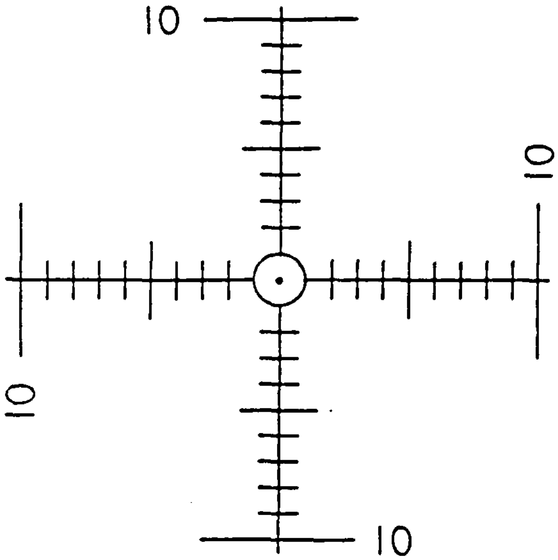


Figure A-1. Illustration of possible reticle design for a boresight telescope with a collimation feature.

Adaptability to an Enlarged Gun Barrel

A gun barrel erodes with repeated firing. The boresight adapters must be capable of maintaining the accuracy standards as the barrel erodes within the allowed tolerances. This requires an adapter that can expand within the gun bore.

Night Capability

The BFV is not currently equipped to boresight at night. As described in the turret technical manual, the buddy-boresight technique can be used during limited visibility conditions to boresight the thermal sight with the day sight, provided it has been boresighted during daylight (TM 9-2350-252-10-2, 1986). Therefore if the daysight has not been boresighted before dark, then the buddy-boresight method can not be used to boresight the thermal sight.

The buddy boresight method requires two BFV, separated by at least 200 meters, to face each other. Because of this procedural requirement, the buddy boresight method has security problems in a tactical environment. It would not be sound to have an entire company or battalion lined-up conducting the buddy boresight method. Using the buddy boresight method also has safety problems when vehicles are uploaded with ammunition.

When boresighting at night, the telescope must have the capability to illuminate the reticle. Boresighting at night also requires a target with a light source that can be seen with both day and thermal optics. An example would be an incandescent street light or any other artificial or natural light source.

Weatherproof

A number of telescopes at Fort Benning had water in the optical component. This totally obscured the sight picture. The telescope should be required to be waterproof and not be susceptible to condensation caused by sudden changes in environmental conditions (e.g., removal of the telescope from the back of a heated BFV into a cold, wet, or snowy environment).

Appendix B

BACKLASH TEST PROCEDURE

1. USE THE FOLLOWING CHECKLIST TO PREPARE FOR TESTING.

    ___ Boresight kit and 25mm adapter available

    ___ Master power on

    ___ Turret shield door shut

    ___ Turret in manual

    ___ Gun in manual

    ___ TOW in power

    ___ Turret power on

    ___ AP selected

    ___ Day ballistic door open

    ___ Sensor select on Clear or Neutral

    ___ Magnification on high

    ___ Range index is 0

    ___ Turret travel lock disengaged

2. INSTALL 25MM BORESIGHT ADAPTER.

    a. Slowly insert the adapter into the gun barrel using a twisting motion.

    b. Check that adapter rotates freely after being fully inserted.

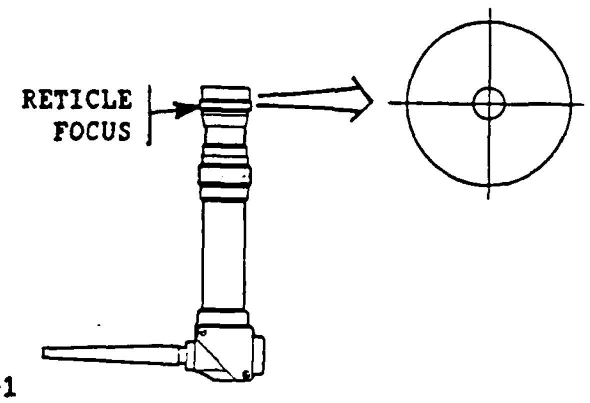
    c. Hang the red streamer on the adapter.

WARNING
Looking at the sun through the boresight telescope may cause blindness. Do not look at the sun with the telescope.

3. INSTALL AND FOCUS THE BORESIGHT TELESCOPE.

    a. Hold the telescope to observe the sky or some other evenly lit area.

