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**ANALYSIS OF BRADLEY FIGHTING VEHICLE GUNNERY WITH EMPHASIS ON FACTORS
AFFECTING FIRST-ROUND ACCURACY OF THE 25-MM GUN**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Analysis of the problems and potential improvements in gunnery effectiveness of the Bradley Fighting Vehicle (BFV) led to research and development focusing on equipment, procedures, and training related to first-round accuracy with the 25-mm automatic gun. Areas addressed included boresighting equipment and procedures, zeroing, range estimation, range cards, aiming rules, preliminary gunnery training and full caliber gunnery. As a result of close coordination with proponents and users concerned with these areas, problem areas have been (OVER.)		

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recognized and solutions either are being or will be developed in efforts to improve gunnery effectiveness. Keywords: Automatic weapons.

Army training; Range finding estimates; Bore sight adapters;
Target angle determination.

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ANALYSIS OF BRADLEY FIGHTING VEHICLE GUNNERY WITH EMPHASIS ON FACTORS
AFFECTING FIRST-ROUND ACCURACY OF THE 25-MM GUN

EXECUTIVE SUMMARY

Requirement:

To develop and evaluate techniques, procedures, and training to improve the gunnery effectiveness of the Bradley Fighting Vehicle (BFV), with particular emphasis on first-round accuracy of the 25-mm gun. A comprehensive analysis provided the basis for selecting certain areas for research and development. Areas addressed were: (a) boresighting and zeroing, (b) range estimation, (c) range cards, (d) aiming, (e) preliminary gunnery training, and (f) full-caliber gunnery.

Procedure:

The methodology for development and evaluation of concepts and products varied across content areas. As appropriate to each area, the methodology employed included literature review; observation of gunnery training and performance; interactions with students, instructors, and experts; application of fundamental instructional principles; mathematical predictions; operational analysis of fielded equipment; and feasibility testing of developed concepts and products.

Findings:

Only a small portion of boresight equipment at Fort Benning passed current accuracy standards; improved screening procedures are required to remove inaccurate equipment from use. Use of accurate boresight equipment prior to zeroing resulted in rounds hitting close to target center. Accuracy of zeroing with 25-mm training ammunition can be improved with redesigned targets, shorter zeroing ranges, and use of three-round shot groups. Use of a 400-m offset zeroing procedure for the 25-mm gun was shown to zero the weapon at a range of 1000 m. The short-range zeroing procedure would be useful when ammunition dispersion levels are high, boresighting is inaccurate, and combat conditions preclude normal zeroing procedures. A concept was developed to allow range estimation using the 25-mm reticle, as an alternative to use of binoculars. The current quick reference table used with reticle-based measurements of target width or length also was simplified. Measurements of the horizontal ranging stadia indicated that it is currently designed to estimate range based on the height of a target's hull. Improved aiming rules were developed for engaging moving targets and for firing while on the move. A technique was developed to categorize target view as either frontal or flank for use in the application of lead rules and for estimating range based on the width of a target. Concepts were developed for using the range card for scanning and target detection, reporting and acquiring targets, range estimation, and planning for and control of fires. Issues discussed for preliminary and full-caliber gunnery include implementation of newly developed concepts and

products, use of training ammunition as a substitute for service ammunition during training and qualification, defining the role of the high-explosive 25-mm ammunition, and restructuring of live-fire training to focus on fundamental of gunnery.

Utilization of Findings:

The concepts and products described in this report were developed in close coordination with proponents and users. The data base provided will apply to decision making in a number of areas to include revision of institutional and unit training, ammunition conservation, training device effectiveness analyses, qualification standards, and the fundamentals of BFV gunnery.

ANALYSIS OF BRADLEY FIGHTING VEHICLE GUNNERY WITH EMPHASIS ON FACTORS
AFFECTING FIRST-ROUND ACCURACY OF THE 25-MM GUN

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ANALYSIS OF BRADLEY FIGHTING VEHICLE GUNNERY WITH EMPHASIS ON FACTORS
AFFECTING FIRST-ROUND ACCURACY OF THE 25-MM GUN

INTRODUCTION

The Bradley Fighting Vehicle

The Bradley Fighting Vehicle (BFV) is a vital element in the AirLand Battle approach to combat. In mechanized units of the U.S. Army, the BFV was designed to replace the M113 which falls short in many of the requirements of the modern day battlefield. The BFV offers speed and mobility, armament against light-skinned vehicles and tanks, target acquisition and engagement during all visibility conditions, firing on the move with overhead protection, and concealment with smoke. These capabilities and others enable the infantry to fight effectively as part of the combined arms concept.

The nine man squad of the BFV includes a gunner and commander who occupy and operate a turret equipped with a 25-mm automatic gun, a 7.62-mm coaxial machine gun, and a TOW missile system. These weapons are employed with the Integrated Sight Unit (ISU) that allows target detection and engagement under unobscured and limited visibility conditions. The turret also contains smoke grenade launchers which can be used for concealment along with a smoke screen generator mounted on the hull. Six M231 5.56-mm firing port weapons (FPW) with seven accompanying vision blocks are mounted on the hull for use by squad members in the troop compartment.

The 25-mm gun provides infantry with an unprecedented capability to defeat the Soviet Union's main personnel carrier, the BMP. Armor piercing discarding sabot-tracer (APDS-T) ammunition is designed to kill personnel carriers and other light-skinned vehicles. High explosive incendiary-tracer (HEI-T) ammunition for the 25-mm gun also extends the infantry's capability to deliver suppressive fire, area fire, and provide overwatch for dismounted infantry. Targets that are beyond the 900-meter tracer burnout range of the 7.62-mm coaxial machine gun can be engaged up to a range of 3000 m with HEI-T ammunition.

The BFV is designed to move and shoot at the same time. Squad members in the turret and troop compartment are capable of acquiring and engaging targets while moving. Furthermore, observation and delivery of fire can be achieved with protection from small arms and indirect fire. Firing port weapons and vision blocks allow close-in local security and the delivery of suppressive fire. These short-range capabilities complement the long-range observation and fire capabilities of turret-bound weapon systems. Both the coaxial machine gun and 25-mm gun are stabilized so that the gunner's sight picture is not affected by rough terrain and changes in vehicle direction.

The modern day battlefield will be laden with enemy tanks. Friendly tanks and other antiarmor weapon systems (e.g., Improved TOW Vehicle) provide the combined arms team with critical antiarmor capability that is now supplemented by the capabilities of the BFV to kill enemy tanks at ranges beyond 3000 m.

The BFV is designed to operate in both daylight and darkness. Squad members in the driver's compartment and turret have access to optical systems

that allow navigation, observation, and target engagement under all visibility conditions. The thermal mode of the ISU is the "light of darkness," presenting a heat signature of the environment during nighttime, smoke, fog, and other conditions that obscure battlefield visibility. The ISU, in both the day and thermal modes of operation, has 4-power magnification for scanning and target detection and a 12-power magnification for target engagement. Both the gunner and commander are capable of using the ISU.

In summary, the BFV is not an improved personnel carrier; it is a new fighting vehicle. Its speed and mobility permit it to maneuver as an essential part of the combined arms team; its firepower can be employed effectively in an antiarmor, anti-vehicular role; the 25-mm gun, coaxial machine gun, and FPWs enhance effectiveness in mounted operations; the infantry element can conduct dismounted operations utilizing organic dismounted weapons with vehicular support; and thermal and night vision devices allow target detection and engagement under limited visibility conditions. The Bradley, thus, represents a significant advance in the use of technology for the U.S. Army. As a result, however, the fielding of the versatile Bradley has required revisions in infantry tactics and techniques, training, and training methods. Optimizing operational effectiveness of the BFV is a fertile field for research.

The Army Research Institute BFV Project

Memorandum of Understanding

The memorandum of understanding for this project was co-signed on 31 May 1983 by the Director of the Training Technology Activity, Office of the Deputy Chief of Staff for Training, U.S. Army Training and Doctrine Command (TRADOC-TTA), the Assistant Commandant of the U.S. Army Infantry School (USAIS), and the Commander of the U.S. Army Research Institute (ARI). The memorandum established responsibilities for coordinated efforts to examine and evaluate currently evolving tactics, newly developing equipment, potential performance aids and techniques, and training programs for the BFV, with special emphasis upon fighting at night and in daytime limited visibility situations.

The final goal of the project was to provide usable products for BFV courses taught by USAIS and BFV units. To this end, specific developments within the project were identified and agreed upon jointly by Project Officers appointed by the three co-signing agencies. In this memorandum, the U.S. Army Infantry Center/School and the Fort Benning Field Unit, ARI, were identified as user/proponent organizations.

The Fort Benning Field Unit, ARI, initiated a contract with Litton Computer Services to implement the provisions of the Memorandum of Understanding. The contract was funded by TRADOC-TTA while personnel, equipment and facilities were provided by the USAIS and Fort Benning Field Unit, ARI. The two-year contract was approved and the project began on 1 September 1983.

The Two-Phase Plan

The overall project was divided into two phases. Phase I was conducted during the first year of the contract. Bradley tactics, equipment, and training were reviewed and analyzed to determine critical issues, deficiencies, and areas of improvement. This served as a basis for recommending approaches for developing solutions. Potential areas of improvement were prioritized for subsequent development. Product or concept development was tested and evaluated during Phase II. Emphasis was placed upon night and limited visibility training and operations in this phase. In summary, Phase I identified and prioritized potential areas of improvement in BFV operations and Phase II developed and tested potential solutions for the areas of improvement with the highest priority.

Research Approach for Phase I

Potential areas of improvement in BFV gunnery were identified, based on the integration of information and data collected from a wide range of sources. These sources included: tactical literature; gunnery training literature; observation and participation in USAIS courses providing gunnery training; participation in gunnery-related conferences and meetings; observation of field exercises; and interactions with gunnery students, instructors and other gunnery experts. The role and importance of this information will be described below.

Tactical literature was reviewed from the squad through the battalion level for BFV-related field manuals (e.g., FC 7-7J, 1985) to obtain an understanding of the intended use of the BFV in a combat environment. A review was conducted of all mechanized infantry instruction provided in the main stream courses conducted by USAIS (BNCOC, ANCOG, IOBC, and IOAC).

The BFV gunnery field manual (FM 23-1, 1983, 1986) was reviewed to determine gunnery principles, methods, and techniques. Gunnery field manuals for tanks (FM 17-12-1, 1982) were reviewed because of the many similarities between tank and BFV gunnery. The technical manual for the turret of the BFV (TM 9-2350-252-10-2, 1984) also was examined in those areas related to gunnery.

Review of gunnery training included examination of the programs of instruction (POI) for the three courses that train BFV gunnery (BFV Gunner Course, BFV Master Gunner Course, and BFV Commander Course) at Fort Benning. Tasks, conditions, and standards were reviewed as well as lesson plans and training aids/devices used to achieve gunnery training goals.

A substantial amount of effort was dedicated to observing and participating in USAIS courses that train gunnery. The BFV Gunner and Commander Courses were attended for one entire class each. The preliminary gunnery and live-fire gunnery portions of BFV training were observed in many other classes. An extensive dialogue with training cadre at all levels was developed and this group served as an important reservoir of subject matter expertise during the project. Conversations with students also provided a critical perspective.

BFV-equipped units in CONUS and Europe were observed during conduct of Army Training and Evaluation Programs (ARTEPs). Observers rode with the squad

on a 24-hour basis to obtain first-hand information of potential gunnery problems in a tactical environment. Observations were obtained also during an exercise (Operation Eagle) planned and conducted by the USAIS to test operational concepts for employment of the BFV and Abrams tank in a combined arms team. Because of the variety in locales visited and types of exercises observed, it was possible to examine operational performance under conditions of adverse weather, fatigue, equipment failure, and prolonged confinement of crew members within the BFV.

Finally, other extremely important aspects of the analysis involved: coordination with technical agencies; participation in seminars, briefings and workshops; and frequent interaction with the proponent. Background and technical details were assimilated on the BFV system and on emerging developments relevant to the BFV, and information was both disseminated and received on urgent problems and issues.

Data accumulated through these multiple approaches provided the basis for identification of areas of improvement that would optimize BFV operational effectiveness.

Development and Testing During Phase II

Phase I identified a number of potential areas of improvement that were important for both day and night activities. From this list of candidate research subjects, ARI, in coordination with the Infantry School, nominated a number of major areas as meriting further study or test. Indeed, the group of subjects constituted a larger menu than could be pursued within the scope of Phase II. Therefore, a specific and manageable list of candidate areas was selected for Phase II research.

These subjects were screened to include research relevant to the night and limited visibility environment, to comply with the original contractual guidance to the maximum extent possible. At the same time, there were a number of subjects which required an immediate research effort due to their importance in all combat environments. The following subjects were selected:

- o Gunnery techniques, procedures, training, and equipment;
- o Platoon/squad leader span of control;
- o Continuous operations;
- o Ammunition handling/storage equipment;
- o Troop compartment visibility;
- o Friendly vehicle identification;
- o Individual crew member equipment;
- o Thermal mode of the ISU;
- o The BFV Commander Course;

- o Night/limited visibility training;
- o Through the sight video;
- o Scaled vehicles/ranges.

Report Organization

The work completed during the development and evaluation phase (Phase II) has been documented in a series of reports (see Bibliography). The present report focuses upon the work done within the first subject area listed above, gunnery techniques, training, and equipment.

This report is organized by general topics related to the overall goal of ensuring the effectiveness of BFV gunnery. The next six sections of this report cover the topics of:

- o Boresighting and zeroing;
- o Range estimation;
- o Range cards;
- o Aiming point;
- o Preliminary gunnery training;
- o Full-caliber gunnery.

The first four sections discuss work resulting in the development or modification of gunnery techniques, procedures, and equipment. Specific development within a topic varies from conceptual development to completion of feasibility testing. Overall, the emphasis of the first four topics is on improved first-round accuracy of the 25-mm gun. The requirement for this is indicated by the following quotation:

Engaging targets out of range or any that do not insure a high probability of a first-round hit must be avoided by M2 gunners. (FC 7-7J, The Mechanized Infantry Platoon and Squad (Bradley), 1985).

The next section (preliminary gunnery training) includes training recommendations based on many of the developments reported in boresighting and zeroing, range estimation, range cards, and aiming point; these topics are included in preliminary gunnery training at USAIS. The content of the final section discusses training of live-fire, principles of target engagement, and gunnery qualification.

Each section of the report will provide background information for the particular topic area; i.e., a description of the topic and its importance in gunnery. This will be followed by discussion of the required improvements, the developmental process for the concept or prototype product, a feasibility or demonstrational test, and specific conclusions. Finally, conclusions are presented to provide the rationale for specific recommendations.

BORESIGHTING AND ZEROING

Introduction

Background

Boresighting and zeroing procedures are performed with the 25-mm gun to increase sighting accuracy. First-round accuracy is increased considerably when boresighting and zeroing are performed correctly. Boresighting is performed prior to the zeroing procedure to increase target hit probability during zeroing. Inaccurate boresighting can lead to target misses during zeroing, making it difficult for the gunner to perform accurate sighting adjustments. Target misses during zeroing also can lead to excessive ammunition expenditure because the gunner makes preliminary adjustments to obtain the first hit and then more rounds are fired to refine the zero.

Boresighting should be followed by zeroing for optimal sighting accuracy. In small-caliber weapons like the 25-mm gun, zeroing is required as a final sighting adjustment procedure because the aiming point of the gun bore during boresighting is not exactly the same as the location of round impact. Large-caliber weapons like the main gun of a tank have a close relationship between aiming point of the gun bore and round-impact location.

While zeroing refines the accuracy obtained by boresighting, it is not always possible to zero in combat conditions. In this situation, the accuracy of the sighting system will depend solely on the sighting accuracy achieved by boresighting.

Inaccurate sighting alignment during boresighting and zeroing can be caused by imprecise boresight equipment, inadequate procedures, and/or ineffective utilization of the equipment and procedures by the gunner. This section will report identified shortcomings in boresighting and zeroing and recommend potential improvements. Before this is done, a brief description will be provided on boresighting and zeroing the turret-bound weapons of the BFV.

Boresighting the BFV

Institutional training in the BFV Gunner and Commander Courses devotes a full day of preliminary gunnery training to boresighting, which is reflective of both the relative complexity of the task and the importance attached to it by USAIS. Boresighting the BFV weapons requires training and practice. Individual steps in the procedure are not difficult, but the number of turret-bound weapons and sighting reticles results in many steps requiring team-work for task completion. One acceptable sequence for aligning the turret-bound weapons with the various sighting systems, for a selected aiming point would be:

- o Align the ISU in day mode with the 25-mm gun;
- o Align the auxiliary sight unit with the 25-mm gun;

- o Align the coaxial machine gun with the ISU in day mode;
- o Align the ISU in thermal mode with the 25-mm gun;
- o Align the TOW launcher and TOW reticle.

The BFV gunnery field manual (FM 23-1, 1983, 1986) recommends use of a target for boresighting that has a 90-degree corner; this allows common alignment of the weapons and the various sighting reticles. The panel has a white background with a centered black cross and should be located at a range from 1200 to 3000 m.

The government furnished equipment (GFE) for boresighting consists of a 7.62-mm boresight telescope, a 25-mm adaptor, and a 7.62-mm adaptor. For the 25-mm gun, the adaptor is inserted into the gun barrel and the tapered stem of the telescope is inserted into the adaptor. The telescope and 7.62-mm adaptor are used for boresighting the coaxial machine gun while only the telescope is used with the TOW launcher.

Zeroing the BFV

The zeroing procedure aligns the sighting reticle with the location of round impact. As stated, boresighting is performed before zeroing to simplify the latter, because accurate boresighting results in an increased target-hit probability during zeroing. The gunner can make more accurate reticle adjustments if he can determine round-impact location.

Recommended procedures and equipment for zeroing turret-bound BFV weapons have undergone only minor changes during the last two years. The zeroing procedures provided in an earlier version of the BFV gunnery manual (FM 23-1, 1983) and the current version (FM 23-1, 1986), will be compared when necessary. The following description of zeroing will be based solely on those procedures outlined in FM 23-1. Observations on actual zeroing procedures will be made later in the section.

After boresighting, the 25-mm gun is zeroed using a boresighting panel positioned at a range of 1200 m. The earlier version of FM 23-1 (1983) recommends a 4-foot square target while a 6-foot square panel is recommended in the current version of FM 23-1 (1986). Zeroing begins with APDS-T ammunition if two ammunition types are fired. A round is fired, the 25-mm reticle is adjusted to round-impact location, and the sighting reticle is repositioned on the initial aiming point using the turret and gun controls; this sequence of steps is continued until the zeroing criterion is met or three rounds have been fired, whichever comes first. The criterion is met when round impact occurs within the 1-mil circle of the 25-mm reticle. Guns not zeroed in three rounds are boresighted again and three more rounds are allowed for zeroing. Direct support (DS) maintenance is notified if the gun can not be zeroed with the second set of rounds (FM 23-1, 1983, 1986).

Two rounds of HEI-T ammunition are fired as confirmation after zeroing with APDS-T ammunition. The gun is considered zeroed for HEI-T ammunition if the rounds hit the target. If either TP-T or HEI-T ammunition is used as the primary ammunition, then the steps outlined for APDS-T ammunition should be followed.

Objectives

An analysis of boresighting and zeroing was conducted to determine areas of improvement. Critical sources of information included training and tactical literature, subject matter experts, equipment manufacturers, and direct observation of gunnery performance in training and field settings. The overall analysis isolated the following critical topic areas, which are treated individually in subsequent sections:

- o Boresight equipment;
- o Dispersion and zeroing;
- o Zeroing ranges;
- o Target design;
- o The 400-m offset zeroing procedure;
- o The auxiliary sight.

Boresight Equipment

Observation of boresighting training during the BFV Commander Course revealed that boresight equipment often failed to meet current accuracy standards. When one student reported a problem with inaccurate equipment, the instructor stated that it was improbable that better equipment would be obtained in exchange for the current kits. While this was an isolated case, informal conversations with troops in tactical units and students and instructors in the institutional environment indicate negative opinions about boresighting the 25-mm gun. Comments of "useless" and a "waste of time" are frequently made during informal discussions of boresighting. The emotional nature of the reaction often makes it difficult to determine whether the user considers the procedure to be unnecessary or if the equipment is believed to be too inaccurate.

These anecdotes reveal two potential problems: the equipment and attitudes about the equipment. Observations of gunnery training over the past two years indicate the basis for these negative attitudes. Gunners frequently miss the zeroing target by substantial margins after boresighting with current equipment and procedures. Boresighting is considered a waste of time because it fails to produce noticeable levels of accuracy during zeroing procedures.

Approach and Findings

With these indications of equipment inaccuracy, a systematic analysis of GFE boresight equipment was conducted to determine the exact extent of the problem. The full details of that analysis are reported by Perkins and Wilkinson (1987) and are summarized below.

The initial part of the analysis focused on the accuracy of typical boresight kits (telescope plus 25-mm adaptor) at Fort Benning. Eighteen pairs of adaptors and telescopes were obtained by hand-receipt from the Basic Issue

Item (BII) room of a BFV company. Two different tests of equipment accuracy were used.

Accuracy of the kit. The first test assessed the capability of GFE boresight equipment to indicate the true centerline of the gun-bore. A boresight assembly manufactured by the Wild-Heerbrugg Corporation was used to determine the true centerline of the gun bore. The amount of error in GFE equipment was established by determining the distance between the aiming point of the GFE boresight telescope and the Wild-Heerbrugg assembly.