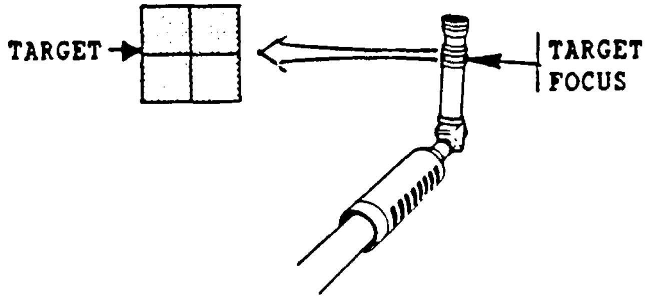
    b. Turn the reticle focus until the boresight reticle appears sharp and clear.



c. Insert the shank of the telescope into the adapter until seated.

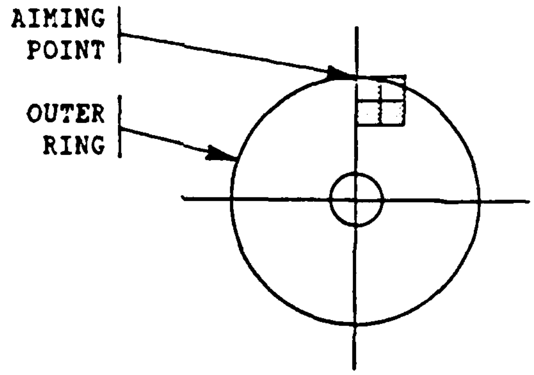
d. Turn the telescope until the eyepiece is facing up.

e. Focus the target using the target focus knob.

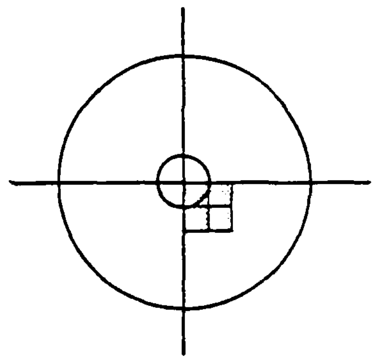


4. HELPER LAYS BORESIGHT RETICLE ON AIMING POINT.

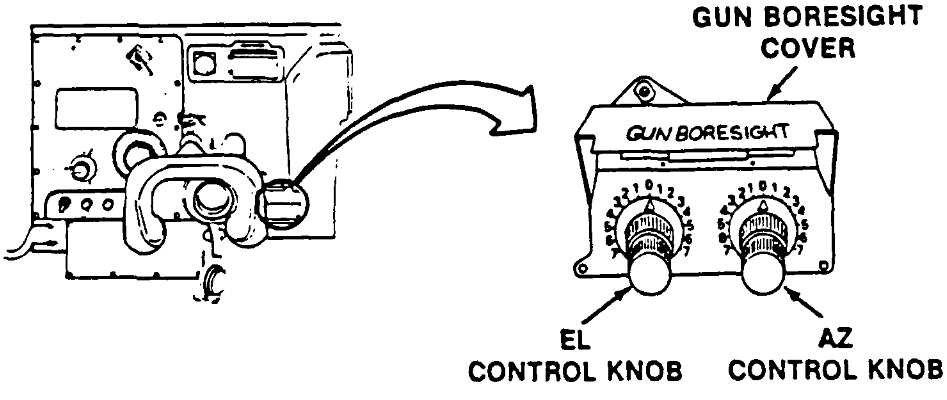
a. Instruct the gunner to aline the top of the outer circle of the BORESIGHT RETICLE on the aiming point (e.g., a corner).



b. Instruct the gunner to aline the boresight reticle with the aiming point.

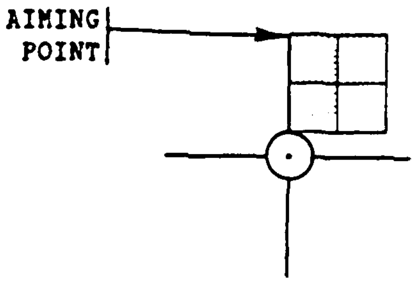


5. ALINE GUN RETICLE ON AIMING POINT USING THE AZ AND EL BORESIGHT KNOBS.

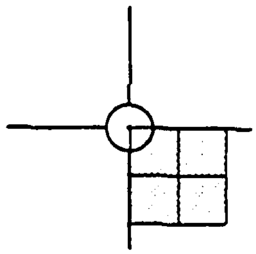


6. LOWER THE GUN RETICLE AND RETURN TO THE AIMING POINT USING THE GUN ELEVATION HANDWHEEL.

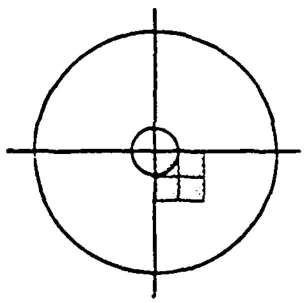
   a. Depress the reticle until the top of the center cross is on the aiming point.



   b. Elevate the reticle until it is alined with the aiming point.

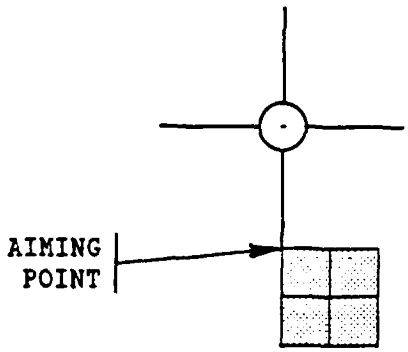


7. HELPER NOTES THE AIMING POINT OF THE BORESIGHT TELESCOPE.

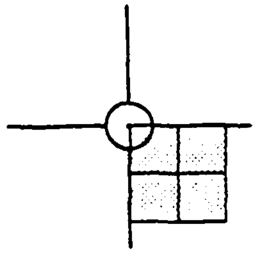


8. RAISE THE GUN RETICLE AND RETURN TO THE AIMING POINT USING THE GUN ELEVATION HANDWHEEL.

   a. Elevate the reticle until the top of the center cross is on the aiming point.



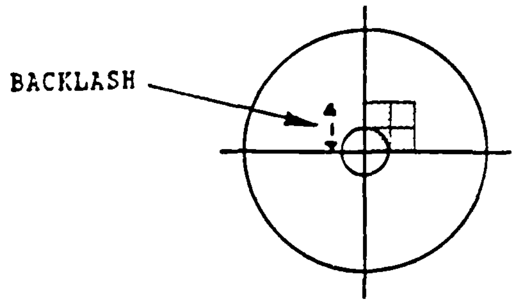
   b. Depress the reticle until it is alined with the aiming point.



9. DETERMINE BACKLASH.

a. Helper notes the aiming point of the boresight reticle.

b. Helper uses the 2-mil, inner ring of the boresight reticle to estimate the change in (mils) aiming point observed in step 7.



Appendix C

BORESIGHTING PROCEDURE MODIFICATIONS

Follow the first 17 steps of the task BORESIGHT 25MM GUN in TM 9-2350-252-10-2. The following describes recommendations for installing the 25mm adapter, focusing the boresight telescope, testing the 25mm boresight kit, and laying the gun before alining the sight.

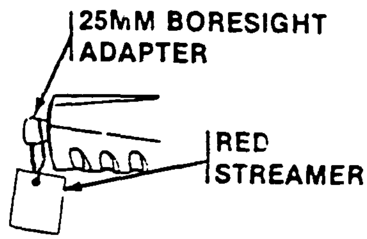
NOTE
To prevent the 25mm boresight adapter from sticking or freezing in the gun barrel, apply a light coat of GMD on the end of the adapter and twist the adapter during insertion.

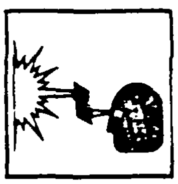
1. INSTALL 25MM BORESIGHT ADAPTER.

   a. Insert the adapter into the 25mm gun barrel until seated.

   b. Check that adapter turns freely after it is seated.

   c. Hang the red streamer on the adapter.





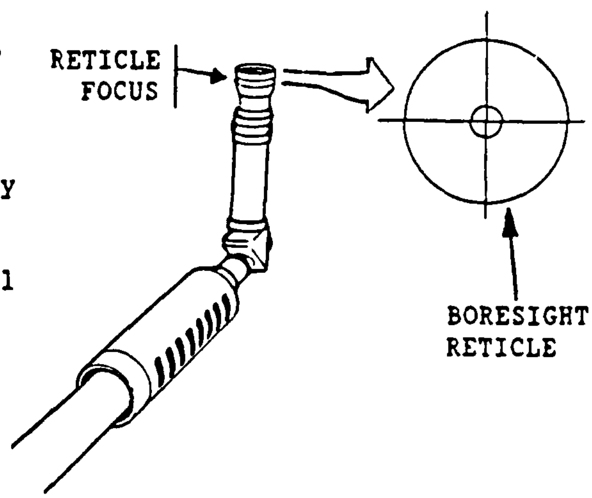
WARNING
Looking at the sun through the boresight telescope may cause blindness. Do not look at the sun with the telescope.