Of the 18 kits tested, the typical kit had an aiming point that was 1.42 mils from the centerline of the gun bore. There was extreme variability from kit to kit; values ranged from 0.54 to 2.0 mils. One third of the kits were inaccurate by 2 or more mils. This amount of error is more than sufficient to cause the gunner to miss a zeroing target; this will be discussed in greater detail in a subsequent section.

The second accuracy test was the telescope rotational procedure. This is used in unit and institutional environments where special equipment (e.g., a Wild-Heerbrugg assembly) is not available to measure the true centerline of the gun bore. For the test, the telescope is positioned to one side and then rotated 180 degrees with the adaptor remaining stationary and emplaced in the gun-bore. The difference in the aiming point of the telescope before and after telescope rotation is an indication of the level of accuracy. According to standards specified in FM 23-1 (1983), a telescope should be submitted to organization maintenance if the aiming point shifts by more than 0.5 mils during telescope rotation. Ideally, the amount of reticle shift after rotation of the telescope is twice that of the true error in the system. For example, if the reticle aiming point shifts 0.5 mil, then the equipment should provide aiming points that are within 0.25 mils of the true centerline of the gun-bore.

None of the 18 kits passed the standard specified in the test version of the gunnery manual (FM 23-1, 1983) for the telescope rotation test. The typical kit (median of the group) had an aiming-point shift of 2.1 mils during 180-degree rotation of the telescope; this value is 4 times that allowed by standards.

Accuracy of the 25-mm adaptor and telescope. The preceding analysis focused on the average accuracy of a sample of boresight kits as they are currently issued to soldiers. Additional analysis was then conducted to examine the accuracy of the individual components of the kit. One highly accurate 25-mm adaptor was identified to use as a constant in a test of a sample of telescopes. Similarly, one highly accurate telescope was identified and used to test a sample of adaptors. The best adaptor and telescope met accuracy standards when assembled as a kit; the shift in telescope aiming point during 180-degree rotation of the telescope for this pairing was very small (0.15 mils). Test adaptors and telescopes were obtained from two sources; (a) the BII room of a BFV company; and, (b) a pool of telescopes and adaptors used by BFV course instructors.

The operational status of the tested telescopes varied; i.e., new, used, and recently turned in for direct exchange (DX). Accuracy varied with operational status. New telescopes paired with the good adaptor produced reading errors that were 0.6 mils from the gun bore centerline. Used telescopes had about a 1.0-mil error while DX telescopes had a typical error of

1.52 mils. Comparison of telescopes in varied levels of operational performance (i.e., new, used, and DX) suggests that telescopes become more inaccurate with repeated use. Quality control in the manufacturing of telescopes may or may not be adequate, but it is clear that repeated use is a major contributor to inaccuracy of the telescope.

The typical adaptor (median of the group), when paired with the good telescope, produced an aiming point that varied 1.3 mils from the centerline of the gun bore (as determined by the Wild-Heerbrugg boresight equipment). In general, the typical adaptor was less accurate than the typical telescope. However, the worst telescopes were much more inaccurate than the worst adaptors. In other words, the range of inaccuracy for telescopes was considerably greater than for adaptors. Quality control in manufacturing of the adaptor may be a problem because one of the least accurate adaptors had not been used prior to testing.

Focusing the telescope. Observations of equipment use indicate problems in focusing the boresight telescope. A common complaint is that confirmation of the telescope reticle aiming point is difficult because the aiming point shifts with changes in the observer's head position. This probably is caused by incorrect focusing procedures. Students in institutional courses often adjust the two focusing rings (the eyepiece and the vernier focus dial) simultaneously.

Newly manufactured telescopes now have instruction labels giving the procedure for adjusting the telescopes. The eyepiece is used to focus the reticle and the image of the target is focused using the vernier focus dial. Following these instructions should alleviate many of the problems encountered by soldiers when attempting to focus the telescope.

Conclusions and Recommendations

Extensive analysis of GFE boresight equipment at Fort Benning indicated significant levels of inaccuracy. However, interpretation of the results is complicated by multiple accuracy standards for the telescope and the lack of performance standards for the adaptor and the kit. Depending on the source, the telescope does not pass standards if 180-degree rotation of the telescope produces a reticle aiming point shift of either 0.5 mils (FM 23-1, 1983) or 1.0 mils (AMCCOM, 1985), or if the 90-degree rotational test shows a deviation of 1.0 mils (TM 9-2350-252-10-2, 1984). Multiple standards complicate performance evaluation by experienced testing agencies; however, the most significant impact is on the soldier. The confusion in guidance undoubtedly has a negative impact on unit and institutional assessment of existing equipment.

The lack of testable standards and testing procedures for the adaptor, that can be used in the units, produces a major problem. If the fit between the adaptor and telescope is poor, then reticle shifts during rotation of the telescope may be caused by either the adaptor or the telescope, and the unit has no way of determining which one is the major cause of inaccuracy. A good adaptor would be required to test telescopes and a good telescope would be required to test adaptors. However, a soldier can not determine if a telescope is good without a good adaptor and vice versa, and there are no known guidelines for soldiers and units to make this type of assessment.

The requirement for standards for the telescope, the adaptor, and the complete kit, is a result of the two-piece design of GFE equipment. Separate standards for the telescope, adaptor, and complete kit would not be required if the equipment was designed as a single component. The 180-degree test is a valid assessment of equipment accuracy if there are no changes in the optical alignment of the equipment during the test. This does not occur with the two-piece design because the telescope rotates in the adaptor during the conduct of the 180-degree rotational test. Problems associated with the two-piece design are further complicated because the telescope and adaptor are manufactured by different companies.

The inaccuracies in equipment at Fort Benning justify many of the negative attitudes toward boresighting and the equipment. Until improved boresighting equipment can be fielded, the problem can be addressed by development of improved standards and equipment screening procedures. In a recent meeting, AMCCOM recommended "turn in bad boresights." The scope of the boresight equipment problem needs further identification if appropriate steps are to be taken to insure that effective equipment is available in the field. One of the best ways to indicate the level of the problem is to turn in all equipment that fails to meet accuracy requirements. A coordinated approach to setting and applying reasonable standards to the present boresight equipment would facilitate this effort. The ARI Fort Benning Field Unit is currently developing screening procedures for telescopes and 25-mm adaptors, and for the components combined.

In summary, the analysis of GFE boresight kits presented here supports the following specific recommendations.

Recommendation 1. Develop screening procedures for the GFE telescope, adaptor, and complete kit.

Recommendation 2. Boresight equipment not passing the standards specified by AMCCOM should be turned in to direct support maintenance.

Recommendation 3. The sight picture of the telescope should be adjusted by using the eyepiece to focus the reticle, followed by use of the vernier focus dial to focus on the target, as recommended in the instruction label provided on newly manufactured telescopes.

Dispersion and Zeroing

Ideally, every round fired would hit the same spot on the target if the aiming point is held constant, but in practice, rounds scatter around a "center-of-impact." The amount of scatter around the center-of-impact is called dispersion. Mathematically, the level of dispersion is indicated by a value called the standard deviation. The larger the standard deviation, the larger the scatter around the shot-group center.

Factors that affect projectile dispersion include the ballistics of the ammunition, characteristics of the gun, excessive erosion and wear in the gun bore, and the mounting of the weapon to the turret. Dispersion of 25-mm ammunition varies with its intended use. An ammunition designed for point-type targets has a lower level of dispersion than ammunition intended for area-type targets. The APDS-T ammunition was designed as a point-type ammunition for

engaging light-and thin-skinned vehicular targets. Area-type targets are engaged with HEI-T ammunition. The training ammunition (training practice with tracer, TP-T) is ballistically matched with the HEI-T round.

During zeroing procedures, better sighting adjustments can be made if the gunner can determine precise round-impact location. Dispersion affects target hit probabilities; therefore, the level of dispersion in the ammunition will affect the zeroing process. Under ideal conditions (i.e., no gunner or system errors other than dispersion), target hit probabilities are determined by the ammunition dispersion level, the target range, and the target size. Accurate sighting adjustments during zeroing will depend greatly on deliberately selecting a target range and size that will produce the highest probability of target hits that can be obtained for a given level of dispersion.

Dispersion also will affect the criterion for zeroing accuracy. Zeroing is performed to align the sighting system with the center-of-impact. The accuracy of this alignment depends on how well the fired round represents the average center-of-impact. A single round may not provide a good estimate of average center-of-impact if a high level of dispersion exists. This is why small-caliber weapons are often zeroed using the center of a three-round shot group.

Approach and Findings

Because dispersion affects so many aspects of BFV gunnery including zeroing, an analysis was conducted to predict the effects of varied levels of dispersion on target hit capabilities. The portion of the analysis related to zeroing focused on hit probabilities for zeroing targets of different sizes and at varied ranges. Further calculations estimated the effects of dispersion on the zeroing criterion. The details of this analysis are presented in Perkins (1987c) and the results relevant to zeroing are summarized here.

Table 1 presents target hit probabilities determined by mathematical analysis, for zeroing targets that were 4-, 6- and 8-foot squares located at ranges from 400 through 1600 m, at 200-m intervals. Hit probabilities were estimated for dispersion values (i.e., standard deviation) that varied between 0.3 and 1.0 mils. The maximum allowed dispersion for HEI-T ammunition and the training ammunition is 0.77 mils; the value for APDS-T ammunition is 0.44 mils.

Of primary interest in Table 1 was the dispersion value of 0.80 mils which is slightly above the maximum limit for TP-T and HEI-T ammunition. The currently recommended zeroing panel is a 6-foot square at a range of 1200 m (FM 23-1, 1986). The hit probability for this target (for a dispersion value of 0.80 mils) was only 45 percent. A hit probability of 90 percent or greater was obtained with ranges of 800 m and less with a 8-foot square target (for a dispersion value of 0.8 mils).

Table 1

Predicted Target Hit Probabilities (%) for Zeroing Targets

Target range (m)	Target size (ft)	Dispersion (standard deviation in mils)									
		.30	.35	.40	.45	.50	.60	.70	.80	.90	1.00
400	4 x 4	100	100	100	100	100	98	95	90	84	78
	6 x 6	100	100	100	100	100	100	100	99	98	96
	8 x 8	100	100	100	100	100	100	100	100	100	100
600	4 x 4	100	99	98	96	93	84	74	65	56	49
	6 x 6	100	100	100	100	100	98	95	90	84	78
	8 x 8	100	100	100	100	100	100	99	98	96	93
800	4 x 4	98	95	90	84	78	65	54	45	40	32
	6 x 6	100	100	99	98	96	90	82	73	65	57
	8 x 8	100	100	100	100	100	98	95	90	84	78
1000	4 x 4	93	86	78	69	62	49	37	32	26	23
	6 x 6	97	98	96	93	88	78	67	57	49	42
	8 x 8	100	100	100	99	98	93	86	78	69	62
1200	4 x 4	84	74	65	56	62	38	29	23	20	16
	6 x 6	98	95	90	84	78	65	54	45	34	32
	8 x 8	100	99	98	96	93	84	74	65	56	49
1400	4 x 4	74	63	54	46	37	29	22	19	15	12
	6 x 6	95	89	82	74	67	54	43	35	29	25
	8 x 8	99	98	95	91	86	74	63	54	46	37
1600	4 x 4	65	54	45	38	32	23	19	15	12	9
	6 x 6	90	82	73	65	58	45	35	29	24	20
	8 x 8	98	95	90	84	78	65	54	45	38	32

The results of the hit probability analysis indicated the importance of selecting targets at less than the currently specified range of 1200 m, if possible. This distance originally was selected because it minimized the effects of parallax between the ISU and gun throughout expected ranges of target engagement. An analysis of effects of zeroing at ranges shorter than 1200 m will be treated in the next subsection. Before this is discussed, the effects of dispersion on zeroing criterion will be presented.

The effects of dispersion can be illustrated using dispersion zones. These zones are circles that indicate the percentage of rounds that should hit within the circle. Figure 1 illustrates 50- and 90-percent dispersion zones

TP-T DISPERSION ZONES

Single Rounds

3-Round Centers

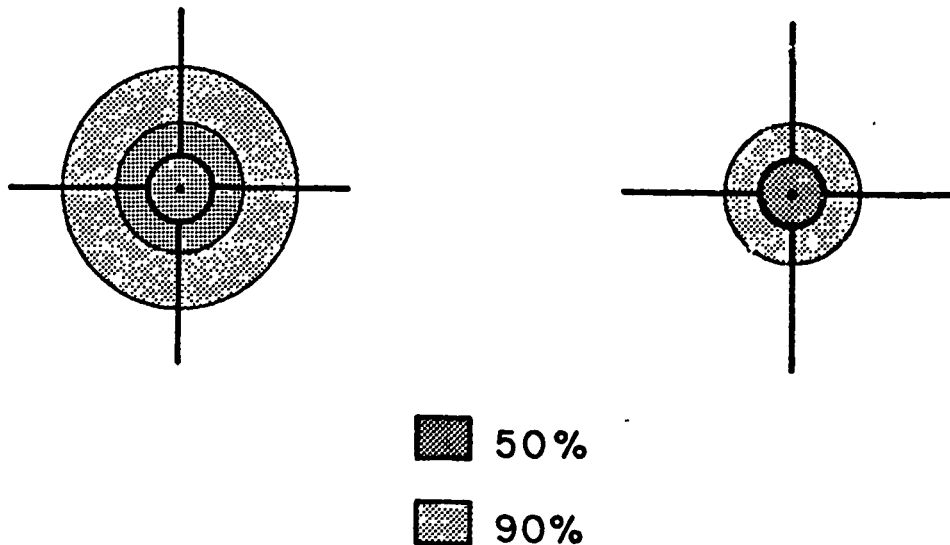


Figure 1. Illustration of 50 and 90-percent dispersion zones with maximum allowed dispersion for TP-T and HEI-T ammunition; predicted dispersion zones for individual rounds and centers of three-round shot groups.

when the dispersion level is 0.77 mils (maximum tolerance for TP-T and HEI-T ammunition). The figure shows the center-cross of the 25-mm reticle; the 1-mil circle has 2-mil lines extending from the outside of the circle. The dispersion zones are superimposed on the reticle. The 50-percent dispersion zone is the predicted area of impact for 50 percent of rounds fired; the outer limit of the 90-percent dispersion zone represents the area within which 90 percent of rounds will fall.

The left portion of Figure 1 illustrates dispersion zones when single rounds are fired. Fifty percent of the rounds would fall within a circle that is 1.8 mils in diameter. A circle 3.4 mils wide would be required to capture 90 percent of the rounds. Based on considerations for ammunition alone, it would be unrealistic to have a zeroing criterion (single round) for TP-T/HEI-T ammunition that is less than 3.4 mils.

The center of a three-round shot group can provide greater zeroing accuracy than sighting adjustments based on a single round. The right portion of Figure 1 illustrates the predicted dispersion zones for centers of three-round shot groups. Ninety percent of three-round shot group centers for TP-T ammunition should fall within a circle about 1.9 mils in diameter. The center of impact of three-round shot groups, therefore, gives a better estimate of the true point of impact than can be obtained with adjustments performed after single rounds.

Conclusions and Recommendations

Small-caliber weapons often are zeroed using the center of three-round shot groups. For a particular amount of dispersion, the dispersion zone for a three-round shot group is about 50 percent smaller than for a single round. That is, the size of the criterion circle for a three-round shot group would be about one-half that for single rounds. Because of the dispersion characteristics of TP-T and HEI-T ammunition, a better estimate of average center-of-impact is provided by three-round shot groups as compared to single rounds. Since three rounds are allowed for zeroing TP-T and HEI-T, reticle adjustment could be made based on the center-of-impact of the rounds.

Analysis of target hit probabilities for zeroing targets of different sizes and at varied ranges predicts a low hit probability for the recommended 6-foot square target at 1200 m (FM 23-1, 1986). The potential use of larger targets at shorter ranges will be discussed in more detail in the subsequent subsection.

A separate report (Perkins, 1987c) presents additional details related to the analysis of projectile dispersion. These data support the following recommendations.

Recommendation 4. The center of a three-round shot group should be used as the basis for reticle adjustment when zeroing with TP-T and HEI-T ammunition.

Recommendation 5. Based on current knowledge, the best estimates of criteria for zeroing accuracy are:

- o 2 mils for TP-T and HEI-T ammunition, for the center of a three-round shot group;
- o 2 mils for APDS-T ammunition, for a single round;
- o 1 mil for APDS-T ammunition, for the center of a three-round shot group.

These values represent the diameter of the criterion circle. A 2-mil criterion means that the zero obtained is anywhere from 0 to 1 mil from the true center-of-impact. Half-mil accuracy or better can be obtained with a criterion level of 1 mil. Use of a three-round shot group for APDS-T ammunition would be beneficial if a particular vehicle was expected to have primarily long-range engagements.

Zeroing Ranges

The ISU is located to the left of and up from the 25-mm gun bore. This parallax is compensated for by zeroing, but only at the range at which zeroing is performed. The aiming-points of the sight and round-impact location will differ at ranges shorter and longer than the zeroing range. To minimize parallax, the target range selected for zeroing should minimize the amount of parallax through the span of ranges that targets will be engaged.

The recommended zeroing range of 1200 m results in low hit probabilities on the zeroing target with TP-T/HEI-T ammunition having maximum allowed levels of dispersion. Therefore a shorter zeroing range would improve sighting adjustments if the shorter ranges would not create too much parallax or misalignment between the sight and the weapon at targets engaged beyond the zeroing range. A shorter target range also would make it easier to observe round-impact location, which should improve zeroing accuracy.

There are other considerations for zeroing at ranges besides 1200 m. The terrain at Fort Benning does not always support effective placement of a panel at 1200 m. Gunners at Fort Benning almost always zero at target ranges shorter than 1200 m. When zeroing at other target ranges, it is important to select targets at even numbered 200-m increments because these are the only values that can be indexed into the fire-control system. One favorite zeroing target on Ruth Range is a dark green frontal view of a BMP at 900 m.

The observation that zeroing is not always conducted at the recommended range of 1200 m and the prediction that 1200 m may be too long to allow high target hit probabilities with TP-T/HEI-T ammunition, suggested the need to analyze the effects of zeroing ranges on the amount of parallax between the sight and round-impact location at varied target engagement ranges.

Approach and Findings

The distance between the aiming point of the ISU and round-impact location was calculated for distances both shorter and longer than the zeroing range. Parallax was determined for zeroing performed at 600, 800, 1000, and 1200 m. Parallax and projectile drift were considered in the calculations. The analysis was conducted separately for APDS-T and TP-T ammunition and for both the day and thermal modes of the ISU. Separate analyses were required for the two modes of the ISU because the day sight is positioned further to the left of the gun than the thermal sight.

Table 2 presents predicted parallax between the ISU aiming point and center-of-impact for target ranges up to 1800-m, (which is just beyond tracer burnout range for APDS-T ammunition), when zeroing was performed at 600, 800, 1000, and 1200 m. Tracer burnout for HEI-T ammunition is 2400 m. However, given the dramatic effect of wind and the ranging accuracy required past 1600 m, the effects of parallax were considered to be the least of the problems with using HEI-T ammunition for target ranges beyond 1600 m.

The data in Table 2 reflect the fact that parallax is zero for targets at the same range at which zeroing is conducted (e.g., the parallax for the 600-m zeroing range is 0.0 when engaging targets at 600 m). For targets up to the zeroing range, line-of-sight is to the left of the center of impact (negative scores). For target ranges longer than the zeroing range, the line-of-sight is to the right of the center-of-impact (positive scores). These relationships hold for APDS-T ammunition, but are not necessarily true for TP-T ammunition because of the considerable drift in the flight of the projectile as target range increases.

Examination of data for TP-T ammunition using the day mode of ISU operation indicates that parallax differs little for zeroing ranges of 800, 1000, and 1200 m. When compared to these latter ranges, the 600-m zeroing

range results in considerably more parallax at target ranges beginning at 800 m. For TP-T ammunition fired in the thermal-mode of operation, 1000-m and 1200-m zeroing ranges produced the least overall parallax.

Inspection of Table 2 suggests that the optimal zeroing range for APDS-T ammunition fired in the day mode is 1000 m. The 1000- and 1200-m zeroing ranges have similar parallax at target ranges beyond the zeroing range but the 1000-m zeroing range shows less parallax at target ranges of 1000 m and less. The APDS-T ammunition in thermal mode has the least overall parallax at zeroing ranges of 1000 and 1200 m; a zeroing range of 800 m is only somewhat less effective.

Conclusions and Recommendations

The BFV gunnery field manual (FM 23-1, 1983, 1986) specifies that zeroing be conducted at 1200 m. However, at Fort Benning, the majority of the boresighting/zeroing panels are placed at ranges other than 1200 m because terrain considerations often affect target placement on the ranges used for BFV gunnery training and live-fire.

The optimal zeroing range depends on parallax between the sight and gun, operational mode of the ISU (i.e., day or thermal), ammunition dispersion, projectile drift, and engagement ranges. The parallax data indicate that 1000 m is the optimal range when both types of ammunition and both modes of ISU operation are considered. The data also suggest that targets positioned at 800 m results in zeroing only somewhat less effective than at 1000 m.

In the event that even-numbered ranges cannot be obtained for zeroing, compensation in sighting adjustment can be made. For example, the following procedure allows compensation for incorrect range control settings for target ranges of 900 and 1100 m when using TP-T ammunition. Zeroing for 900 m should be conducted with a range index of 800 m while zeroing at 1100 m should index 1000 m. After all zeroing rounds have been fired and the reticle adjustment made based on the location of the rounds, the boresight adjustment knobs should be used to elevate the reticle 1 mil (i.e., the width of the center circle on the reticle), which is an estimate of the required compensation.

These conclusions support the following recommendations.

Recommendation 6. Effective zeroing of the 25-mm gun can be performed at distances shorter than 1200 m.

Recommendation 7. Conduct zeroing using targets positioned at an even-numbered range interval whenever possible; zeroing not conducted at these ranges should make a compensatory reticle adjustment as the final step.

Target Design

Clear feedback on round-impact location is critical for effective sighting adjustments during zeroing. Extensive observations of gunnery performance identified aspects of target design that fail to optimize zeroing accuracy. These factors are discussed below, along with potential modifications that may improve feedback on round-impact location.

Table 2

Direction and Magnitude of Parallax (Mils) Between the ISU Line-of-Sight and Center-of-Impact for Selected Combinations of Zeroing Range and Target Range

Zeroing range (m)	Target range (m)								
	200	400	600	800	1000	1200	1400	1600	1800
TP-T in day mode									
600	-15.2	-8.0	0.0	8.0	12.1	14.7	21.2	15.2	13.1
800	-17.2	-12.0	-6.0	0.0	2.2	2.8	7.2	-0.7	-4.8
1000	-17.9	-13.0	-7.4	-1.8	0.0	0.2	4.3	04.0	-8.5
1200	-17.7	-12.9	-7.4	-1.8	-0.1	0.0	4.0	-4.4	-8.9
TP-T in thermal mode									
600	-10.9	-5.8	0.0	5.8	7.8	8.2	12.5	4.4	0.1
800	-12.4	-5.7	0.2	0.6	-0.7	2.4	-7.2	-13.0	-27.9
1000	-12.5	-8.9	-4.7	-0.4	0.0	-1.2	1.6	-8.1	-13.9
1200	-12.3	-8.5	-4.1	0.3	1.0	0.0	-2.9	-6.5	-12.2
APDS-T in day mode									
600	-16.0	-8.0	0.0	8.0	16.0	19.4	26.6	33.2	41.0
800	-18.0	-12.0	-6.0	0.0	6.0	7.4	12.6	17.8	23.0
1000	-19.2	-14.4	-9.6	-4.8	0.0	0.2	4.2	8.2	12.2
1200	-28.4	-23.7	-18.7	-14.1	-9.4	0.0	4.0	7.9	11.9
APDS-T in thermal mode									
600	-11.7	-5.8	0.0	5.8	11.7	12.9	17.9	23.0	28.0
800	-13.1	-8.8	-4.4	0.0	0.0	4.2	7.7	11.3	14.9
1000	-14.0	-10.5	-7.0	-3.5	0.0	-1.0	1.6	4.3	7.0
1200	-12.9	-9.4	-5.9	-2.4	1.1	0.0	2.7	5.4	8.1

The bottom edges of boresighting/zeroing targets at Fort Benning do not rest on the ground, and it is often difficult to determine whether a round either penetrated or passed under the target. Targets positioned on the ground or at ground level provide better visual feedback for rounds hitting in front of the target.

Location of round impact can be detected more easily if the tracer can be tracked all the way to target impact or penetration. The color of the target relative to the tracer is critical in tracking the tracer. The currently-used white boresighting/zeroing target makes it difficult to follow the bright tracer of 25-mm ammunition all the way to the target.

A zeroing target with a dark background allows better detection and localization of the projectile. As observed during institutional training and conduct of experimental zeroing procedures by ARI, zeroing can be performed on dark green vehicular silhouettes provided they are positioned at appropriate ranges. Combination boresighting and zeroing targets could be designed to have a predominantly dark background, with boresighting and firing aiming points added using a bright color (e.g., white). One possible target design is a color reversal of the current panel; a white cross could be centered on a darkly colored background. Another possible target could have a white edge around the outside of the target for boresighting and a white center dot for an ISU aiming point. However, a center of mass marking is not necessary for zeroing with the ISU because it is relatively easy to position the center circle of the reticle on the target center.

At Fort Benning, all targets except the boresighting/zeroing targets have automated scoring devices to record target hits. Knowledge of hits and misses is as critical for zeroing as for normal target engagement, and a zeroing target should have the same round-impact detection mechanism as do other targets on the range.

The latest version of FM 23-1 (1986) recommends a 6-foot square zeroing panel. Boresighting/zeroing targets at Fort Benning measure 8 feet. Relative to the smaller sized targets, this 8-foot target allows a greater target hit probability under ideal conditions (see Table 1), and offsets some of the negative effect of factors to include boresighting inaccuracy and ammunition dispersion. Effective zeroing would be supported by use of a larger panel than currently recommended in the gunnery manual.

Conclusions and Recommendations

In order to increase the probability that zeroing rounds impact on the zeroing target and provide the gunner clear feedback on the exact location of impact, improvements in the present panel configurations can be made. Specifically, the following recommendation presents four considerations for boresighting/zeroing panels.

Recommendation 8. Targets used for zeroing should have the following characteristics:

- o The bottom of the target should be, or appear to be, flush with the ground;

- o The background color should be dark green or some other dark color;
- o The panel should be connected with an automated scoring system, if available;
- o The recommended boresighting and zeroing panel should be an 8-foot square.

The 400-m Offset Zeroing Procedure

The preceding analyses focused on a number of factors that have negative impact on zeroing. For example, inaccurate boresighting and excessive ammunition dispersion can lead to target misses, making reticle adjustment more difficult. Further, round-impact location is difficult to detect at recommended zeroing ranges because holes in the target are not visible with the ISU and the white boresighting panel does not facilitate locating round penetration by the brightly colored tracer.

Therefore, equipment and procedures were developed with the intent of overcoming many of the potential difficulties associated with zeroing the 25-mm gun. Equipment and procedural modifications were developed to achieve the following objectives:

- o Design a combined boresighting/zeroing panel;
- o Increase likelihood of hitting the zeroing target after boresighting;
- o Improve estimation of round-impact location;
- o Improve zeroing accuracy.

Approach

A full report of the details of panel design, development of procedures, and experimental evaluation of the 400-m offset zeroing procedure can be found in a report by Perkins and Wilkinson (1985); these details are briefly summarized here. The first step was to design a boresighting/zeroing panel that incorporates the modifications suggested in earlier analyses. Figure 2 illustrates the recommended version of the 400-m offset zeroing panel. The 8-foot square target uses a dark green background. A center dot was used as the aiming point for the gun bore (indicated by the boresight telescope), with circles of 2- and 4-mil diameters surrounding the center-dot. An important additional feature for this short-range target is the use of a yellow cross for the ISU aiming point, placed at an off-set distance from the gun-bore aiming point.

Boresighting was performed prior to zeroing, using off-set aiming points for the ISU and gun bore. The distance between the aiming-points of the ISU and 25-mm gun compensates for the effects of parallax between short-range zeroing (i.e., 400-m) and zeroing at the recommended ranges of 1000 or 1200 m. Even though zeroing was conducted at 400 m, the line-of-sight and trajectory of the round crossed between 1000 to 1200 m.

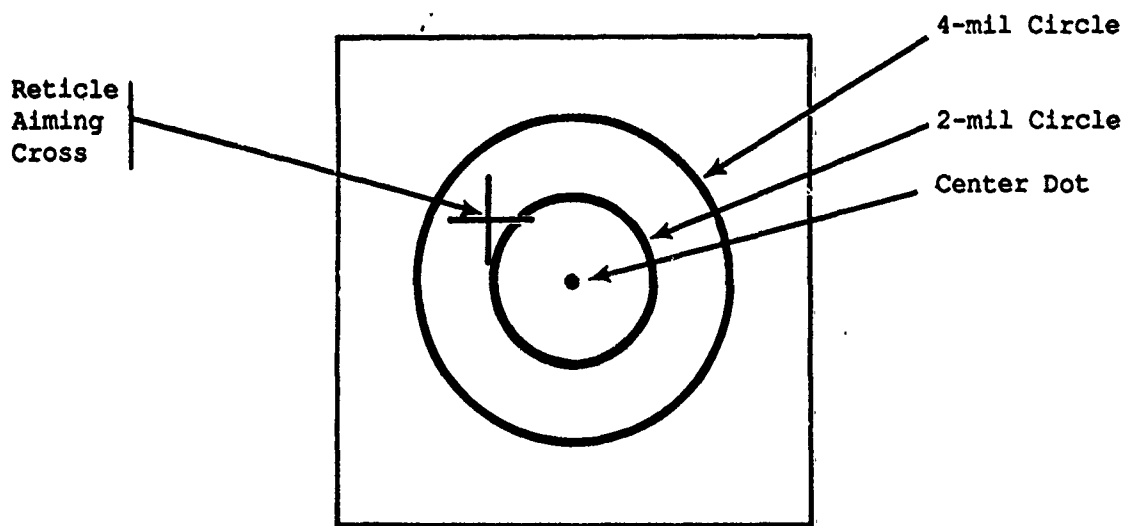


Figure 2. Illustration of the 400-m offset zeroing panel.

Following development of the panel, procedures for use of the 400-m offset panel were specified. Three-round shot groups were used with TP-T ammunition to increase zeroing accuracy. As discussed earlier, a shot group gives a more accurate and reliable estimate of the true center-of-impact, particularly with an area-type ammunition like HEI-T and TP-T ammunition.

Recording of round-impact location was a team task. The gunner fired the rounds and usually plotted round-impact location on a score sheet while the commander observed. Data plotted on the score sheet allowed the BFV commander and gunner to concur on estimated round-impact location.

Play or slack between the gun and sighting systems when the direction of the gun-elevation drive is reversed is called backlash. A standardized gun-lay procedure minimizes the effect of backlash during live-fire. A common gun lay technique used by the armor community is the "G-pattern." Movement of the gun and turret are such that the reticle "draws" a G-pattern during gun lay. After the initial loop of the "G," the final and critical movement is elevation of the gun. Gun lay during boresighting and 400-m offset zeroing were performed using the G-pattern.

The modified panel and zeroing procedures were tested after development was completed. There were three stages in the feasibility test. After boresighting, the first three rounds were fired at the 400-m offset panel and the ISU reticle was adjusted based on the shot-group center. Next, a second set of three rounds were fired on the 400-m offset target to determine the sighting accuracy obtained with the first reticle adjustment. Finally, confirmation of zeroing accuracy was conducted by firing a third three-round shot group at a 1000-m target.

Two experiments were conducted; zeroing was performed by students of one BFV Commander Course (Experiment 1) and one BFV Gunner Course (Experiment 2). Course selection was based on availability of students during the desired time

frame of testing. The 400-m offset zeroing procedure was substituted for normal zeroing procedures during live-fire training exercises.

Findings

Effect of boresighting on round-impact location. One difference between Experiments 1 and 2 was the accuracy of the boresighting equipment used. Experiment 2 was conducted using boresight equipment that was the most accurate of that equipment evaluated and reported on in an earlier subsection (Boresight Equipment). Experiment 1 was conducted with equipment normally used by the instructors for USAIS courses that train BFV gunnery.

Figure 3 illustrates location of shot-group centers for the initial three rounds fired after boresighting. The inner- and outer-circles in the figure are 2- and 4-mils in diameter. Part A of Figure 3 represents location of shot-group centers after boresighting with equipment brought to the range by instructors, while data for Part B were obtained using the most accurate equipment as determined by prior evaluation.

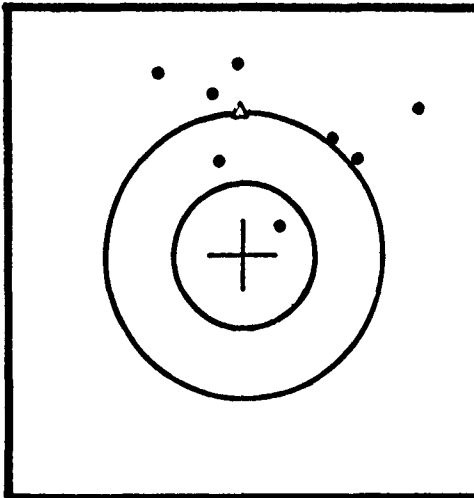
Round-impact location after boresighting with unscreened equipment was considerably above the center of the target. The average distance of shot-group centers from the target center was 2.7 mils. Use of the screened boresight equipment resulted in dramatically improved accuracy as indicated by data in Part B of Figure 3; the average distance of shot-group centers was 1.05 mils from the target center.

With screened boresight equipment, five of six shot-group centers were within the 2-mil circle of the target. This would have been a valuable asset if zeroing had been conducted at the currently recommended range of 1200 m (FM 23-1, 1986). While FM 23-1 (1986) recommends use of a 6-foot target for zeroing, the boresighting and zeroing targets at Fort Benning measure 8-foot square, which is a visual size of 2.1 mils. Although rounds were fired at a 400-m target, the data suggest that five of six shot group centers would have hit the 1200-m target when accurate boresight equipment was used.

Accuracy of adjustment. A second three-round shot group was fired on the 400-m target to determine the level of accuracy that was achieved by the first reticle adjustment. The average shot-group center fell 0.7 mils (Experiment 1) to 0.8 (Experiment 2) mils from the center of the target. In the two experiments combined, 13 of 14 of the shot-group centers (93%) fell within the 2-mil circle of the target. The only shot-group center outside the 2-mil circle was from a vehicle that missed the 400-m target after boresighting.

Confirmation. A third three-round shot group was fired on a target at 1000 m for confirmation. A 1200-m target was not available on firing lanes used for testing. A very high percentage of rounds hit the 1000 m target. The desired 1000-m target was not always operational so a 900-m target was substituted when necessary. With 1000 m indexed into the fire control system, rounds on this target were above the center-of-mass of the target.

A. UNSCREENED



B. SCREENED

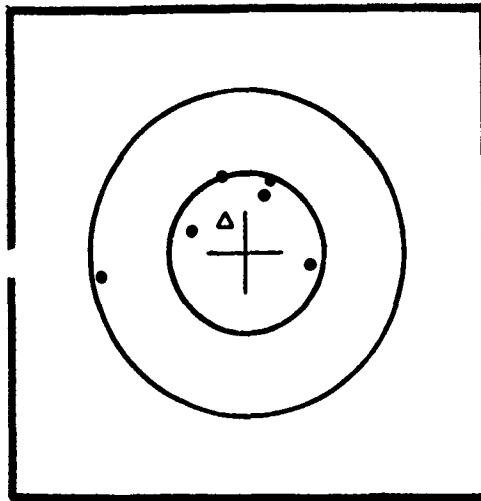


Figure 3. Illustration of the center of three-round shot groups for TP-T ammunition following boresighting with (A) unscreened and (B) screened boresight equipment.

Conclusions and Recommendations

The 400-m offset zeroing procedure was designed to be used as an alternative zeroing procedure when boresighting inaccuracy, excessive ammunition dispersion, and combat-related factors do not favor normal zeroing procedures. Experiment 1 indicates that effective zeroing can be obtained at 400-m even when boresighting is performed first with unscreened, inaccurate boresight equipment. Rounds hit the target even after extremely inaccurate boresighting. Target hits, on the first shot group, allowed quick and effective reticle adjustment.

Use of accurate boresight equipment produced sighting alignment that was only slightly less accurate than that produced by firing of rounds to zero. With accurate boresight equipment, shot-group centers were 1.05 mils from

target center after boresighting and 0.8 mils from target center after the first reticle adjustment.

The 400-m offset zeroing procedure could also be useful in combat environment. Current zeroing equipment and procedures for the 25-mm gun will not necessarily be applicable to a combat environment. White panels will not be down-range. Furthermore, operational security is not maintained when zeroing is performed from defensive positions. The 400-m offset-zeroing procedure was designed to allow zeroing in a smaller area of terrain away from defensive positions (e.g., the backside of a large hill or mountain). Potential techniques are discussed in a separate report (Perkins & Wilkinson, 1987b).

Importantly, the confirmation test fired at a range of 1000 m demonstrated that the zero obtained with the 400-m offset procedure is effective at a target range that would be used with standard zeroing procedures. In general, the results of the field testing support the following recommendations.

Recommendation 9. The 400-m offset zeroing procedure should be used as an alternative zeroing procedure when boresighting inaccuracy, excessive ammunition dispersion, and combat-related factors do not favor normal zeroing procedures.

Recommendation 10. Gun lay during both boresighting and zeroing should be performed using the "G" pattern to eliminate slack or play between movement of the gun and sighting systems.

The Auxiliary Sight

The BFV gunnery field manual (FM 23-1, 1983, 1986) noted that the auxiliary sight would be used if either the ISU was not operational or turret backup power was not functioning. In that it is impossible to predict either of these occurrences, particularly in a combat environment, the auxiliary sight should always be ready for use. Therefore, the auxiliary sight should be referenced or adjusted to the ISU every time the 25-mm gun is zeroed. This may seem to be unnecessary in most training environments, but the task should be performed to reinforce the proper zeroing procedures that will be needed in combat. When both HEI-T/TP-T and APDS-T ammunition are fired during zeroing, the auxiliary sight should be adjusted during zeroing with APDS-T ammunition because it is more accurate (i.e., has less dispersion) and is less affected by wind (FT 25-A-1, 1984).

Recommendation 11. The following information and procedural details related to the auxiliary sight should be implemented for training and training literature:

- o Always adjust the sight to the ISU after zeroing with the 25-mm gun;
- o When the 25-mm gun is zeroed with APDS-T ammunition, followed by confirmation with either TP-T or HEI-T ammunition, then the auxiliary sight is referenced after zeroing with APDS-T ammunition.

RANGE ESTIMATION

Introduction

Background

Range estimation affects target engagement accuracy with the 25-mm gun. Underestimation of range results in rounds falling short of the target, while rounds fly over the target if range is overestimated. The latter case is often considered the more serious error because burst-on-target adjustments are more difficult if the gunner cannot determine round location as it passes the plane of the target. The effects of range estimation errors are less critical with APDS-T ammunition than TP-T and HEI-T because APDS-T has a much flatter trajectory.

Estimating maximum engagement ranges is critical for BFV weapons, particularly for the TOW missile system. Engaging targets beyond the maximum effective engagement range can result in unnecessary expenditure of the limited number of missiles stowed on a BFV.

The gunner should know when a target reaches the tracer burnout range for 25-mm ammunition because the tracer is critical in determining direct fire adjustment. The HEI-T round has a longer tracer burnout range (2400 m) than APDS-T ammunition (1700 m). Accurate estimation of the tracer burnout range is more critical for APDS-T than HEI-T ammunition in that the high-explosive round produces a definite target signature on round impact at any range.

The fire control system of the BFV allows the gunner to set range control settings at 200-m intervals. Accurate range estimation is necessary for effective range setting when engaging targets with the 25-mm gun and coaxial machine gun. A first-round hit is very likely when target range and the range control setting are the same, the weapon is accurately zeroed, and the proper aiming point is used.

Current Range Estimation Techniques

Range estimation techniques are classified by the BFV gunnery manual as assisted and unassisted (FM 23-1, 1983, 1986). The unassisted techniques are based on the soldier's ability to estimate range without the aid of special equipment. The soldier's past experience is the critical factor in his ability to estimate range. Three assisted techniques are presented in the gunnery manual. These will be described below.

The WORM technique. This technique is recommended for long-range observation and surveillance. The soldier uses the reticle of the binoculars and the WORM formula to estimate range. The reticle is used to measure target size in mils (1/6400 of a circle). The formula for range estimation is:

$$\text{RANGE (M)} = \frac{\text{TARGET WIDTH (M)}}{\text{TARGET SIZE (MIL)}} \times 1000$$

Accuracy of range estimation using the WORM formula depends on both accurate measurement of target length and width in mils and knowledge of the actual size of the target. It is difficult to remember target sizes, so a quick reference table has been developed to simplify the procedure. The table categorizes targets into four groups. Three of these groups are vehicular targets while the fourth is for a HIND-D helicopter. Vehicles are categorized based on a common size; that is, vehicles in a particular group have similar side and frontal dimensions (FM 23-1, 1983, 1986).

When this table is used, range estimation is a four-step procedure. The soldier: (a) measures the target size in mils using the reticle of the binoculars; (b) categorizes the target as a front or flank view; (c) determines the target group; and (d) reads the range data listed in the table.

Techniques using ranging stadias. The sight picture of the ISU has a horizontal ranging stadia underneath the 25-mm reticle. The stadia is used to estimate range to a BMP based on the height of the vehicle. This stadia is used for precision gunnery (i.e., accurate range information required) from defensive and overwatch positions, when time permits.

The horizontal ranging stadia consists of two lines. The bottom line is level and has no markings. The upper line is slanted with range markings graduated at 500-m intervals for target ranges from 0 to 3000 m. The gunner aligns the reticle to "choke" the target between the top and bottom lines. Target range is estimated where the top of the target touches the upper slanted line of the stadia.

The stadia of the auxiliary reticle is designed differently. Range estimation is based on either the width (front) or length (side) of the BMP-sized target; this contrasts to the horizontal ranging stadia which relies on the height of the vehicle. The auxiliary stadia is used for precision gunnery when time permits. The stadia is designed to allow both range estimation and gun elevation correction during target engagement. Separate stadia markings exist for APDS-T and HEI-T ammunition.