NOTE
The reticle focus and target objective focus of the boresight telescope must be adjusted in the correct order to prevent parallax.

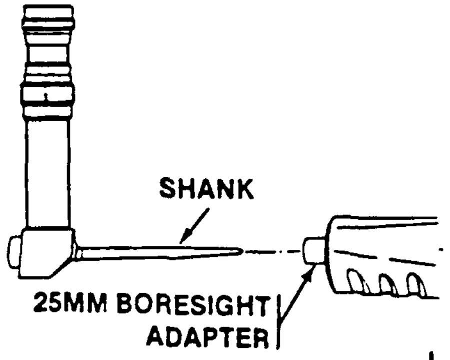
2. INSTALL AND FOCUS THE BORESIGHT TELESCOPE.

   a. Hold the telescope to view the sky or some other evenly lit area.

   b. Turn the reticle focus until the boresight reticle appears sharp and clear.

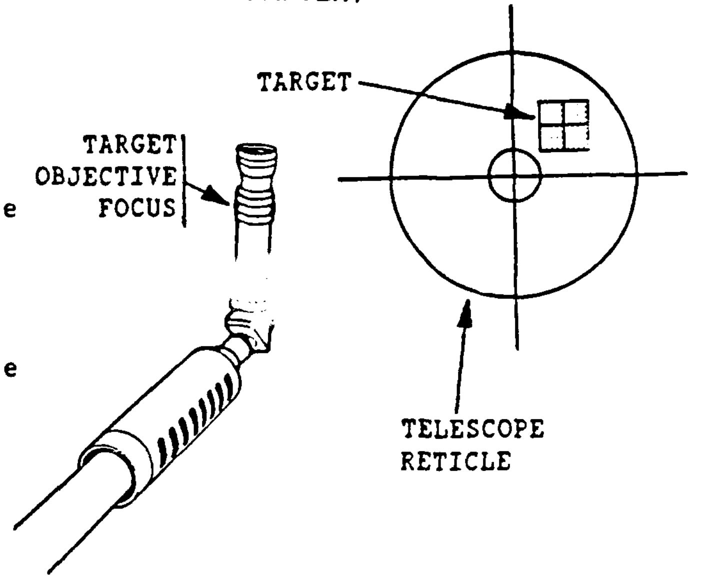


c. Insert the shank of the telescope into the adapter until seated.



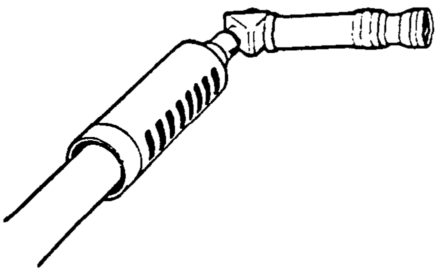
d. Turn the telescope in the gun barrel so that the eyepiece is facing up.

e. While looking at the reticle and moving your head slightly from side to side, turn the target objective focus until there is no movement between the reticle and target.



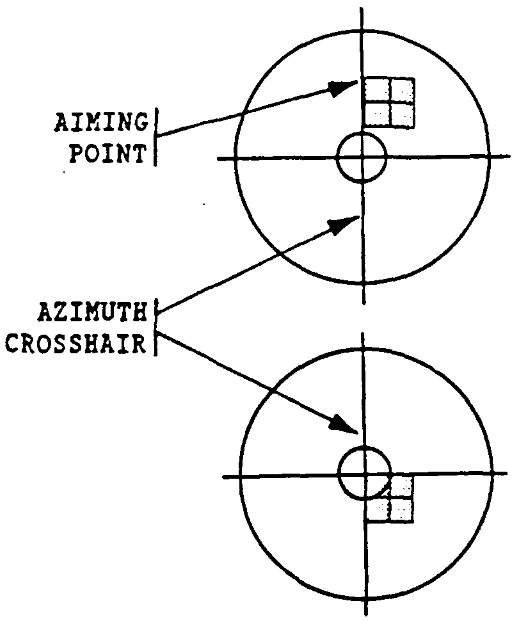
3. HELPER CHECKS ACCURACY OF BORESIGHT KIT.

a. Turn the telescope until the eyepiece is facing right.



WARNING
Fast motion of 25mm gun during boresighting could cause injury. Make sure turret is in MANUAL mode. Move 25mm gun very slowly during boresighting.