Range cards. The preceding techniques are the only ones covered in the section entitled Range Determination in FM 23-1 (1986). Range cards are described in the section on Limited Visibility Engagements. As stated in the manual, range cards are used to plan and control fires, detect and engage targets, and orient replacement personnel or units. The phrase range card implies a critical role in range estimation; however, use of range cards for range estimation for either precision or battlesight gunnery is not discussed in the gunnery field manual (FM 23-1, 1986). Because of the potential use of range cards for purposes other than range estimation, a separate section of this report has been dedicated to the range card.

Objective

Range estimation is one of the more difficult tasks to perform, but effective performance is critical to effective BFV gunnery. During observations of gunnery training and performance conducted over the past two years, major areas of difficulty experienced by BFV gunners and commanders were noted and analyzed. The objective was to identify ways in which present range

estimation techniques could be simplified or improved. The following subsections will cover the topics of:

- o Understanding the mil;
- o Calibration accuracy of the horizontal ranging stadia;
- o Determination of frontal and flank views of a target;
- o A simplified quick reference table;
- o Measuring target width with the ISU gun reticle;
- o Range control setting and battlesight gunnery;
- o Using the reticle to determine critical engagement ranges.

Understanding the Mil

Technically, the mil is an angle that equals $1/6400$ of a circle. Mils are used to measure the visual size of the target; that is, how large the target appears to the observer. A practical understanding of the mil as a measure of visual angle is important for range estimation. Visual size of the target depends on its actual size (e.g., meters) and the distance from the observer. Therefore, as range increases the visual size of the target decreases.

The common military illustration of the relationship among mils, target size and distance, is that 1 mil equals 1 m at a range of 1000 m. The typical soldier probably knows this relationship; however, conversations with trainees and instructors indicate confusion about what a mil represents at ranges other than 1000 m.

In referring to the fact that 1 mil equals 1 m at 1000 m, FM 23-1 (1986) states that "this relation is constant as the angle increases from 1 mil to 2 mils and the range increases from 1000 m to 2000 m." This statement can be interpreted a number of ways. To insure that the relationship between a mil and range is more clearly understood, the analysis illustrated the meaning of the mil at different target ranges.

Approach and Findings

Size of target covered by a mil. The visual size of a target depends on its range, so a smaller target at a shorter range can have the same visual size in mils as a larger target at a longer range. Figure 4 illustrates this principle. The figure illustrates the size of a target in meters that could be viewed with a 1-mil field of view, as range increases. As indicated by this drawing, an angle of 1 mil covers a taller (or wider) distance as target range increases. Therefore, a 3-m target at 3000 m has the same visual size as a 1-m target at 1000 m.

A mil is used to measure angles while distances are measured in meters so it is somewhat confusing when a definition states that 1 mil is 1 m at 1000 m. In this statement, the 1 m refers to the physical size of the target that is

visible at 1000 meters with a 1-mil field of view. Therefore, 1-mil field of view covers a 1-m target at 1000 m.

While range estimation is the focus of this section, it is important to recognize that system and gunner errors also are measured in mils. For example, maximum allowed vertical play between the ISU and gun (i.e., backlash) is 2.0 mils, and maximum allowed dispersion for TP-T ammunition is 0.77 mils. As illustrated in Figure 4, a 1-mil error will have a greater affect on gunnery accuracy at 2000 m than at 1000 m.

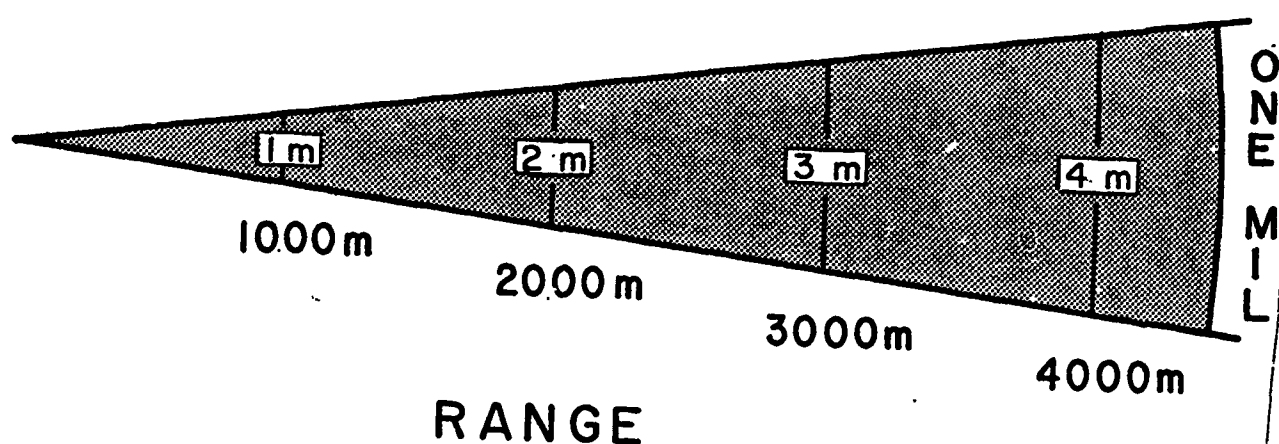


Figure 4. Size of target covered at different ranges by a visual angle of 1 mil.

Figure 4 illustrated actual size of an object covered by a 1-mil visual angle as range increases. The following describes how the visual size of a 2-m target changes as range changes.

Visual size in mils of a 2-m high target. Errors in range control setting affect the height of the round's trajectory. A range setting that overestimates distance to the target produces a trajectory that carries the round over the target, while underestimation of range results in rounds falling short of the target. The effects of ranging errors on the target hit probability will depend on the target height. Of the three dimensions (height, length and width) of a target, height is the smallest. A major limiting factor in the gunner's capability to hit targets often will be the visual height of the target. The following describes how the visual height of a BMP is affected by range.

The actual exposed height of a BMP depends on factors to include weapon systems attached to the turret and the amount of cover and concealment. To illustrate the effect of range on visual height of the target, the height of a

typical BMP was set at 2 m. The effect of target range on visual size of the target is illustrated in Table 3.

Examination of Table 3 indicates that the visual size of a 2-m target decreases from 2 to 1 mil as target range increases from 1000 to 2000 m. Visual size at the range of tracer burnout for APDS-T ammunition (i.e., 1700 m) was estimated to be 1.2 mils.

Table 3

Visual Height of a 2-m High Target at Various Ranges

Target range (m)	Visual size of target (mils)
200	10.2
400	5.1
600	3.4
800	2.5
1000	2.0
1200	1.7
1400	1.5
1600	1.3
1800	1.1
2000	1.0
2200	0.9
2400	0.8
2600	0.8
2800	0.7
3000	0.7

These data indicate that the margin for gunner and system errors is low from a range of 1000 m to tracer burnout (1700 m) when the target decreases in size from 2 to 1.2 mils. For this span of ranges, there is only 1 mil (1000 m) to 0.6 mil (1700 m) of exposed target above and below the center of mass. Projectile elevation errors that exceed these limits will produce target misses.

As illustrated in Figure 4, the effect of a 1-mil error will depend on target range. Round impact would deviate from target aiming point by only 1 m at 1000 m as compared to 3 m at 3000 m.

Again the effect of the gunner and system errors on target hit probability will depend on target size in mils; for example, a 1-mil elevation error will have minimal effect on a target 10-mils high (i.e., at a 200-m distance) as compared to a target only 1-mil high (i.e., at a distance of 2000 m).

Conclusions

The relationship between the size of a target, its range and visual size enters into many tasks performed by gunners. Detailed knowledge of the theory and principles is not required for effective task performance, but it is important for soldiers to have a working understanding of the concept of visual angle measured in mils. Currently, most gunners can state the common military example, which is that 1 mil equals 1 meter at 1000 m. It is doubtful that many know the size of target covered by 1-mil visual angle at distances greater or lesser than 1000 m, or what visual angle is produced by an object 2 m in size at varying ranges. Therefore, the following recommendation is presented.

Recommendation 12. Develop improved techniques to illustrate the concept and importance of the mil as it is related to range estimation and reduction of gunner and system errors.

Calibration Accuracy of the Horizontal Ranging Stadia

It is frequently stated during training that the horizontal ranging stadia is designed to estimate target range based on the height of a BMP. The recommended procedure for using the stadia (FM 23-1, 1986) is to choke the target between the stadia lines until the top of the BMP turret touches the upper line and then read the range according to the range markings on the upper line. For the size of target for which the stadia is designed, the distance between the two lines at any given range (e.g., 500 m) should be equal to the visual size (i.e., mils) of the overall height of the vehicle at that range.

Approach and Findings

An analysis was conducted to determine the size of vehicle for which the stadia is actually calibrated or designed. Analysis indicated that the actual vehicle height that would fit between the two stadia lines at each range, varied from about 1.5 to 1.7 m. These values are noticeably smaller than the height of a BMP (2.2 m) as given in the gunnery manual (FM 23-1, 1983). The actual calibration of the stadia, as determined in the analysis, more closely matches the height of the BMP hull rather than the top of the turret from which measurements are recommended (FM 23-1, 1986). When used as currently recommended, the stadia technique would produce a 25-percent range estimation error on the average.

Conclusions

Calculations revealed that the horizontal ranging stadia, as presently calibrated, indicate the range to objects 1.5 to 1.7 m in height. Therefore, the current recommendation to choke a BMP target at the top of the turret will incorrectly estimate range; in light of this, a change in the recommended procedure is required.

Recommendation 13. Estimate range with the horizontal ranging stadia of the 25-mm reticle, using the height of the vehicle as measured from the bottom to the top of the hull.

Determination of Frontal and Flank Views of a Target

Range estimation using the binoculars and the quick reference table requires the gunner to determine whether the target view is either frontal or flank. However, targets will not always approach with either full flank or frontal exposures. For targets at oblique angles, the gunner will have to determine whether the target should be categorized as a frontal or flank view. Currently, there are no guidelines to assist the gunner in categorizing target view as frontal or flank. The report by Perkins (1987b) describes a technique that will allow the gunner to categorize target view. The approach is summarized here.

Approach and Findings

As developed, the technique requires the gunner to identify the visible front and side portions of the vehicle, as illustrated in Figure 5. The amount of visible front and side of the vehicle depends on the orientation of the target to the observer, as will be described.

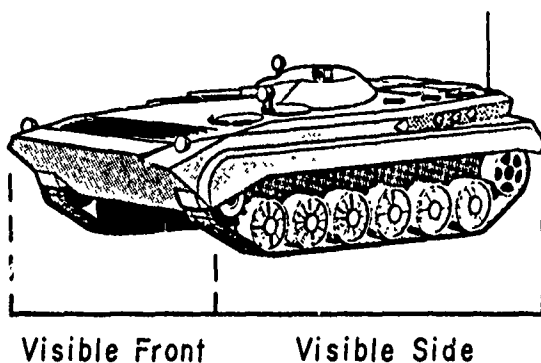


Figure 5. Amount of visible front and side of a BMP at a 45-degree angle to the observer.

For full-flank views (a 90-degree viewing angle), only the side of the vehicle is visible while only the front can be seen for full frontal views (a 0-degree viewing angle). The relative amount of exposed side and front changes with the angle of the target to the observer, as does the total width of the vehicle. Figure 6 illustrates a BMP positioned at a 45-degree angle to the observer. As can be seen in the illustration, the side of the vehicle appears larger than the front. The distance between the vertical lines above and below the BMP indicate the amount of visible side and front at various viewing angles. The vehicle is widest (visible front plus visible side) at about 65 degrees rather than at the 90-degree full-flank view.

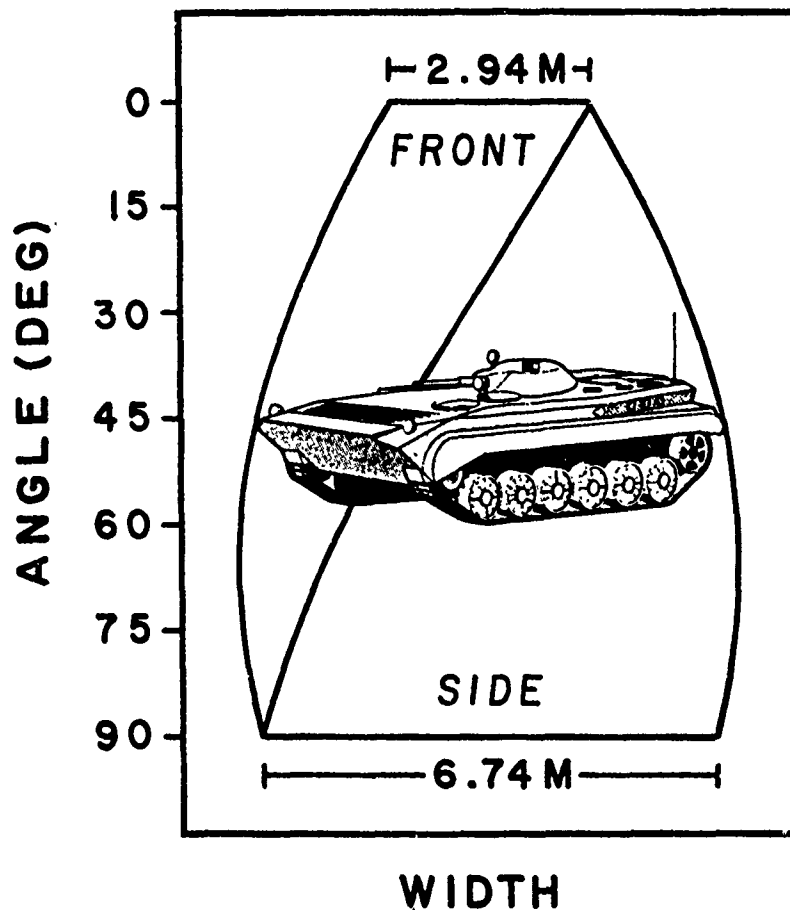
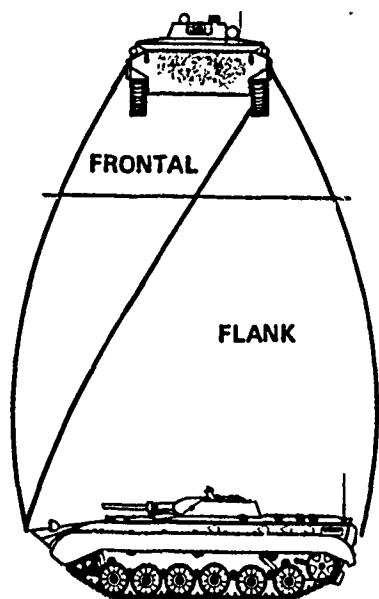


Figure 6. Illustration of the relative amounts of side and front of a BMP visible at different angles to the observer.

The analysis further demonstrated that the visible front and side of a BMP will appear nearly equal to the observer when viewed at a 25-degree angle. This supports a simple procedure that will be designated the "target view" (TV) technique. The target is categorized as a frontal view if the front appears larger than the side (as it will be at angles less than 25 degrees). For a target categorized as a flank view, the side of the vehicle appears larger than the front (angles between 25 and 90 degrees). A potential training aid for categorizing target view is presented in Figure 7.



- **FRONTAL VIEW**
Front Appears Larger
Than Side

- **FLANK VIEW**
Side Appears Larger
Than Front

Figure 7. Diagram illustrating a training aid for categorizing flank or frontal views of a target.

Conclusions

To use the quick reference table, the gunner must determine whether the target view is either frontal or flank. The gunner can easily categorize target view if only the front or side of the target is facing him; however, many targets will be oriented at oblique angles. The analysis presented above provides a technique that can be applied easily by the gunner and the following recommendation is presented.

Recommendation 14. Use the TV technique to categorize a vehicle as a frontal view if the front appears wider than the side and as flank view if the side appears larger than the front.

A Simplified Quick Reference Table

The organization of the table requires the gunner to categorize vehicular targets into one of three groups. To use the quick reference table, the gunner must first identify the target. Combat vehicle identification is difficult under ideal conditions and it is further complicated when long-range observation is required and thermal optics are being used.

Approach and Findings

An analysis was conducted to determine if the quick reference table requires three groups of vehicles. Details of the analysis are presented in the report by Perkins (1987b) and are briefly summarized here. Analysis indicated that visual size (mils) of the target Groups I and II varies little

for ranges beginning as short as 2200 m; therefore, Groups I and II were combined into a single group called Group I. The selected dimensions for the representative target (width = 3.00 m and length = 6.75 m) are intermediate to the values for Groups I and II in the current table. Personnel carriers and tanks in Groups I and II, respectively, represent the major vehicular targets for the BFV. Data for the single-vehicle target group is presented in Table 4. Target dimensions selected for the revised table allow effective range estimation for a BMP-sized target engaged with the 25-mm gun. The following recommendation is made.

Table 4

Recommended Data to Replace Groups I and II of the Current Quick Reference Table

Vehicle size (mils)	Target range (m)	
	Frontal-view	Flank-view
1.0	3000	6900
1.5	2000	4600
2.0	1600	3400
2.5	1200	2800
3.0	1000	2300
3.5	900	2000
4.0	800	1800
4.5	700	1600
5.0	600	1400

Recommendation 15. Replace data in Groups I and II of the current quick reference table with data in Table 4 to form a modified Group I.

Measuring Target Width with the ISU Gun Reticle

Accurate measurement of vehicle width in mils is required when estimating range with a reticle. Binoculars are recommended for measurement (FM 23-1, 1983, 1986) but, unfortunately, the gunner rarely has access to them. Even if he did, the 25-mm reticle provides the gunner with greater magnification, smaller graduated markings on the reticle, and a steadier position.

Approach and Findings

With the binoculars, the gunner measures width of the target with a reticle marked every 10 mils. This makes it difficult to obtain accurate measurement of long-range targets which may be as small as 1 mil in size. In contrast to the wide intervals of the markings of the binoculars, the ISU gun reticle has markings on the center cross at 2, 2.5, 3, and 5 mils, if readings are taken from one end of the cross to the other. Accuracy of measurement is further enhanced by the 71 percent higher magnification provided by the ISU relative to binoculars. Furthermore, it is possible to achieve a more stable sight picture with the ISU. Figure 8 illustrates positioning a target on the 25-mm reticle to measure target width.

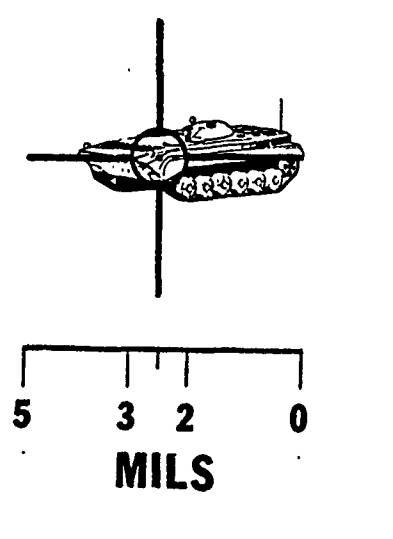


Figure 8. Illustration of a possible technique for measuring target width with the 25-mm reticle. The target measures 4 mils wide (range of 1800 m).

Conclusions

The binocular reticle can be used to determine target width for purposes of range estimation; however, the gunner will seldom have access to binoculars. In any case, the ISU gun reticle provides a preferable alternative because of the higher magnification, more precise mil markings, and a more stable platform. The center cross and adjoining lead lines provide markings at 2, 2.5, 3 and 5 mils. Furthermore, the gunner can be trained to recognize some simple relationships between these markings and critical target engagement ranges, as will be discussed in the next section. The following recommendation is presented.

Recommendation 16. Use the center cross and lead lines of the ISU gun reticle rather than the reticle on the binoculars, to measure target size for purposes of range estimation.

Range Control Setting and Battlesight Gunnery

Battlesight gunnery is a target engagement technique that produces the quickest delivery of fire with the 25-mm gun. The BFV gunnery manual (FM 23-1, 1983, 1986) recommends battlesight gunnery to place 25-mm fire on the enemy before he can fire. Reduction in engagement time is achieved if the gunner preselects both ammunition and the range control setting. A preset range setting eliminates the need to estimate range with stadia lines on the reticle. The battlesight gunnery technique is most effective for APDS-T ammunition because of its flat trajectory.

While battlesight range control settings are prescribed for quick and effective delivery of fire, the concept has utility on a more general basis. Use of a preselected range control setting eliminates the need to change the setting for every target engagement. A preselected range also minimizes the need for range estimation on every engagement if the gunner knows that the target is within the effective range for the battlesight setting.

The latest version of the BFV gunnery manual (FM 23-1, 1986) provides an example for determining battlesight range for targets beginning at point-blank range. With a center-of-mass aiming point on a 2-m high target, the battlesight setting for APDS-T ammunition is 1200 m.

Trajectory Curves

The trajectory of the round partly determines the effectiveness of battlesight gunnery techniques. The current analysis investigated the effect of varied range control settings on projectile trajectory (see Figure 9). In this illustration, the firing BFV is in a hull defilade position with its barrel 1 m above the ground. A center-of-mass aiming point is used on a 2-m target. The shaded area represents a 2-m target positioned at ranges from 0 through 2000 m. Each curve represents the trajectory of APDS-T ammunition with a different preselected range setting which is marked on each curve. These range control markings on the curves also were used to indicate potential target range; for example, the marking of 12 on the trajectory curve indicates a range control setting of 12 and a target range of 1200 m.

As indicated in Figure 9, a range control setting of 12 covers a 2-m high target from ranges of 0 through 1400 m with the exception of a small (0.1 mils or less) miss over the target at ranges between 500 and 700 m. A range control setting of 16 would produce hits at ranges from 1400 m through slightly over 1700 m. In other words, the two range settings of 12 and 16 would allow nearly total hit probability at target ranges from 0 through 1700 m for APDS-T ammunition.

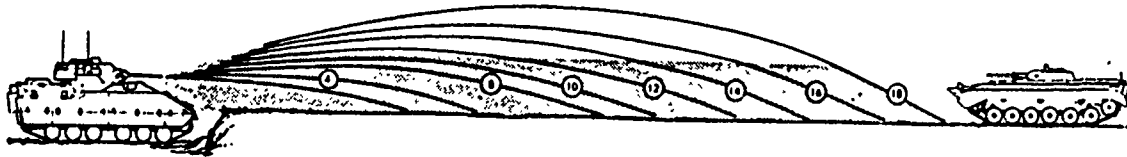


Figure 9. Illustration of the hit capability of APDS-T ammunition on a 2-m high target with various range control settings. A target hit is indicated for all portions of the trajectory curve that cross through the shaded area.

The HEI-T and TP-T rounds are not ballistically designed for engaging point-type vehicular targets. The HEI-T/TP-T round is produced with more dispersion, has a less flat trajectory compared to APDS-T ammunition, and does not have the penetration capabilities of APDS-T ammunition. Despite this, the gunnery manual (FM 23-1, 1986) recommends use of HEI-T against thin-skinned vehicles like the BRDM.

As indicated in Figure 10, a range control setting of 8 provides the widest range of target-hit capability for HEI-T/TP-T ammunition; target hits will occur from 0 through 900 m. Overall, HEI-T and TP-T ammunition have minimum tolerance for range estimation errors for target ranges beyond 800 m. The trajectory of HEI-T and TP-T ammunition does not allow establishment of meaningful battlesight ranges for engagement of vehicular targets beyond this range.

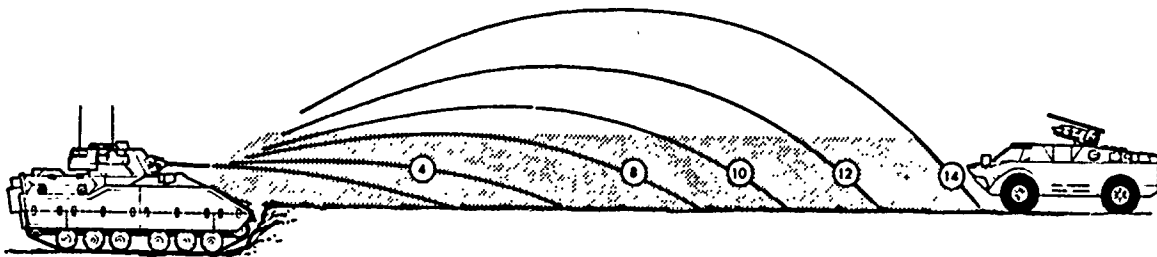


Figure 10. Illustration of the hit capability of HEI-T ammunition on a 2-m high target with various range control settings. A target hit is indicated for all portions of the trajectory curve that cross through the shaded area.

Burst-on-Target Adjustments for Short Rounds

It is frequently stated that the fire control system of the BFV was not developed for first-round hit capability. Burst-on-target (BOT) adjustments after first-round misses are supposed to allow target hits on subsequent rounds. Unfortunately the BOT technique will underestimate the necessary aiming-point adjustment for rounds that impact short of the target. The

trajectory curves presented in Figures 9 and 10 can be used to illustrate this fact.

Underestimation of direct-fire adjustment will be illustrated for a 2-m high target positioned at 1600 m. If an initial APDS-T round is fired with a range control setting of 12, then the round will hit the ground at 1400 m (see Figure 9). The gunner would make his adjustment based on the visual angle (mils) between center-of-mass of the target and the point of round impact. It was mathematically determined that the adjustment applied by the gunner using the BOT adjustment technique would be 0.7 mils. Superelevation data provided in the 25-mm firing tables (FT 25-A-1, 1984) indicate that a 1.4-mil correction would be required (i.e., the superelevation data are 3.7 and 5.1 mils, respectively, for ranges of 1200 and 1600 m). Therefore, the BOT adjustment estimated by the gunner would be half that actually required. The percentage of error becomes larger as range underestimation errors become greater.

The situation described for APDS-T ammunition also was applied to TP-T ammunition. As illustrated in Figure 10, the sensing round would hit the ground at about 1300 m. The adjustment made by the gunner would be 0.8 mils which is considerably less than the 5.4-mil correction that is indicated by the firing tables.

An alternative to the BOT-adjustment technique is changing the range control setting. This alternative could be applied for rounds that miss the target by 200 m or more and when rounds fly over the target. In this latter case, it is particularly difficult to perform direct-fire adjustment because the gunner may not detect where the round passed the plane of the target.

Conclusions

The gunnery manual (FM 23-1, 1986) describes how to determine a battlesight range for ammunition. The calculated battlesight range for a BMP-sized target is 1200 m for APDS-T ammunition. The current analysis confirmed this value and illustrated that a range control setting of 12 allows target hits through a range of 1400 m. Target ranges from 1400 m through 1700 m (tracer burnout), are covered effectively by a battlesight range control setting of 16.

The BFV gunnery manual does not specify a battlesight range for HEI-T and TP-T ammunition. The latter would be useful because TP-T is often used to train against targets that would normally be engaged with APDS-T ammunition. As a result of this analysis, the recommended battlesight range for HEI-T and TP-T is 800 m (see Figure 10). The trajectory of HEI-T and TP-T does not allow any other meaningful battlesight range for engagement of vehicular targets beyond the ranges covered by a battlesight range of 800 m; that is, any range control setting greater than 8 will produce first-round hits for only a small span of target ranges.

Battlesight gunnery is used when quick delivery of fire is required. Precision gunnery, which requires accurate range information, is used when time permits (e.g., during the occupation of a defensive position). However, time may not permit range estimation on each target engagement against an enemy with numerical superiority. Because of this, battlesight gunnery may be more widely used than currently indicated in the gunnery manual.

It is also critical to recognize that the effectiveness of battlesight gunnery is dependent on zeroing accuracy. Inaccurate zeroing will result in rounds that follow a trajectory that is either higher or lower than expected for a given range control setting.

Finally, it should be noted that the BFV gunnery field manual describes a procedure for calculating battlesight ranges for targets of varying heights. The procedure requires the 25-mm firing table which is not included in the manual. Firing tables provide the gunner with the critical information on his weapon system. The firing table should be available for the inquisitive gunner.

Therefore, the following recommendations would add important information to the content of BFV gunnery training.

Recommendation 17. Training literature should be developed to:

- o Specify two battlesight ranges for APDS-T, to cover target ranges up to tracer burnout;
- o Specify one battlesight range for TP-T and HEI-T ammunition;
- o Illustrate the effects of range control setting on projectile trajectory and target hit capability.

Recommendation 18. The 25-mm firing tables should be included in the BFV gunnery field manual.

Recommendation 19. When 25-mm rounds (a) miss a target by 200 m or more and (b) when they fly over the target, an alternative to BOT adjustment could be changing the range control setting.

Using the Reticle to Determine Critical Engagement Ranges

25-mm Engagements

There is a relatively simple method for determining when a target reaches the maximum effective range of 1400 m for a 1200-m battlesight setting with APDS-T ammunition. A flank view of a BMP is about 5 mils wide at 1400 m. This is the same size as either the total length of the center-cross of the 25-mm reticle or the distance between the edge of the cross and the far lead line. This is illustrated in Figure 11. Similarly, a frontal view of a BMP reaches 2-3/4 mils at 1400 m, and this can be measured easily by the center cross of the reticle. Illustrations of the sight picture for a frontal view of a BMP is presented in Figure 12.

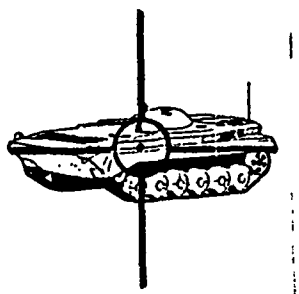


Figure 11. Size of a flank view of a BMP at 1400 m which is the maximum range for a battlesight range control setting of 12.

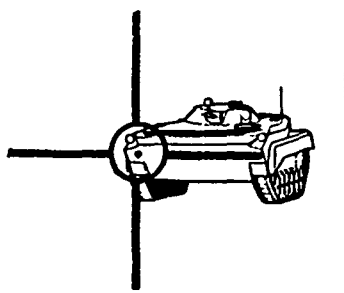


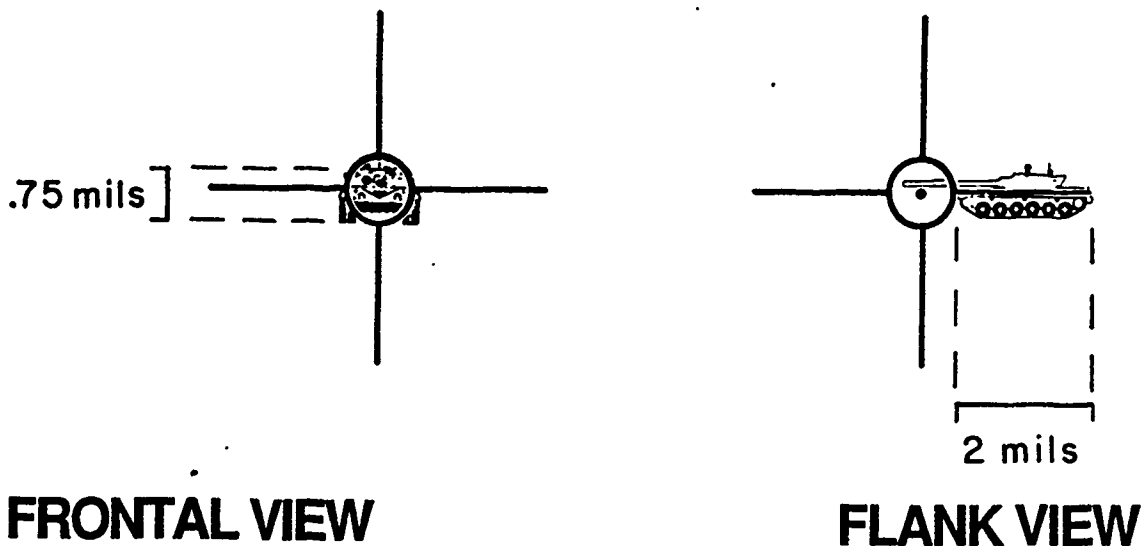
Figure 12. Size of a frontal view of a BMP at 1400 m which is the maximum effective range for a battlesight range control setting of 12.

TOW Engagements

The analysis of range estimation has focused on critical ranges for engaging targets with the 25-mm gun. However, the single most important range in BFV gunnery is the maximum effective engagement range for the TOW missile. Because of the importance of this range, guidelines were developed to allow the gunner to use the ISU gun reticle to determine when a target is within the maximum effective range of 3750 m.

The development of guidelines to determine the maximum effective range of the TOW considered the fact that the most serious range estimation error for a TOW engagement is to fire at a target that is beyond 3750 m. Therefore, the sight-picture rules that were developed are based on the visual size of a target that is at (or within) a range of 3750 m.

There are two critical target sizes for determining a maximum effective range of 3750 m. If a flank view of a target (determined using the TV technique) is 2-mils wide or larger, then the target is within 3750 m. A flank view of a tank with a 2-mil width is illustrated in Figure 13. Target range can be determined by target height in mils; a gunner can fire the TOW if target height is at least 0.75 mils. This is three-quarters of the diameter of the center circle on the ISU gun reticle, as illustrated in Figure 13.



Less Than 3750 M

Figure 13. Size of a tank target that is within 3750 m.

It is recognized that the ISU gun reticle is not available to the gunner when the TOW missile has been selected. Therefore, target size could be measured with the ISU gun reticle prior to selection of the TOW. Alternatively, BFVs could work in pairs, with one having TOW pre-selected and the other vehicle having the 25-mm gun prepared for fire. The latter vehicle would signal the TOW-ready vehicle when the target reached critical range. As will be discussed in the next section, the range card also can be used to estimate a target range of 3750 m. A terrain feature at that range could be selected and the TOW is fired when the target reaches the selected reference feature.

Conclusions

The size of the target as measured by the ISU gun reticle can be used to determine when the target has reached a critical target engagement range. Guidelines were developed to determine when a BMP-sized target has reached a range of 1400 m which is the maximum effective range for a range control setting of 12 for APDS-T ammunition. Target size of a tank within a range of 3750 m (maximum effective range of the TOW system) was also determined. The following recommendation is made.

Recommendation 20. Use the ISU gun reticle to determine critical engagement ranges for the TOW and 25-mm gun.

RANGE CARDS

Introduction

Background

A range card is a self-made job performance aid. The BFV gunnery field manual recommends use of the range card for planning and control of fires, for rapidly detecting and engaging targets, and for orienting replacement personnel or units (FM 23-1, 1986). The gunner prepares a BFV range card for all types of defensive fighting positions (i.e., primary, alternate, and supplementary) and during occupation of any other stationary position (e.g., in an assembly area).

The range card contains a sketch that represents critical terrain features within the sector of fire and observation. Other information to be placed on the card, as specified in the gunnery field manual, includes:

- o A symbol for the weapon;
- o Distance (meters) and direction (degrees) of the BFV from an easily recognized terrain feature or the eight-digit grid coordinate of the BFV position;
- o Boundaries of the sector to include right and left limits and maximum engagement lines;
- o Range, turret deflection, and gun elevation to critical terrain features from the vehicle's position as well as the ammunition/weapon selected to obtain the readings;
- o Dead space or areas that can not be observed or covered by fire;
- o Maximum engagement lines;
- o Direction of magnetic north when the range card is oriented to the terrain;
- o Unit designation, type of firing position, and time and date that the range card was prepared.

Each range card is made in duplicate with one copy given to the platoon leader. In addition to use by the gunner, the range card is used by the squad leader for preparation of a squad sector sketch to be used for planning for and controlling fires. All squad sector sketches within a platoon are then integrated by the platoon leader into a platoon sector sketch.

Objective

The analysis examined: (a) the required and possible uses of the range card; (b) the information that is most critical for each particular type of use; and (c) techniques for using and constructing the range card to optimize

each particular use. Concepts presented in this section are developmental in nature since they were not field tested during Phase II of the project.

Types of Range Cards

Background information was obtained by reviewing use of the range card by infantry with crew-served weapons, by mechanized infantry equipped with BFVs, and by armor crews. Literature sources examined included soldiers manuals and squad and platoon level tactical manuals. Preparation of range cards for crew-served weapons was examined to reveal similarities and differences in the use of range cards for crew-served weapons and for the BFV. Use of the range card by armor was included in the analysis because of the many similarities between use of the tank and use of the BFV. The focus of the following review and analysis is on the BFV range card, and not range cards for crew-served weapons and tanks. However, information related to the former type of range cards will be presented as necessary to provide background information related to the BFV range card.

Range Cards for Crew-Served Weapons

The Soldier's Manual of Common Tasks for Skill Level 1 (FM 21-2, 1982) lists three uses of the range card for the M60 machine gun. They are:

- o Place fires on designated targets during periods of limited visibility (e.g., night, fog, smoke);
- o Facilitate relief of a gunner;
- o Provide information for platoon and company fire planning.

A primary function of the range card for the M60 machine gun is to enable the gunner to fire at a target without actually observing it. Primary and secondary sectors of fire are marked on the range card and terrain features marking targets of opportunity are drawn in each sector. Weapon deflection and elevation settings are recorded in the data section of the range card for each designated target. A description of terrain features (i.e., lone tree) also are included on the range card.

Range cards for crew-served weapons are used by the squad leader to construct squad sector sketches. Primary items of information obtained from the range card for the sector sketch are the critical terrain features and range to them, primary and secondary fields of fire, final protective line (FPL), and dead space.

BFV Range Cards

Overall, there are minor differences in information required for a crew-served weapon and a BFV range card. The BFV range card requires ammunition/weapon designation for each reference feature, whereas the crew-served weapon range card does not. Furthermore, because of the variety of weapons on the BFV, more than one maximum engagement line is required for the BFV range card. Another difference is inclusion of a FPL for the crew-served

weapon but not the BFV. Despite minimal differences in the content of the crew-served and BFV range cards, there is a major difference in the way they are used. The BFV has greater capability to observe under limited visibility conditions. Unlike the M60 machine gun, the BFV does not have to fire "blindly" at targets. This results in differences in utilization of the range cards for BFV and crew-served weapons.

The current analysis divided uses of the BFV range card into the following categories:

- o Scanning and target detection;
- o Locating and reporting targets;
- o Acquiring reported targets;
- o Estimating range;
- o Planning and control of fires;
- o Replacement of personnel and units.

Under limited visibility conditions, the first three uses of the BFV range card are different than for the M60 machine gun and are primarily a result of the thermal-viewing capabilities of the BFV. The M60 range card is used to engage targets that are not visible. The thermal sight of the BFV allows the gunner to: (a) scan for and detect targets under limited visibility; (b) report detected targets and respond to designated targets relative to reference features marked on the range card; and, (c) estimate range to targets that are both on and around a designated terrain feature.

Techniques for using the BFV range card to aid in performing the preceding five tasks will be discussed after certain critical terms are defined.

Definition of Reference Features

Two types of references that should be included on the range card are:

- o Target reference points (TRP). Features designated at the platoon level for planning for and controlling direct and indirect fire, and for designating target locations and acquiring reported locations. It may be necessary to design TRPs for direct fire that are not used for indirect fire.
- o Squad reference point (SRP). Features designated and used at the squad/vehicle level when there is an insufficient number of TRPs available for scanning and range estimation.

The definition for a TRP is consistent with current infantry usage (FC 7-7J, 1985; FM 23-1, 1986). The SRP is a new term. The SRP is used at the gunner and commander level primarily for range estimation during target engagement and maintaining orientation to the terrain during scanning. The SRPs are added at the squad level when the number and location of TRPs is insufficient for target detection and range estimation. The TRPs and SRPs on

the range card should be clearly distinguished so that the platoon and squad leaders do not attempt to use SRPs with other squads.

While the final word in TRP and SRP is "point," it is important to recognize that not all reference features are points. Reference features can be categorized by the shape of the terrain feature. A point feature is a hill top, road intersection or any other feature whose location can be specified by a single distance and direction from the BFV. A linear feature is a road, stream or any other elongated feature that can be used as a phase line for the control of fire and as a means of estimating range (if it does not change significantly along the length of the feature). An area feature is a section of terrain that has both width and depth, where boundaries may be marked by point and linear features. Area features are used primarily for designating target engagement areas.

The following recommendations related to these definitions are presented.

Recommendation 21. Squad reference points should be added to the range card for purposes of scanning (target detection) and range estimation.

Recommendation 22. The SRPs and TRPs on a range card should be clearly distinguished.

Scanning and Target Acquisition

When a BFV moves into a stationary position, a top priority task is the initiation of scanning to detect the enemy. Scanning is usually restricted to a sector whose right and left limits indicate boundaries for scanning. Detection of potential targets is most critical at ranges within the maximum engagement ranges of both BFV and enemy weapon systems. Detection of the enemy beyond maximum effective engagement ranges also is critical for estimating time until enemy contact and other aspects of fire planning and control. Certain vehicles may scan above the horizon to detect enemy aircraft.

When using the ISU for scanning, it usually is not possible to observe the sector in its entire depth. And even if this were possible, a systematic scanning pattern would be necessary to insure that all terrain was thoroughly scanned. The following will provide further background on scanning and the relevance of the range card.

Scanning Within a Sector

The gunner must have a technique for scanning the sector in depth. During darkness, gunners have been observed to be disoriented. They were observed to be scanning directly in front of the BFV and in the skyline when aerial surveillance was not the objective.

The TRPs and SRPs could be used to indicate the shortest and longest distances in the sector. Identification of TRP/SRPs would indicate when the furthest distance of the sector had been reached. However, if appropriate reference features are not detected and the gunner gets disoriented, then the gunner should know the minimum and maximum gun elevation readings that indicate the shortest and longest ranges, respectively, in the sector. These elevation

readings could be marked on the range card using a technique that is described in a later subsection (entitled, A Technique for Recording Scanning Information).

The gunner must also maintain an appropriate orientation to the terrain so that scanning will be confined within designated lateral limits. The range card can be used to enhance scanning effectiveness, particularly when using the thermal mode of the ISU. Reference points should be used to determine when the right and left limits of a sector are reached during scanning.

It should not be overly difficult for the gunner to maintain his orientation to the terrain during unobscured or near-normal visibility conditions. By contrast, orientation may be less than optimal when the thermal mode is used, particularly during darkness when the terrain has lost much of the heat that was gained during daylight. In this case, the TRPs/SRPs marking the lateral limits may not be easily detectable. Furthermore, if the TRPs/SRPs are located at long range and the gunner is scanning at shorter ranges, then the depth of view may not allow detection of TRPs/SRPs for the limits. If the gunner becomes disoriented and cannot locate RPs, then the range card can be used to determine if scanning has occurred outside the limits. This could be achieved by comparing the value of the turret azimuth indicator with the deflection values on the range card for the right and left limits.