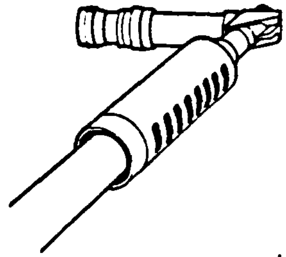
b. Tell gunner to traverse to aline the azimuth crosshair of the boresight reticle on the aiming point.



c. Tell gunner to elevate or depress the gun to aline the boresight reticle on the aiming point.

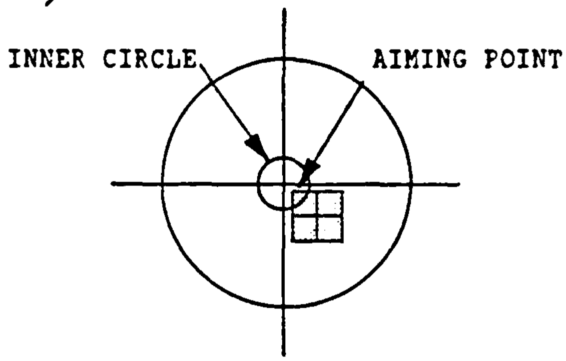
NOTE

Hold both the telescope and adapter during rotation to keep the telescope from slipping in the adapter.

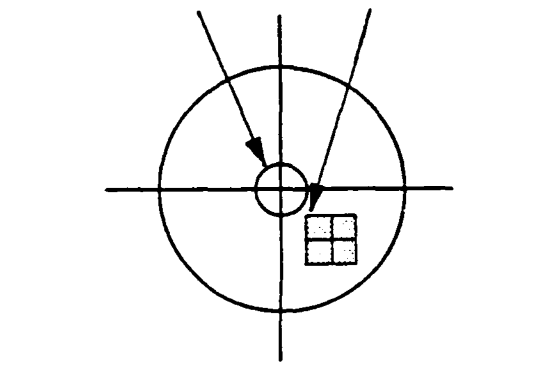


d. Turn both the telescope and adapter until the telescope is facing left.

e. If the aiming point is inside or on the inner circle of the boresight reticle, go to step 4.



e. If the aiming point is outside the inner circle of boresight reticle, insert another boresight kit and repeat steps 1 through 3.



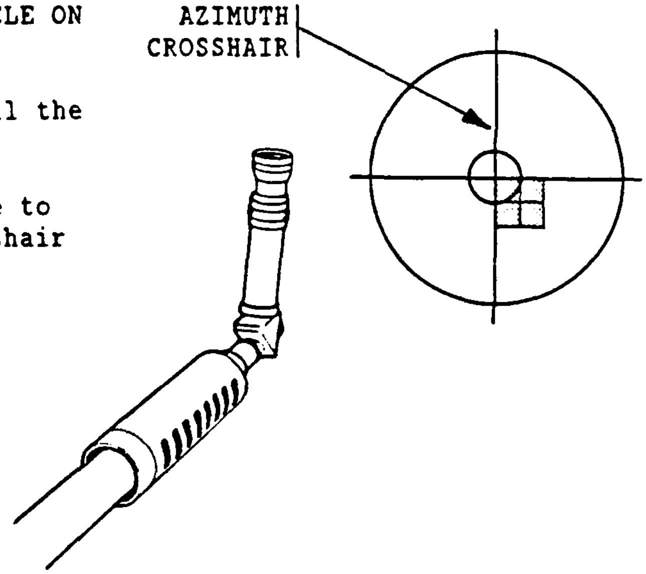
NOTE

The gun lay ends in elevation to control for backlash error between the sight and gun.

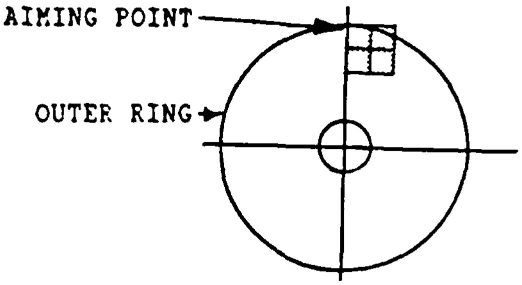
4. HELPER LAYS BORESIGHT RETICLE ON AIMING POINT.

   a. Turn the telescope until the eyepiece is facing up.

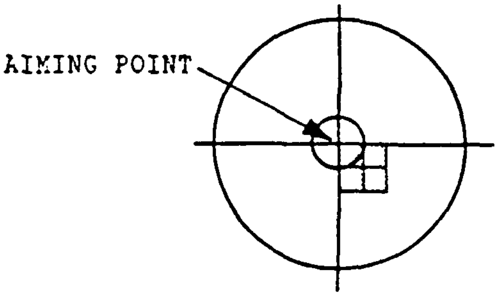
   b. Tell gunner to traverse to aline the azimuth crosshair of the reticle on the target.