The 50-m Scanning Technique

The 50-m scanning technique is recommended in the BFV gunnery manual for scanning the sector in sections with the ISU. A section 50-m deep is searched during a scan (e.g., right to left), and each subsequent 50-m section should overlap a portion (about half) of the terrain observed on the previous scan. Scanning is performed with low magnification (4 power); high magnification is used for intensive investigation of a potential target.

A potential problem with the 50-m scanning technique is that an excessive number of scanning sections is required to cover a sector in depth. With a 50-percent overlap between subsequent 50-m sections, it would take 160 scans to cover a sector with a depth of 4000 m, which is just beyond maximum engagement range of the TOW. Use of the 50-m technique would take the gunner an unacceptably long time to complete scanning of an entire sector.

Depth of View

The gunner can see much more than 50 m in depth with the ISU. Depth of view is the span of ranges in which targets can be detected through the sighting system. For example, a 1000-m depth of view would allow the gunner to observe the terrain at all ranges between 500 and 1500 m. Observations during the conduct of thermal testing (see Rollier et al., 1985) indicate that it is possible to obtain a depth of view of at least 1000 m with the thermal mode in low power.

Given the potential depth of view that can be obtained using the ISU in low power for day and thermal modes, the depth of sections that can be observed during one scan could be considerably greater than 50 m. However, the depth of

view that can be effectively covered has not been formally determined for day or thermal modes of ISU operation.

Depth of view for a sighting system like the ISU is determined by the visual height of the view (visual angle) displayed through the optics. The height of the sight picture "window" in low and high magnification of the thermal mode is 60 and 20 mils, respectively.

The 30-mil Scanning Technique

About half of a 24-hour period involves darkness, so a BFV may pull into a defensive or stationary position and not be able to locate reference points. If TRP/SRPs can not be easily located or identified, then other techniques need to be used to insure systematic scanning.

Instead of using a scanning depth of only 50 meters, scanning depth could be determined by the amount of terrain visible through the ISU. Initial scanning could begin with gun elevation set for observing the shortest ranges in the sector. Gun elevation would be increased 30 mils (i.e., half the height of the sight in low magnification and thermal mode) on each successive scan. The depth of view of each scan would depend on the shape of the terrain. However, use of the 30-mil technique would allow a 50-percent overlap of terrain observed on the previous scan when the thermal mode is used in low magnification.

Thirty-mil increments in elevation could be achieved as follows. When the lateral edge of a sector is reached for a particular scan, the gunner could pick an object in the vertical center of the sight picture. The gun would then be elevated until that object was at the bottom of the field of view. An alternative method would be to use the gun elevation indicator and pointer to achieve 30-mil increments in scanning depth. A technique for recording gun elevation values for scan lines will be presented next.

A Technique for Recording Scanning Information

The present range card does not have a section for recording information that would help control scanning when TRPs can not be used as references. A special section could include the turret deflection readings for the right and left limits of the sector, and gun elevation readings for all scan lines. The illustration shown in Figure 14 provides a format for recording scanning-related data on the range card when the 30-mil scanning technique is used. A scanning data section of this type could be placed in the lower right or left area of the drawing on the range card.

This scanning data section also could be used when scanning at depths other than 30 mils. Gun elevation and turret deflection data could be recorded for any systematic scanning pattern that uses the same scanning locations throughout the sector. For example, scanning can be performed at 1000-m intervals (see Rollier et al., 1985). The gun elevation readings for each of these 1000-m intervals would be recorded in the scanning information diagram. If visibility conditions develop that make detection of reference points difficult (e.g., smoke), then the gunner would control scanning patterns using the gun elevation data.

LIMITS

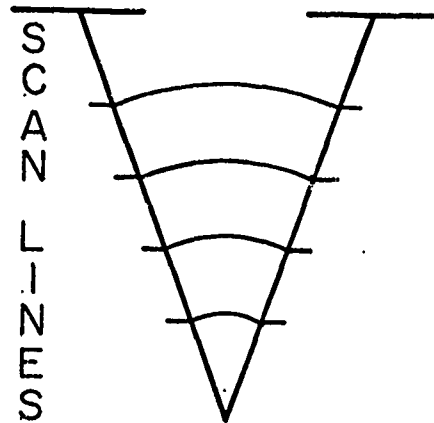


Figure 14. Illustration of a scanning data section that could be included on the BFV range card.

Thermal Scanning During Unobscured Visibility Conditions

Thermal scanning is a requirement under limited visibility conditions. Scanning in the thermal mode also can be highly effective during unobscured visibility conditions. Targets that may be concealed using the day optics may be visible through the thermal sight. The thermal mode of the ISU should be prepared for use during all visibility conditions because battlefield obscurants could produce limited visibility conditions quickly. Therefore, the gunner must always be prepared to shift immediately to the thermal mode of the ISU.

Range cards often are used for target engagement under limited visibility conditions and description of the BFV range cards in FM 23-1 is in the chapter entitled Limited Visibility Engagements. However, if a range card can provide data during the night, then it can provide it equally well during the day. Preparation of the range card by the gunner increases his familiarity with the terrain in his sector and it should be continually assessed and upgraded.

An unobscured battlefield may become visually obscured quickly, so the gunner should always know the appearance of the terrain as viewed through the thermal mode of the ISU. Terrain viewed in daylight conditions should appear familiar whether smoke is or is not present. The gunner should become familiar with the thermal signature of the terrain when scanning under unobscured visibility in preparation for limited visibility conditions that may develop quickly.

A possible technique for scanning during unobscured daylight conditions would be to alternate between day and thermal modes of the ISU during successive 30-mil scanning patterns. This technique would allow a 50-percent overlap between successive scans so that each section of a sector would be scanned in both day and thermal modes.

Conclusions

The gunner needs a systematic technique to insure that the entire sector is scanned in depth. The depth of view during scanning is largely determined by the height of the sight picture. The height of the sight picture in low magnification of the thermal mode of the ISU is 60 mils. This information is important for systematic scanning, particularly in cases where TRPs and SRPs are difficult to locate with thermal imagery. One possible technique for scanning in sections is to increase gun elevation by 30 mils on successive scans. This would allow a 50-percent overlap of terrain observed on the previous scan. Alternating between day and thermal modes of operation on successive 30-mil scans during daylight conditions could enhance target detection capability and allow the gunner to be more familiar with the thermal signature of the terrain.

Sectors are usually scanned in sections that extend between right and left limits. The TRPs and SRPs can be used to control scanning. If visibility conditions make detection of TRPs difficult, then a scanning technique like the 30-mil method can be used. If the 30-mil method is used, then gun elevation should be the same each time a particular section is scanned. And when right and left limits of the sector are straight lines, the deflection to each limit will be the same for every section in the sector. Figure 14 presents a technique for recording scanning related information in one portion of the range card to allow easy access by the gunner.

Scanning in the thermal mode of the ISU is a requirement in limited visibility conditions. Scanning during unobscured daylight conditions using the thermal mode would allow detection of images not visible using day or normal optics (e.g., camouflaged targets) and the gunner would become familiar with the thermal signature of the terrain in preparation for sudden changes in visibility conditions (e.g., smoke) that might require thermal operations.

Recommendation 23. The feasibility of using the 30-mil scanning technique should be examined.

Recommendation 24. Determine the feasibility of recording deflections for right and left limits and gun elevation for each scan line on a centralized location on the range card.

Recommendation 25. Determine the benefits of scanning with the thermal mode of the ISU in operational readiness under all visibility conditions and alternating scanning between day and thermal modes of the ISU during unobscured visibility conditions.

Recommendation 26. Use of range cards should be stressed during both daylight and limited visibility conditions to familiarize the gunner with the terrain.

Designating Target Locations and Acquiring Reported Targets

As a result of scanning, the Bradley commander may use TRPs to report potential target locations to the platoon leader. Conversely, a gunner or commander may be required to acquire a target based on information provided by the platoon leader. Based on the fire command delivered by the platoon leader,

the gun elevation and turret deflection data from the range card could be used to lay the gun on target. If the target is not positioned directly on the TRP, then the gunner would have to lay the gun at a particular distance and direction from the TRP.

The gunnery manual (FM 23-1, 1986) recommends that distance of a target from a TRP be reported in mils. Use of this technique requires a reticle marked in mils. The ISU gun reticle has markings with a total width of 20 mils for deflection measurements and a height of 5 mils for elevation. The platoon leader also provides the direction (e.g., right) of the target from the TRP.

The ISU gun reticle occupies a relatively small portion of the entire sight picture in low power of the thermal mode. When this is combined with the limited total length of reticle markings (5 and 20 mils in vertical and horizontal dimensions, respectively), the mil-adjustment method could have utility only for targets positioned relatively closely to the TRP.

A possible alternative adjustment procedure would be to use window forms of the sight picture. One window form is the view observed through the ISU. The distance from the bottom to the top of the ISU is one elevation window while the width of the screen is one deflection window. Directional commands (right/left and up/down) would be given with the window form data. In addition, references would be given when using low magnification because this presents a wider field of view.

The distance of a target from a TRP could also be given in meters. However, estimation of distances in front of and behind the TRP is difficult because depth of view is perceived as being shorter than normal with a magnified image.

In conclusion, targets do not always appear directly on the TRP. Reports of targets frequently require information on distance and direction of the target from a particular TRP. A recommended method for achieving this is to give target distance from the TRP in mils. A potential alternative method is to report target location in terms of fractions (i.e., one-half) of the ISU sight picture in low magnification.

Recommendation 27. The feasibility of using the window method to indicate target distance and direction from a TRP/SRP should be examined.

Range Estimation and Target Engagement

Critical Target Ranges

Accurate ranging data is critical for determining when to engage targets (i.e., maximum effective engagement range). The criticality of accurate range estimation within the maximum engagement range is dependent on a number of factors, to include the ballistics of the ammunition, the type of fire control system, and gunner errors.

The critical ranges for BFV gunnery are: (a) the maximum engagement range of the TOW missile; and (b) from 900 to 3000 m. The latter span of ranges is important for the following reasons. The maximum engagement range for the

coaxial machine gun is 900 m. This report recommends a battlesight range control setting of 8 for HEI-T ammunition; this setting results in hits on a 2-m high target for ranges extending from 0 to 900 m. Range estimation accuracy to within 200 m is critical for HEI-T beyond 1000 m because of the curved nature of the trajectory. Tracer burnout for HEI-T ammunition is 2400 m although FM 23-1 (1986) recommends a maximum effective range of 3000 m. For APDS-T ammunition, a battlesight setting of 12 can allow hit of a fully exposed 2-m high target out to a range of 1400 m. A range control setting of 16 will allow target hits from 1400 m to 1700 m for a fully exposed vehicular target. The TOW system has a line-of-sight fire control system. If the target is within maximum effective range of the system, then range estimation is not a problem.

In summary, some of the critical ranges for BFV gunnery are: (a) 900 m (i.e., maximum range for battlesight range setting of 8 for HEI-T and just beyond maximum effective engagement range for the coaxial machine gun); (b) 1400 m (i.e., maximum range for a battlesight range control setting of 12 for APDS-T ammunition); (c) 1700 m (i.e., tracer burnout for APDS-T ammunition); (d) 2400 m (i.e., tracer burnout for HEI-T ammunition); and (e) 3000 m or greater (i.e., maximum effective engagement range for the TOW missile). The ideal range card should have features designated at the critical ranges for BFV gunnery. In that there may not be enough TRPs to cover all necessary critical ranges, the gunner and Bradley commander should designate SRPs that meet range estimation requirements for gunnery.

Ranging Accuracy

The range card can be used as an aid for range estimation for gunnery. The range to a TRP/SRP is known and appropriate engagement procedures can be used based on the location of the target relative to the TRP/SRP. If the target is located away from the reference point, then it will be necessary to add or subtract the appropriate distance from the range to the TRP/SRP to obtain the range to the target.

It is important to emphasize that the utility of a range card for target engagement is largely determined by the accuracy of the ranging data. Ranges included on the range card are no more accurate than the methods used to estimate or determine range. The problem is further complicated when the target is located at positions other than the TRP/SRP. The target and TRP are viewed with magnification which produces an illusion of a shorter range than actually exists.

Mechanical devices like laser range finders (hand-held or ISU-integrated) present the best solution to accurate range estimation. Range estimation by soldiers may be a moderately reliable alternative if the correct soldier is chosen. In a review of range estimation, Thompson (1982) concluded that there may be merit in identifying soldiers that have a proven capability to estimate range. Range estimation training could both train all soldiers within a unit and identify those with the greatest ability. These personnel could be used within the platoon to perform the estimation task during preparation of range cards. The forward observer assigned to the platoon also is an important source of information for range estimation. Maps may also be used.

It should be emphasized that many of the uses of the range card do not require accurate range information. Targets can be detected, located, and reported, using only the deflection and elevation data within the data section. Once a target is detected and located, other techniques can be used to estimate range for the purposes of gunnery. These include use of the horizontal ranging stadia, the ballistic stadia of the auxiliary sight, and the 25-mm gun reticle used with the quick reference table.

Ammunition Selection and Range Control Setting

Elevation data for a TRP or SRP is determined by the type of ammunition selected and the range that is selected. Because of this, the designated ammunition/weapon for a TRP/SRP must be selected and the correct range set before the ISU reticle can be placed on the target. Field manuals for BFV gunnery (FM 23-1, 1986) and mechanized squad and platoon (FC 7-7J, 1985) do not provide guidance on ammunition selection for reference features. However, gunnery instruction on range cards at Fort Benning requires designation of ammunition/weapon for TRPs.

The requirement to designate target range and ammunition type for each TRP/SRP creates problems. As discussed in the previous section, the range data is no more accurate than the technique used to estimate it. Range data on a range card could be updated as more accurate data is obtained, but a change in range would also require changing the elevation data because a new range control setting would be used.

Designation of the ammunition/weapon for each TRP/SRP is intended to produce faster engagement of targets located around each TRP/SRP. However, designation of ammunition/weapon type is only a best guess of the type of targets that will be around each TRP. Prediction of the types of targets that will occupy particular portions of the terrain would seem to be beyond the capabilities of soldiers within a platoon. Many TRP/SRPs could be likely locations for targets requiring different types of ammunition/weapons. If a target requires a different ammunition/weapon than was preselected, then there is no savings in engagement time resulting from the preselection.

The requirement to select a designated range control setting at each TRP/SRP also can create problems. Preselection of a range control setting for a TRP may be meaningless for certain 25-mm gun and coaxial machine gun engagements, because the TRP may be at a range that is beyond the maximum engagement range of the weapon/ammunition. Furthermore, target ranges beyond 3000 m cannot be set into the fire control system and no guidelines are provided in the setting to be used in this situation.

An alternative solution to designating ammunition/weapon and range for each TRP/SRP is to base the elevation data for each TRP/SRP on a single ammunition and range control setting. This would prevent the need for setting ammunition/weapon and range for every reference to a TRP. The gunner could acquire a reported target using only the deflection and elevation data without first selecting the ammunition and the range control setting.

It should be emphasized that use of a single ammunition/weapon and range setting does not eliminate the need to obtain accurate ranging data to each TRP/SRP. Overall, use of separate settings for ammunition and range for each

TRP/SRP, in an attempt to allow faster target engagement, assumes unrealistic conditions (e.g., prediction of target locations on the terrain) in the majority of cases.

A single ammunition/weapon and range setting for all TRPs and SRPs also should provide effective target engagement capability. Two primary candidates for a single setting are a TOW-ready system, and the battlesight range for APDS-T. Preselection of the TOW system would allow a kill of any type of target. However, the TOW reticle does not allow range estimation with either the horizontal stadia reticle or the ISU gun reticle. A preselected battlesight range control setting for APDS-T (e.g., 1200 m) would allow immediate engagement of light-skinned vehicular targets and would allow range estimation with the reticles and horizontal ranging stadia.

Conclusions

There are four ammunition/weapon types that can be fired from the BFV turret and each has a critical range for target engagement. Terrain features located near these critical ranges should be indicated on the range card (if possible).

Elevation data for each TRP/SRP is determined by the ammunition/weapon type and range control setting. Preselection of range and ammunition/weapon shortens target engagement time if range estimation is accurate and the type of target appearing at a TRP/SRP can be predicted. There is some question that both of these conditions can be met for typical TRPs. For this reason, preparation of the range card and certain applications of the range card (e.g. scanning, locating reported targets) could be simplified if a single ammunition/weapon and range control setting were used for determining elevation data. Then, when targets appear at or around the TRPs, the exact range needed for determining the proper range control setting could be obtained using (a) the stadia or reticle lines and (b) data from the range card.

Recommendation 28. Reference features should be marked on the range card to indicate critical target engagement ranges.

Recommendation 29. The feasibility of using a single ammunition/weapon and range control setting for determining elevation data to TRPs and SRPs should be examined.

Planning for and Control of Fires

The following discussion will focus on those aspects of planning for and controlling fires that affect use of the range card. When indirect fire targets are located on easily identified terrain features, a platoon leader also may use the indirect fire target as a TRP for control of direct fire. However, the number of indirect fire targets designated at platoon level may be insufficient to allow the necessary control of direct fires. As a result, the platoon leader will probably have to designate TRPs other than those given as indirect fire targets.

Not all TRPs will lie within the sector of every vehicle in a platoon. The platoon leader should determine the capability of each vehicle to observe and engage TRPs so that platoon leaders do not request direct fire from

vehicles that are unable to respond. This point is mentioned in the armor field manual for gunnery (FM 17-12-1, 1982) but it is not mentioned in BFV field manuals (FC 7-7J, 1985; and FM 23-1, 1986).

The range card and squad sector sketch should clearly distinguish between TRPs and SRPs because the platoon leader normally responds to reports of enemy activity referenced using TRPs.

AIMING POINT

Introduction

Background

First-round hits with the 25-mm gun lead to faster kills and more efficient use of ammunition than if direct-fire adjustments are required. In a conflict between Warsaw Pact countries in a European environment, first-round hit capability will depend greatly on aiming-point accuracy for moving targets and for targets engaged from a moving BFV. Gunnery techniques related to moving-target engagements and firing on the move should be considered a fundamental and basic training requirement, and not an advanced form of gunnery.

The gunner must lead (aim in front of) a target that is moving in a lateral direction relative to a stationary BFV. During the first year of analysis of this research project, gunners often were observed to shoot behind moving targets. Inadequate aiming-point lead may have been caused by both training-related factors and ballistic differences between training and service ammunition. It is also possible that the recommended lead rules contributed to first-round misses.

The recommended lead rules have changed during the last several years. The 1983 test version of the gunnery field manual recommended that the reticle be centered on the front edge of the target. In 1986, a 2.5-mil lead from the target center-of-mass was recommended. For HEI-T ammunition, the recommended lead was increased from an aiming point on the front edge of the target (FM 23-1, 1983) to a 5-mil lead from target center-of-mass (FM 23-1, 1986).

When a moving BFV fires over its side or flank at a stationary target, the movement of the BFV "pulls" the round in the direction of movement. Because of this, the gunner must aim behind target center-of-mass relative to direction of BFV movement. The aiming-point offset in this situation is called reverse-lead. The recommended reverse-lead rule requires the gunner to center the reticle on the "trailing-edge" or the edge of the vehicle opposite from the direction of BFV movement (FM 23-1, 1983, 1986).

Observation of gunnery training at Fort Benning has not revealed inadequate reverse-lead during moving engagements; however, speeds of the BFV during training (5 to 10 miles/hr) are much slower than would occur in a combat environment. In that the amount of aiming-point offset is directly related to vehicle speed, it is possible that the currently recommended reverse-lead rule would be insufficient for faster BFV speeds.

Other situations also require aiming-point compensation for engaging moving targets. If the target is approaching a stationary BFV, the aiming point should be slightly below target center-of-mass. When the target is fleeing from a stationary BFV, the aiming point should be slightly above target center-of-mass (FM 23-1, 1983, 1986). When both the target and BFV are moving in parallel but opposite directions, a center-of-mass aiming point is used (FM 23-1, 1983, 1986).

Objective

The overall objective was to determine lead and reverse-lead rules that optimize first-round hit capabilities for both APDS-T and HEI-T ammunition. A detailed report of the analysis (Perkins, 1987a) is summarized here.

The first step in the development of lead rules was to conduct a mathematical analysis to determine aiming-point offset required for engaging moving targets from a stationary BFV. This provided background data for a subsequent analysis that calculated the predicted hit capabilities of selected aiming-point rules. Optimal lead rules were then determined for both APDS-T and HEI-T ammunition based on hit capability, reticle design, and ease of use and training the rule.

Development of reverse-lead rules began with calculation of the required aiming-point offset when engaging stationary targets from a moving BFV. Optimal engagement rules were then based on the amount of required aiming-point compensation, reticle design, compatibility of the rule(s) with other aiming-point rules (e.g., lead rules), and ease of use and training.

Lead Requirements

Very simply, the aiming-point lead requirement is the lateral distance traveled by the target during flight of the projectile. Flight time of the projectile is determined by ballistics and target range. Lateral distance traveled by the target is determined by flight time of the round, target speed, and angle of approach of the target relative to the observer. Targets approaching the gunner require no lead while the greatest amount of lead is required for a target moving perpendicularly (at a 90-degree angle) to the gunner.

Approach

For APDS-T and HEI-T ammunition, aiming-point lead requirements were calculated for varied target speeds, ranges, and angles of approach. Target range varied from 200 to 3000 m at 200-m intervals, target speeds ranged from 8 to 48 km/hr at 8-km/hr intervals, and target angles were varied from 10 to 90 degrees at 10-degree intervals. Data were inspected to achieve an understanding of lead requirements under a wide variety of conditions.

Findings

This preliminary analysis indicated that the amount of aiming-point lead is highly dependent on vehicle speed. The next stage of analysis focused on lead requirements for a representative vehicle speed of 32 km/hr (FM 23-1, 1983). The lead requirements for a target traveling 32 km/hr are shown graphically in Figure 15. The figure can be read to determine the lead requirement (in mils) based on ammunition type, range to the target, and angle of approach.

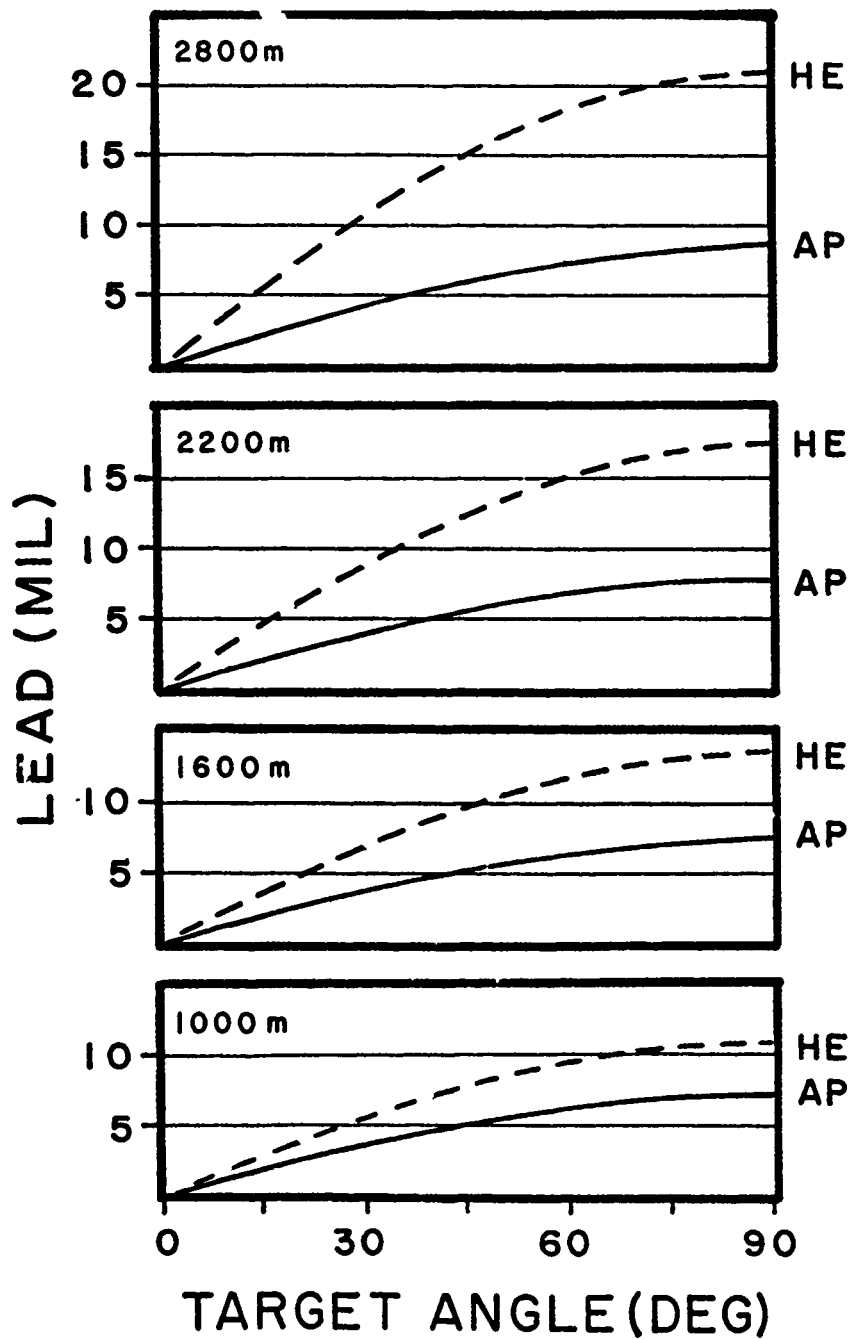


Figure 15. Aiming-point lead requirements for APDS-T and HEI-T ammunition at ranges of 1000, 1600, 2200, and 2800 m for a vehicle traveling 32 km/hr at varied angles to the BFV. Target angle of approach varies from a straight frontal view (0 degrees) to a fully exposed flank view (90 degrees).

Target angle of approach dramatically affects lead requirements. The lead required for a target oriented at a 30-degree angle to the observer is 50 percent of that required for a 90-degree target (only the side of vehicle is visible) for both types of ammunition.

Lead requirements in mils for APDS-T ammunition are only slightly affected by target range. The lead requirement is approximately 7.5 mils for a 90-degree target for ranges from 1000 through 2200 m. The lead requirement for a 45-degree angle target is about 5 mils while a 20-degree target requires a lead of about 2.5 mils.

In contrast to APDS-T ammunition, HEI-T has lead requirements that are noticeably affected by range. Required lead for a 90-degree target increases from 11 mils at 1000 m to 17.5 mils at 2200 m. The dramatic effect of target range on lead requirements is a result of the substantial loss in velocity of the HEI-T projectile as range increases.

Hit Capabilities of Selected Lead Rules

Following calculation of the aiming-point lead requirements, further analysis was required to determine optimal lead rules for APDS-T and HEI-T ammunition. The next stage of analysis determined hit capabilities of candidate lead rules for targets traveling 32 km/hr at varied ranges and angles of approach. Final recommendations on lead rules were based on hit capability and ease of use and training. The results of the analysis will be presented separately for APDS-T and HEI-T ammunition.

APDS-T Ammunition

Approach. Target hit capabilities of the candidate lead-rules were examined for target ranges of 400 to 2800 m and for target angles from 0 through 90 degrees at 10-degree intervals. Target angle is a critical criterion for determining when to apply a lead rule for a moving target. Target lead is required only when the target has lateral motion, in which case the side of the vehicle should be highly visible to the gunner. By contrast, a target oriented with only its front exposed requires no lead. A technique is described in the report by Perkins (1987b) for categorizing a target view as either frontal or flank. This target-view categorization technique could be used to determine when to apply a lead rule. Lead would be applied for flank views of the target but not frontal views.

With the target-view categorization technique, a target is a flank view when the target angle is about 25 degrees and greater. The analysis closely examined the capability of a lead-rule to produce target hits for a flank view of a target (oriented from 25 to 90 degrees).

Reticle design partly determines the aiming-point rules that can be applied by the gunner. The 25-mm reticle of the ISU is marked in 2.5-mil increments up to 10 mils and the selected rule must consider use of these reticle markings for application of the rule.

An analysis of predicted hit capabilities was conducted on seven candidate APDS-T lead rules. They were:

- (a) Center-of-mass aim using the center dot (i.e., zero lead);
- (b) Front-edge aim using the center dot;
- (c) 2.5 mils from target center-of-mass;
- (d) 2.5 mils from front edge;
- (e) 5 mils from center-of-mass;
- (f) 5 mils from front edge;
- (g) 7.5 mils from center-of-mass.

The last five aiming points were the most likely candidates for the optimal lead rule. Aiming points (c) and (d) are or were taught during gunnery instruction at Fort Benning and aiming points (e), (f), and (g) were selected as candidates after the lead requirement analysis was completed.

The calculation of hit capability of a lead rule is dependent on target size. The target selected was a BMP-sized vehicle with a frontal-width of 2.94 m and a side-length of 6.74 m. The exposed total width of a vehicular target depends on its angle of orientation to the observer. The total width (front plus side) was adjusted for angle of approach as described in the report by Perkins (1987b).

For the analysis, it was assumed that the range control setting was identical to target range and that round-impact location coincided with the center-dot of the reticle. These assumptions are equivalent to a perfectly zeroed weapon with ammunition having no dispersion. These ideal conditions were assumed so that factors specifically related to lead could be varied and analyzed. The predicted hit capabilities that were obtained are not intended to specify the hit probabilities in training and combat environments.

Findings. Hit capability of a lead rule for APDS-T ammunition is affected by both target angle (smaller angles have less lateral motion) and target range. Target range affects hit capability because the visible width of the target in mils decreases with range.

Analysis indicated that the 5-mil lead from target center-of-mass provides the best hit capability of the seven rules examined. Target hits were predicted for target ranges from 400 m through 1600 m. Misses began to occur at more severe target angles at 1800 m which is just beyond the tracer burnout range for APDS-T. The second-best rule was a 2.5-mil lead from the front edge of the target. Target misses began to occur at large target angles at 1600 m.

Aiming-point rules expressed in mils are often difficult for the gunner to remember. For this reason, the recommended AP lead rule (5 mils from center-of-mass) could be called GAP LEAD because the target is centered in the gap of the lead lines. The rule is illustrated in Figure 16 using a BMP target at a range of 1700 m (tracer burnout).

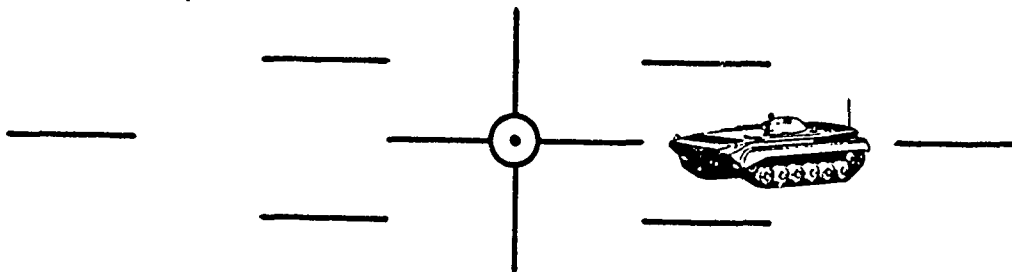


Figure 16. Illustration of GAP LEAD used against a BMP target at a range of 1700 m.

Conclusions. The TV technique described in the section on Range Estimation can be used to determine whether a target view is either frontal or flank. Lead rules are required when the target has lateral movement and, because lateral movement by a vehicle exposes its flank, the TV technique provides the gunner a method to determine when to apply a lead rule.

Of the seven candidate lead rules for APDS-T ammunition examined as described, a lead of 5.0 mils from the center-of-mass gives a consistently high hit capability over the span of ranges and target angles that can be anticipated in combat. Lead rules expressed as mils are often difficult to remember. For that reason, the recommended rule for APDS-T ammunition will be described as GAP LEAD. An illustration of the rule is provided in Figure 16.

The "gap" on the reticle has an additional use for engaging moving targets when efficient use of ammunition is required. A flank view of a BMP-sized target is about 5 mils wide (the width of the box) at a range of 1400 m. This is the maximum effective range for a battlesight range control setting of 12. With this information, a gunner could use battlesight gunnery techniques to engage moving targets that are at least 5 mils wide. If first-round hits were not obtained, direct-fire adjustment would be simplified because adjustments would be restricted primarily to deflection and not elevation (range/related).

Recommendation 30. Use the TV technique (see Recommendation 14) to categorize moving targets as frontal and flank views and apply the lead rule for targets determined to be flank views.

Recommendation 31. Apply an AP lead rule of 5.0 mils from target center-of-mass (i.e., GAP LEAD).

Recommendation 32. For efficient use of ammunition during engagement of moving targets that require an aiming-point lead, engage targets that are 5-mils wide (size of the gap) or larger.

HEI-T and TP-T Ammunition

The HEI-T round (and its training counterpart, the TP-T round) is designed for suppressive fire so the manufacturing specifications allow for more projectile dispersion than for the point-type ammunition (APDS-T). Despite its ballistic nature, one recommended use of HEI-T is engagement of light-skinned vehicles. Gunnery tables in FM 23-1 (1986) have HEI-T/TP-T engagements of BRDMs and BMDs.

Approach. The ballistic characteristics of HEI-T and TP-T ammunition result in a greater lead requirement than for APDS-T ammunition. As a result, the potential lead rules for HEI-T/TP-T have a greater lead than for APDS-T ammunition. Candidate lead rules investigated were:

- (a) Center-of-mass aim using center-dot of reticle;
- (b) Front-edge aim using center-dot of reticle;
- (c) 5 mils from center-of-mass;
- (d) 7.5 mils from front-edge;
- (e) 7.5 mils from center-of-mass;
- (f) 8.75 mils from center-of-mass;
- (g) 10 mils from center-of-mass.

The gunnery literature does not indicate a specific maximum engagement range for moving target engagements with HEI-T and TP-T ammunition. The enormous lead requirements for the HEI-T and TP-T round would seem to place some upper limit on maximum effective engagement ranges for moving targets. The lead lines on the 25-mm reticle extend only 10 mils to the right and left of the center dot. Aiming points requiring more than a 10-mil lead would seem impractical for performing burst-on-target adjustments using the reticle. For a target speed of 32 km/hr, a target at 1000 m moving at a 90-degree angle requires a 10-mil lead, as does a vehicle at 1600 m moving at a 45-degree angle. For this reason, the analysis of lead rules will focus on target ranges through 1600 m.

Findings. The effect of target angle and range was more dramatic with HEI-T/TP-T than for APDS-T ammunition. The investigation of hit capabilities across a span of target angles and ranges showed that no single candidate lead-rule for HEI-T/TP-T ammunition had the hit capabilities of the APDS-T lead rule.

There are four aiming points that differ only slightly in hit capability for HEI-T ammunition. They are: (a) 1.5 mils from center-of-mass; (b) 7.5 mils from front edge; (c) 8.75 mils from center-of-mass; and (d) 10 mils from center-of-mass. Differences in hit capability for these aiming points depend on target range and angle. The aiming point of 8.75 mils from center-of-mass was selected for use in a single lead rule because of considerations related to use of the reticle for burst-on-target adjustment. The 8.75-mil lead from center-of-mass equates to the center of the far lead-line on the ISU gun reticle. With this lead-line centered on the target, projectiles should impact

symmetrically around the line, giving the gunner more systematic feedback for rounds that fall in front of, or behind the target.

The recommended lead-rule for engagement of moving targets with HEI-T, is called FAR LEAD because the far lead line is centered on the target. The HEI-T/TP-T lead-rule is illustrated in Figure 17, using a BRDM target.

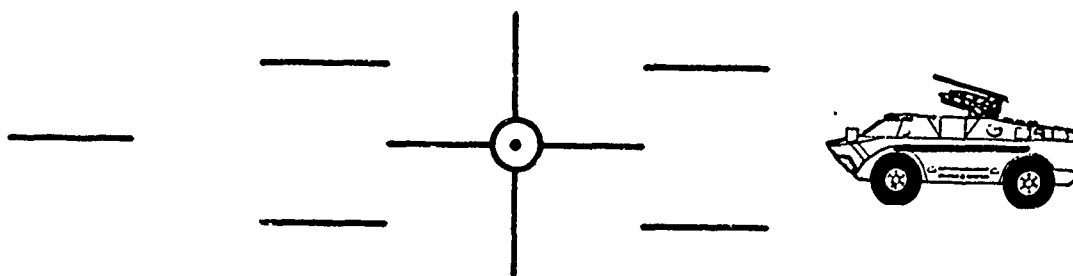


Figure 17. Illustration of FAR LEAD for HEI-T and TP-T ammunition used against a BRDM moving from right to left.

Conclusions. HEI-T normally would not be the ammunition of choice for engaging moving vehicular targets. However, a single, optimal lead rule for this ammunition is required because circumstances sometimes dictate its use. A lead of 8.75 mils is recommended because reticle design allows easy application of the rule and burst-on-target adjustments.

Recommendation 33. Apply an HE lead rule of 8.75 mils from target center-of-mass (i.e., FAR LEAD).

Reverse-Lead Requirements

Reverse-lead requirements for a given type of ammunition are affected by speed of the firing BFV and the orientation of the gun relative to direction of movement. Unlike lead requirements, reverse-lead requirements are not dependent on target range, as long as the aiming-point offset is expressed in mils. The angular deviation of the round is determined when the round leaves the barrel.

Approach

Reverse-lead requirements were determined for APDS-T and HEI-T/TP-T ammunition for BFV speeds of 8 to 48 km/hr at 8 km/hr increments. Gun orientation relative to direction of movement varied from 0 to 90 degrees at 10-degree intervals. If the gun is oriented in the direction of movement of the vehicle, this is represented by a 0-degree angle while a 90-degree angle represents firing directly over the flank of the vehicle.

Findings

Figure 18 presents the reverse-lead requirements for both APDS-T and HEI-T ammunition. The difference between APDS-T and HEI-T for a given angle is a result of the higher muzzle velocity of APDS-T ammunition. Gun angle is relative to direction of movement; 0 degrees is in the direction of movement while 90 degrees (firing over the flank) is perpendicular to direction of movement.

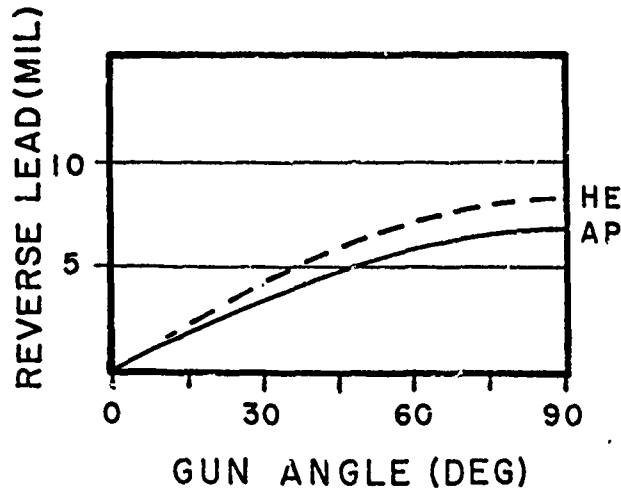


Figure 18. Reverse-lead requirements for APDS-T and HEI-T ammunition for a BFV traveling at 32km/hr.

The reverse-lead requirements for APDS-T and HEI-T ammunition differ by about 20 percent. This difference does not justify use of separate reverse-lead rules for each type of ammunition so a single reverse-lead rule was developed. A 5-mil reverse lead from target center-of-mass was selected for two reasons. First, the 5-mil reverse-lead is about the reverse lead requirement for a gun-barrel orientation of 45 degrees; it is unlikely that all firing will be directly over the flank of the vehicle and the 45-degree oblique gun orientation was selected as a representative case.

Secondly, the rule involves use of the same portion of the reticle as for the AP lead rule. This minimizes the number of reticle positions the gunner has to learn. The recommended reverse-lead rule is illustrated in Figure 19.

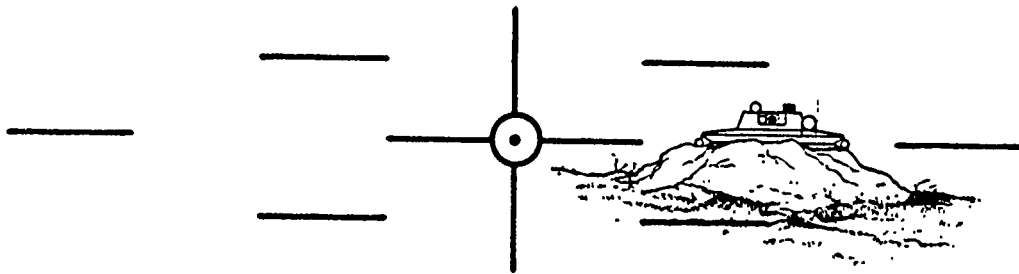


Figure 19. Illustration of the recommended reverse-lead rule against a BMP target in a defilade position. The gun barrel is facing over the left side of the BFV.

Conclusions

The small difference (20 percent) in reverse-lead requirements for APDS-T and HEI-T ammunition makes it suitable to choose a single reverse-lead rule for both types of ammunition. The 5-mil reverse lead was chosen because (a) it is a representative value for a 45-degree gun barrel orientation and (b) it can be used with the current reticle design in the same manner as the lead rule for APDS-T ammunition (i.e., gap lead). A general guideline for using the reverse-lead rule when firing at stationary targets is to apply the rule when the turret indicator is from 1 to 5 o'clock (gun facing to the right) and from 7 to 11 o'clock (gun facing to the left).

Recommendation 34. When the BFV is moving and firing over its flank at a stationary target, apply a 5-mil reverse lead (from center-of-mass) for both APDS-T and HEI-T ammunition.

Summary

Aiming-point rules are "best guesses" or estimates of the aiming-point compensation required when the BFV and/or target is moving. First-round hit capabilities when an aiming-point rule is applied will depend in part on how accurately actual combat and training conditions match those conditions used to develop the aiming-point rules. The recommended aiming-point rules were based on a target and BFV speeds of 20 miles/hr (32 km/hr). Target or BFV speeds slower or faster than 20 miles/hr will obviously affect the success of the aiming-point rules.

Separate lead rules (moving target and stationary BFV) were recommended for APDS-T and HEI-T/TP-T ammunition. The recommended AP lead rule is GAP LEAD (5 mils from center-of-mass). The HEI-T lead rule is FAR LEAD. Lead rules are applied when the target view is categorized as a flank view.