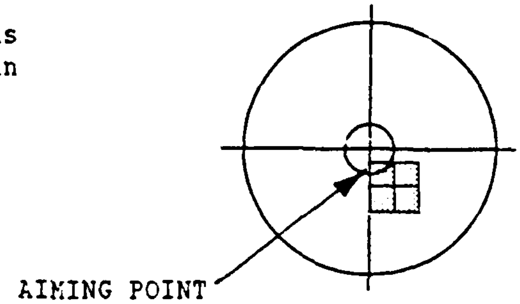
c. Tell gunner to depress/elevate the gun to aline the top of the outer circle of the boresight reticle on the aiming point.



d. Tell gunner to elevate the gun to aline the boresight reticle with the aiming point.



e. If the boresight reticle was accidently moved higher than the aiming point during d, repeat a through d.

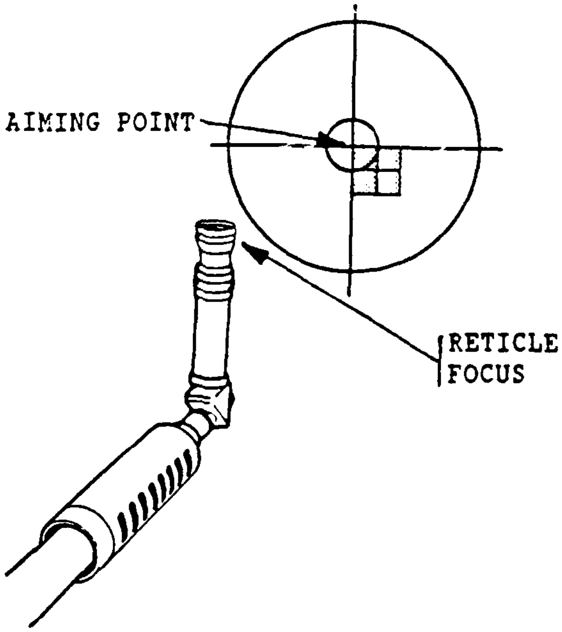


5. CONFIRM AIMING POINT.

   a. Gunner exits turret to check aiming point of boresight telescope.

   b. If necessary, gunner uses the reticle focus knob to focus the boresight reticle.

   c. Gunner checks that gun is alined on the aiming point.



6. GO TO STEP 23 OF THE TASK BORESIGHT 25MM GUN IN TM 9-2350-252-10-2, P. 2-210.

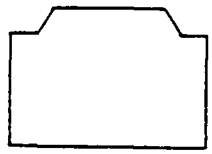
ZEROING PROCEDURE FOR TP-T AMMUNTION

The following is the proposed procedure for zeroing the 25mm gun with TP-T ammunition. The procedure would be added to the task ZERO ISU AND 25MM GUN (TM 9-2350-252-10-2, September 1986) starting after step 4. Numbering of steps refers to the proposed procedure and not the step numbers in the manual.

NOTE
Steps 1 through 7 only are used for TP-T ammunition.

NOTE
Hit sensors on the target are recommended.

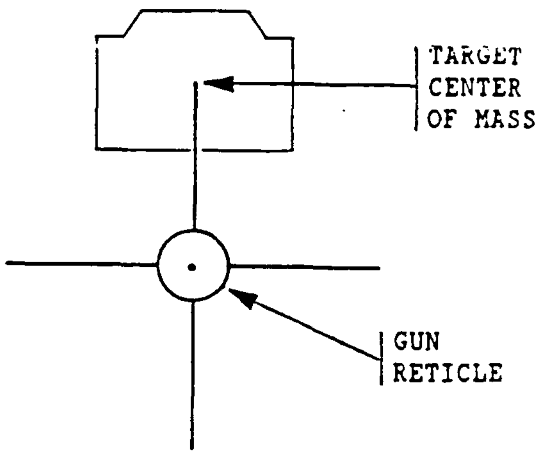
1. SELECT A BMP FRONTAL TARGET AT EITHER 1000 OR 1200 METERS. See FM 25-7, page B-33, BMP 1981 Front Target.



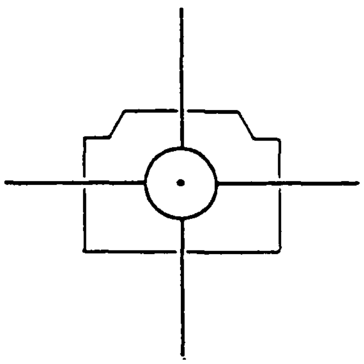
NOTE
Gun lays should always end in elevation to control for backlash.

2. AIM THE GUN RETICLE AT TARGET CENTER OF MASS.

   a. Aline the top of the gun reticle with target center of mass using the gunner's hand station. See task: OPERATE TURRET IN POWER MODE, page 2-170.



   b. Elevate the gun reticle to target center of mass. See task: OPERATE TURRET IN POWER MODE, page 2-170.



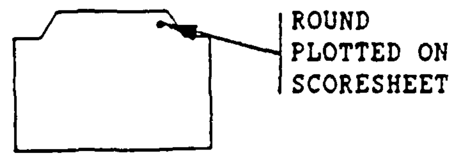
NOTE
Use of a scoresheet improves zeroing accuracy. If a standardized scoresheet is not available, draw the target on a sheet of paper.

NOTE
The trigger switch is used to fire to prevent accidental movement of the turret and gun during firing.

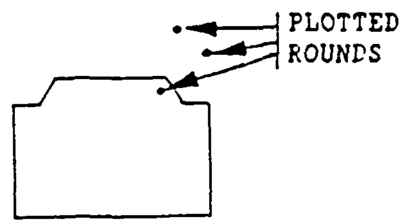
3. FIRE A THREE-ROUND SHOT GROUP.

   a. Fire one round at target using the trigger switch on the turret traverse wheel.

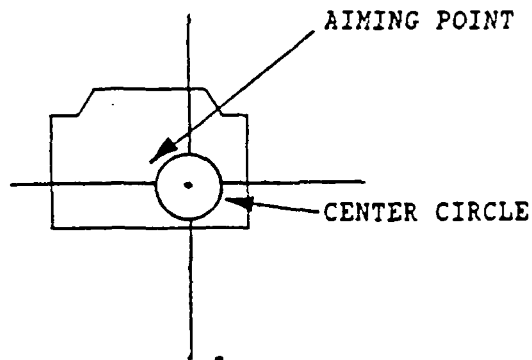
   b. Place a dot on the scoresheet showing the strike of the round or where the round passed the plane of the target.



   c. Repeat a and b for the second and third rounds of the shot group.



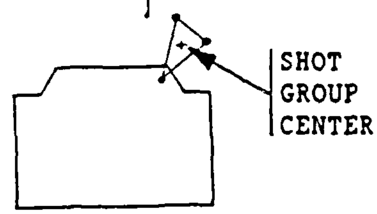
   d. Notify organizational maintenance if the aiming point is outside the center circle of the reticle.



4. MARK SHOT-GROUP CENTER ON SCORESHEET.

   a. Draw lines connecting the 3 rounds plotted on the scoresheet.

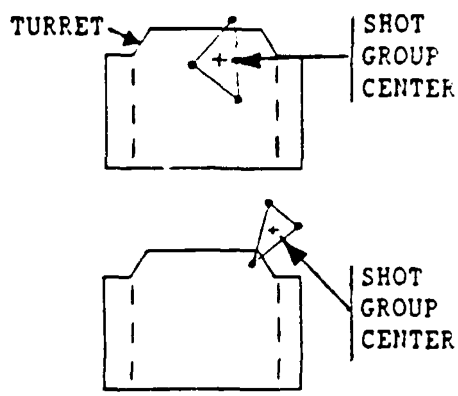
   b. Draw a cross in the middle of the triangle to mark the shot group center.

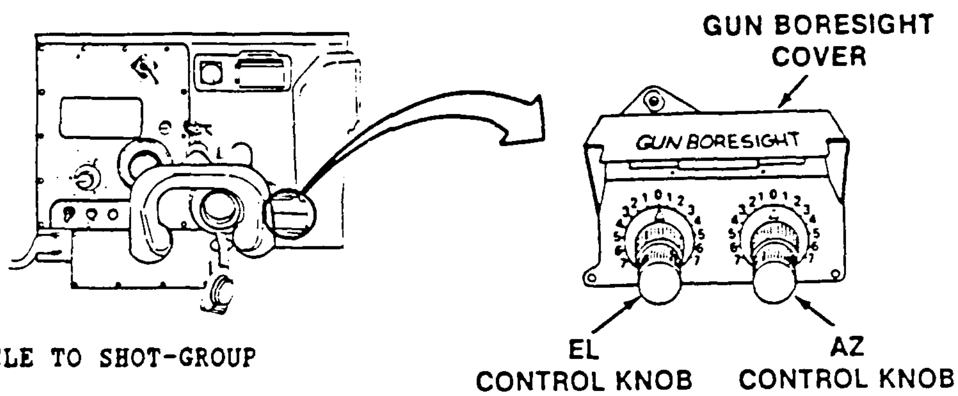


5. SCORE ACCURACY.

   a. The 25mm gun is zeroed if two criteria are met: (1) 2 or more target hits are obtained and (2) the shot-group center is on or under the turret of the target.

   b. If both criteria are not met, go to step 6.





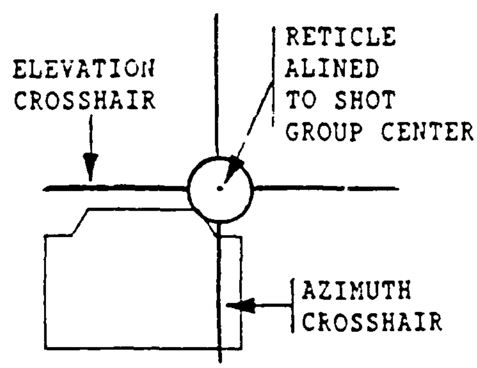
6. ALINE RETICLE TO SHOT-GROUP CENTER.

   a. Open *GUN BORESIGHT* cover.

   b. Turn EL control knob to aline elevation crosshair on shot-group center.

   c. Turn AZ control knob to aline azimuth crosshair on shot-group center.

   d. Close GUN BORESIGHT cover.



NOTE

The gun lay should end in elevation to control for backlash.

7. REPEAT STEPS 2 THROUGH 6 FOR A SECOND SHOT GROUP.

8. NOTIFY ORGANIZATIONAL MAINTENANCE IF 25MM GUN CANNOT BE ZEROED IN TWO SHOT GROUPS.

END OF TASK

Appendix E

TP-T ZEROING SCORE SHEET

DATE______________ TIME_______________ VEHICLE NUMBER________________

GUNNER___________________________ COMMANDER___________________________

1. Using the gunner's hand station, aim reticle at target center-of-mass using a gun lay ending in elevation.

   NOTE: Do not press palm switches when firing or between rounds of a shot group.

2. Fire a three-round shot group.

   A. Fire 1 round using the trigger switch on the traverse handwheel.
   B. Plot round-impact location in SHOT-GROUP block of score sheet.
   C. Circle HIT or MISS in SHOT-GROUP block of score sheet.
   D. Repeat A, B and C for two more rounds.
   E. Notify organizational maintenance if the aiming point moves outside of the center circle of the ISU after the shot group is fired.

3. Score accuracy.

   A. The zeroing procedure is completed if two criteria are met:

      (1) 2 or more target hits
      (2) shot-group center is on or under the turret of the target.

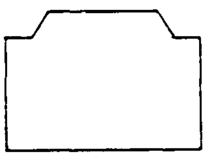
   B. If both criteria are not met, go to step 4.

4. Align gun reticle to shot-group center using the AZ and EL boresight knobs.

5. Repeat steps 1 through 3 for a second shot group.

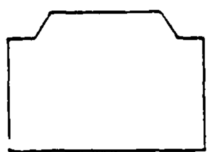
6. Notify organization maintenance if 25-mm gun can not be zeroed in two shot groups.

<u>SHOT-GROUP 1</u>



Round 1: H / M
Round 2: H / M
Round 3: H / M

<u>SHOT-GROUP 2</u>



Round 1: H / M
Round 2: H / M
Round 3: H / M

END

Appendix F

COAXIAL MACHINE GUN ZEROING SCORE SHEET

DATE______________ TIME______________ VEHICLE NUMBER______________

GUNNER____________________ COMMANDER____________________

1. Using the gunner's hand station, aim the ISU reticle at target center-of-mass using a gun lay ending in elevation.

2. Fire a 5 to 10 round burst.

3. Mark an "X" on the score sheet showing the center-of-burst in relation to the gun reticle.

4. Adjust the gun in AZ as indicated by score sheet.

   a. Determine the number of clicks required for the AZ adjustment.
   b. Determine the direction of AZ correction.
   c. Turn the AZ knob the direction and number of clicks indicated in a & b.

5. Adjust the gun in EL as indicated by score sheet.

   a. Determine the number of clicks required for the EL adjustment.
   b. Determine the direction of EL correction.
   c. Turn the EL knob the direction and number of clicks indicated in a & b.