The FAR LEAD will have applications besides that of engaging moving targets with HEI-T ammunition. Situations that will probably require a FAR LEAD aim with APDS-T ammunition include: (a) moving targets beyond 1700 m

engaged from a stationary BFV; (b) medium-and long-range target engagement when both the target and BFV are moving toward each other; and (c) engagement of fast moving targets (about 25 miles/hr and faster). Use of HEI-T ammunition in any of the above situations would require aiming-point compensation even greater than applied with the far lead rule.

A single reverse-lead rule (BFV firing over its flank at a stationary target) was developed. The reverse-lead rule for both APDS-T and HEI-T ammunition is 5 mils from center-of-mass. The rule is applied when the turret indicator reads 1 to 5 o'clock (gun facing right) and 7 to 11 o'clock (gun facing left).

Different lead rules for APDS-T and TP-T ammunition creates a potential training problem; vehicular targets that would be engaged with AP ammunition in combat are engaged with TP-T during training. If target speeds during training are about 15 miles/hr or less (which occurs at Fort Benning), then the GAP LEAD can be effectively applied when TP-T ammunition is used as a substitute for APDS-T ammunition.

The discussion to this point has made a distinction between lead and reverse-lead rules. However, there is an important commonality between the two types of rules; the aiming point is offset from target center-of-mass in the direction in which the turret is being traversed. In other words, a general principle that applies to situations requiring lead and reverse-lead is LEAD IN THE DIRECTION YOU ARE TRAVERSING. If a gunner is traversing the turret while tracking the target, then the center of the reticle should always lead the target.

The just mentioned principle is fairly evident for situations requiring application of a lead rule, but is probably less evident for reverse-lead applications. The principle will be explained for a BFV firing over its right flank at a stationary target. When a gunner is tracking a stationary target positioned to the right of a moving BFV, he must traverse to the right to keep the reticle on the target. The gunner would offset the center of the reticle to the right of the target while traversing to the right.

PRELIMINARY GUNNERY TRAINING

Introduction

Background

The BFV gunnery field manual (FM 23-1, 1986) states that preliminary gunnery training reinforces the critical skills for target acquisition, gun lay, ranging, and target tracking during all visibility conditions. Preliminary gunnery training can be followed by subcaliber firing before target engagement with full-caliber ammunition. Preliminary gunnery training is provided in the three institutional courses that train BFV gunnery at Fort Benning (Gunner Course, Master Gunner Course, and Commander Course).

Description of Training

During the two years of observation and analysis of preliminary gunnery training, there have been relatively minor changes in the content and sequencing of training. Training provided in the BFV Commander Course (Class 1-85) is representative and a short description is included to provide an orientation to preliminary gunnery training as conducted at Fort Benning.

The training objectives for preliminary gunnery training are presented in Table 5. These objectives were obtained from a program of instruction (POI) in effect about midway between the two years of the current analysis. The 23 hours of POI training occurred over a 3-day period. Day one was devoted entirely to boresighting of turret-bound weapons using the ISU gun reticle and the auxiliary sight.

The morning of the second day of preliminary gunnery focused on range determination. Concurrent training stations for three techniques were utilized: (a) preparation of range cards; (b) use of the binoculars and the WORM formula for range estimation; and (c) use of the horizontal ranging stadia of the ISU for range estimation.

In early afternoon of the second day, a lecture was given on fire commands, target tracking, gun lay, and aerial target engagement techniques. The remainder of the afternoon utilized three concurrent stations to provide hands-on training. Stations existed for: (a) simultaneous execution of fire commands and gun lay; (b) target tracking using the snake-board; and, (c) boresighting.

The morning of the third and final day of preliminary gunnery employed one concurrent training station for target tracking using the snake board, and a second station for a dry-fire target engagement exercise with a moving BFV. A 30-minute lecture covered topics of target acquisition, scanning techniques, identification of target signatures, target classification (most dangerous, dangerous, and least dangerous), battlesight and precision gunnery techniques for the 25-mm gun, lead rules for engaging moving targets, target engagement techniques with the coaxial machine gun, and use of the auxiliary sight. During the afternoon, concurrent training was conducted for: (a) dry-fire

target engagement from a moving BFV; (b) boresighting turret-bound weapons; and, (c) loading and unloading the 25-mm feed chutes.

Table 5

Training Objectives Listed in the POI for Preliminary Gunnery

1. Identify and inspect components of the boresight kit.
 2. Boresight the 25-mm gun, the coaxial machine gun, and the TOW launcher.
 3. Boresight the 25-mm gun and the coaxial machine gun to the auxiliary sight.
 4. Scan for targets.
 5. Identify target signatures.
 6. Classify targets.
 7. Identify friendly and enemy vehicles.
 8. Identify friendly and enemy helicopters.
 9. Identify the characteristics and capabilities of combat vehicles.
 10. Determine target range using the ranging stadia of the 25-mm reticle.
 11. Determine target range using the binoculars and the WORM formula.
 12. Determine target range using the stadia lines of the auxiliary sight.
 13. Prepare a BFV range card.
 14. Lay gun for direction (BFV commander).
 15. Track a moving target.
 16. Issue a fire command.
 17. Engage targets with the TOW.
 18. Engage targets with the 25-mm gun.
 19. Engage targets with the 7.62-mm coaxial machine gun.
 20. Engage targets using the auxiliary sight.
 21. Familiarization with air defense artillery techniques.
-

Note: Training objectives were obtained from a POI of the BFV Commander Course dated 9 August 1984. The objectives were reordered and, in some cases, slight wording changes were made to shorten the description.

It is important to recognize that the current amount of time dedicated to preliminary gunnery is minimal given the broad scope of the training objectives. Boresighting training takes one complete day of training leaving only two days for other tasks. Preliminary gunnery training is complex because effective gunnery performance requires the integration of a number of separate tasks. Procedures that are relatively simple to perform (e.g., selecting ammunition, changing magnification, adjusting the thermal sight, traversing the turret using the correct speed and technique, selecting the range control setting, and communicating using the correct fire commands) become difficult when performance is required in an integrated fashion.

As indicated by the description of the three days of preliminary gunnery training, a considerable amount of administrative organization is required to accomplish the training objectives. Enormous improvements have occurred in the organization of preliminary gunnery training over the two years of observation. A high level of training efficiency has been achieved by the use of well-conceived concurrent training stations. These improvements have been accomplished by both a highly competent administrative staff and highly motivated and experienced instructors. Given the scope of the current training objectives and the limited time available in which to achieve them, the training effectiveness of current preliminary gunnery training appears to be at a very high level.

The observation and analysis of current training conducted over a two-year period did identify some areas where potential improvements can be suggested. Many of the recommendations that follow are based on knowledge that has become available since BFV gunnery training was initiated. Improved techniques and concepts require changes in training organization. A large number of recommendations will be presented, but it is recognized that many cannot be implemented on an immediate basis. Progressive changes are required until the highest levels of gunnery performance can be achieved.

Objectives

The remainder of this section will provide conclusions and recommendations that are intended to improve gunnery performance. Recommendations will be divided into the following seven content areas:

- o Boresighting;
- o Zeroing;
- o Range estimation;
- o Target acquisition;
- o Targets and ammunition selection;
- o Aiming-point acquisition;
- o Fire commands.

Many of these content areas are treated in a technical context in previous sections of this report. The conclusions and recommendations for preliminary

gunnery training that are presented here are, in some cases, reiterations of issues that were previously discussed.

Boresighting

Accurate boresighting facilitates accurate zeroing and decreases the number of rounds required to zero. The number of rounds used to zero the 25-mm gun in typical gunnery training, at Fort Benning, often exceeds the allotment specified in FM 23-1 (1983, 1986). Accurate boresighting should reduce ammunition expenditure during zeroing and this point should be emphasized during training.

Accurate boresighting requires accurate equipment and much of the excessive round expenditure during zeroing is caused by inaccurate boresighting equipment. Despite widespread equipment deficiencies, it is possible to find boresight equipment having tolerable levels of accuracy. Instruction should emphasize the need to screen equipment for accuracy prior to boresighting. A criterion of 1-mil shift in aiming point during the 180-degree telescope rotation test was specified by AMCCOM (1985) and research conducted by ARI suggests that equipment can be obtained that meets this minimum accuracy criterion.

Recommendation 35. Identification and inspection of the components of the boresight kit should emphasize checks for equipment accuracy, using a criterion of 1.0 mil for the shift in boresight telescope aiming-point during the 180-degree telescope rotation test.

Zeroing

Recognition of the importance of boresighting is indicated by the time devoted to it; yet accurate and effective boresighting is meaningless unless zeroing is performed correctly. The guidance for zeroing presented in the training literature and actual zeroing procedures conducted at Fort Benning do not correspond. Zeroing rarely occurs on a white boresighting panel at 1200 m as recommended; in fact, most white boresighting panels are not even positioned at 1200 m. This is primarily a result of terrain factors which do not support target placement at 1200 m. For this reason, alternative target distances should be specified in the gunnery manual. The section Boresighting and Zeroing (subsection Target Ranges) specifies alternative target ranges for zeroing the 25-mm gun.

Accurate zeroing procedures are dependent on accurate feedback of round location. A number of procedural, equipment, and range modifications would improve zeroing accuracy. Darker targets provide a better background to observe the trajectory of the bright tracer. A closer target makes it easier to hit the target and makes it easier for the gunner to see where the round hits the target. Placing the target at ground level makes it easier to determine if the round falls short of the target. Automated scoring confirms target hits. In most cases, zeroing should be conducted under conditions that improve feedback on round-impact location; however, this information is not formally taught in gunnery instruction. Finally, use of the center of a three-round shot group for zeroing area-type ammunition (TP-T and HEI-T) provides a better estimate of the true center-of-impact.

Instruction should clearly indicate why certain target ranges are critical for zeroing. The target range during zeroing should minimize parallax between the sight and round-impact location throughout the span of ranges in which targets will be engaged.

Recommendation 36. Instruction on zeroing should emphasize the reasons for zeroing as well as the techniques and equipment for improving zeroing accuracy to include:

- (a) The zeroing distance minimizes parallax between the round-impact location and the reticle for the span of ranges in which targets will be engaged;
- (b) Zeroing can be performed at 1000 and 1200 m for all ammunition in addition to 800 m for TP-T and HEI-T;
- (c) Zeroing on a panel with a dark background facilitates spotting of round-impact location;
- (d) Zeroing on a target positioned at ground level provides feedback on rounds falling short of the target;
- (e) Use of the center of three-round shot groups and scoring sheets improves accuracy when zeroing with HEI-T and TP-T ammunition;
- (f) Zeroing targets should provide automated target hit and miss information;
- (g) When TP-T/HEI-T ammunition is zeroed at a range of either 900 or 1100 m, final adjustment of the sight is required to compensate for not being able to index an odd-numbered target range;
- (h) The auxiliary sight is always referenced to the ISU gun reticle in case an ISU malfunction occurs.

Target Acquisition

Commander Gun Lay

Care must be taken to insure that certain critical tasks are learned to at least a moderate level of proficiency before they are paired with others. Currently, the first experience at laying the gun usually occurs at the same time the student first practices fire commands in the turret.

In early stages of gun laying, the student should drop down into the turret to observe the lay of the gun in relation to the sight picture on the ISU. Once the student has become relatively proficient at laying the gun, then a fellow student observing from the gunner's position can provide the feedback on gun-lay accuracy to the commander.

Effective gun lay often requires use of the fast-slew mode of turret operations for timely execution of the task. Learning to use the fast-slew

mode usually takes some practice and this practice often is not provided in training.

Because of parallax between the position of the gun and the commander, effective gun lay is best achieved on full-scale ranges in large open areas. Gun laying can be practiced on terrain features other than vehicular targets.

Recommendation 37. The Bradley commander should become relatively competent at gun lay, before this task is integrated with other tasks.

Thermal Imagery Training

Instruction in thermal sight operations was a part of preliminary gunnery in the earlier versions of gunnery POIs. Thermal operations are now taught as part of turret-operations training conducted prior to preliminary gunnery.

Only two colors are present in the thermal mode of operation; however, looking at thermal images is not exactly like looking at a black and white TV screen. Gunners need to be shown what various hot objects (terrain and targets) look like in thermal imagery, using a more formal approach with improved training aids and materials.

Practice in the use of the thermal mode of the ISU, is currently obtained during target acquisition training conducted under daylight conditions. Target-acquisition training is part of a dry-fire exercise from both a stationary position and while on the move. Targets are typically wooden silhouettes.

Scanning from a stationary position at nighttime requires knowledge of thermal operations and signatures, in addition to techniques for using the range card to facilitate scanning and range estimation. These skills and techniques need to be integrated into a single practical exercise. The ARI Fort Benning Field Unit, has conducted such training as part of its analysis of techniques to improve use of the thermal sight for target acquisition. The results of this analysis are presented in previous reports (see Bibliography).

Recommendation 38. Instruction in thermal operations and illustration of the factors affecting thermal signatures should be improved.

Range Cards

One purpose of the BFV range card is to facilitate target detection (FM 23-1, 1986). However, no guidance is provided in either institutional training or the training literature on the way the range card is used for target acquisition. Target reference points are placed on range cards but these TRPs alone are usually insufficient to provide the necessary reference points for scanning. The gunner needs to add reference points to the range card for use in initiating and terminating scanning patterns through the sector. Properly selected reference points also aid in estimating the range of detected targets.

Recommendation 39. Training for scanning under limited visibility conditions should emphasize use of the range card and how to construct it to optimize scanning effectiveness.

Recommendation 40. A practical exercise should be conducted at night with real targets to reinforce the skills of thermal operations, scanning, target detection, and use of the range card for scanning and range estimation.

Range Estimation

WORM Technique

Use of the binoculars with the WORM formula primarily is intended for long-range observation and surveillance. Such use requires high levels of accuracy in measuring target size because of the small target size at long ranges. Use of the ISU gun reticle instead of the binoculars provides better accuracy because of higher magnification and more frequent mil markings on the reticle. Use of the ISU gun reticle also provides a more stable observation platform so that visually-small objects can be more accurately measured. Moreover, the gunner has constant access to the ISU, but binoculars usually are not available to him.

The quick reference table presented in FM 23-1 (1986, p. 4-9) eliminates the need for the mathematical calculations required with the WORM formula. However, use of this table requires the gunner to classify vehicular targets into one of three groups, a potentially difficult task with long-range targets. Target identification also can be difficult for thermal images.

A range estimation table has been developed that compresses two groups of vehicles into one (see Table 4). This should simplify the range estimation procedure considerably without significantly affecting range estimation accuracy, particularly for long-range targets.

A potential problem with use of the quick reference table is that target view must be categorized as either a frontal or flank. The TV technique has been developed to perform this categorization (Perkins, 1985b).

Recommendation 41. Estimation of target range using the binoculars and WORM formula should be modified as follows:

- o Use the ISU gun reticle to measure the visual size of the target in mils;
- o Use of the modified Group I data for the quick reference table (see Table 4);
- o Use the target-view technique to categorize target view as either frontal or flank.

Horizontal Ranging Stadia

Current training and training literature (FM 23-1, 1983, 1986) recommends that the horizontal ranging stadia be used by "choking" the target from its bottom to its highest portion. The stadia supposedly is designed to estimate range to a BMP with a height of 2.2 m. Analysis indicates that the true calibration is for a target about 1.5 m to 1.7 m high, depending on the portion of the stadia lines where the measurement is taken. More accurate use of the

sight could be obtained if the vehicle is choked from the bottom to the top of the hull, and not the top of the turret. The conditions in the training objective for use of the stadia indicate that range estimation can be done with a vehicular target in a defilade position; however, the stadia is accurate only if the entire height of the vehicle is exposed (i.e., it can not be in a defilade position).

Recommendation 42. When estimating range using the horizontal ranging stadia of the ISU gun reticle, use the height of the vehicle at the top of the hull as the reference point.

Range Cards

Instruction usually recommends designation of three TRPs when preparing a range card. This may not be enough reference features to allow the gunner to accurately estimate target ranges and maximum engagement ranges. Terrain features that indicate critical engagement ranges should be marked. The section titled Range Card (subsection Range Estimation and Target Engagement) provides guidelines on critical gunnery ranges for the BFV.

By preparing the range card, the gunner becomes familiar with the terrain in his sector. After the range card has been prepared and further refined, the gunner will know the range to many key terrain features without looking at the range card. Overall, the range card can be just as useful for range estimation in good visibility conditions as during limited visibility. However, it must be emphasized that the utility of the range card for purposes of range estimation is limited by the accuracy of the technique used to estimate/determine range to reference features.

Recommendation 43. Instruction on preparation of range cards should include selection of reference points/features to be used by the gunner for range estimation and scanning during both day and limited visibility conditions (see Recommendations 21 and 22).

Battlesight Gunnery and Range Control Setting

The battlesight gunnery technique can be used with a high degree of accuracy with APDS-T ammunition, at ranges through the range of tracer burnout. This can be achieved using only two range control settings. For a fully-exposed BMP, target ranges from 0 through 1400 m can be covered with a range control setting of 12, while ranges from 1400 m through 1700 m can be covered by a setting of 1600 m.

For target engagements with APDS-T ammunition, use of two range settings for battlesight gunnery requires the gunner to focus on only two target ranges: (a) the maximum effective range of 1400 m for a range control setting of 12; (b) the tracer burnout range of 1700 m. Critical terrain features at these ranges can be marked on the range card. Also, the ISU reticle can be used to determine a target range of 1400 m.

Recommendation 44. Two battlesight range control settings should be taught for APDS-T ammunition in addition to the techniques that can be used for

determining when a target is within the battlesight range (see Recommendation 20).

Targets and Ammunition Selection

After a target has been detected, the crew must determine if it is friend or foe, and if the target is enemy, then the target must be categorized or identified so that the appropriate ammunition/weapon can be selected. The BFV crew has four types of ammunition to select from: TOW missiles, 25-mm APDS-T ammunition, 25-mm HEI-T ammunition, and 7.62-mm coaxial machine gun ammunition. In general, a more lethal ammunition/weapon system should not be used if a lesser one will meet the engagement requirement.

Ammunition/weapon selection for vehicular targets is primarily restricted to the TOW system and the two service ammunitions for the 25-mm gun. This creates an enormous categorization problem for the gunner if he is to choose the most appropriate ammunition or weapon system. Probably the most important vehicle classification is tank vs. non-tank; this distinction is critical for the decision whether to use the TOW missile system or the 25-mm gun. Furthermore, based on current guidance, the gunner must next decide on whether to use HEI-T or APDS-T ammunition for light-skinned vehicles.

There is no current BFV instruction that trains the task of ammunition selection. The task that most closely approximates this need is combat vehicle identification (CVI). Since CVI is a Skill Level 1 common task (FM 21-2, 1982), it is evaluated but not trained during BFV gunnery instruction. However, it is important to recognize that identifying a vehicle does not mean that the gunner knows the weapon best suited to kill the vehicle or the potential lethality of the target to the BFV. This information is critical for the BFV gunner, and this is not currently trained.

Recommendation 45. Training and evaluation should prepare the gunner and commander to select the appropriate ammunition, based on the type of target.

Aiming Point Acquisition

Engagements with the 25-mm gun are made with a center-of-mass aiming point when firing from a stationary BFV at a stationary target. However, use of the 25-mm gun when either the BFV or the target is moving requires aiming-point compensation. Effective application of aiming-point rules during live-fire requires practice during dry-fire training.

Instructors and students occupying a turret with the gunner should insure that the proper aiming point is employed during dry-fire. This typically does not occur in training at Fort Penning. Some classes have received dry-fire target engagement training before they had received instruction on aiming-point rules.

Current evaluation of student mastery of the aiming-point rules asks the student to choose the correct rule expressed as a number (e.g., 2.5 mils from the leading-edge of the target). A better format for evaluation would require selection of the appropriate sight picture from a set of alternatives.

Recommendation 46. Dry-fire training should reinforce application of aiming-point rules for engaging moving targets and firing when on the move.

Fire Commands

Observations of student performance during dry-fire practice of fire commands revealed the following areas of difficulty:

- o Inappropriate ammunition for the target (i.e., Sabot - Tank);
- o Inappropriate combination of ammunition, target type, and range (i.e., HE - Troops - 500 m);
- o Difficulty identifying targets over 1000 m without magnification;
- o Using incorrect terms (e.g., AP for Sabot, BMP for PC);
- o Reversing the order of presentation for ammunition and description of target.

It is possible that students are really aware that APDS-T ammunition is not used on tanks and that they did not say what they were thinking. More practice may be the solution. These links (i.e., between the ammunition and target) need to be firmly established in the vocabulary of the vehicle team so that they are automatic under live-fire conditions.

The POI referenced at the beginning of this section states a 5-sec standard for execution of the fire command. Observations of classes conducted subsequent to implementation of that POI indicate that 10 sec actually is allowed. In many cases, there is a natural tendency for beginning students to attempt to execute fire commands too quickly. This often leads to mistakes.

The current time standard for execution of a fire command is questionable. The time allowed for execution of the fire command (5 sec) is shorter than the standard for some of the component tasks in the total fire command. For example, the time standard for recognizing a vehicle as either friend or enemy is 15 sec. This time will be even longer if the commander cannot identify the target and the gunner must use magnification to do so.

Students and instructors discussing APDS-T ammunition call it AP throughout the course, until they are required to refer to AP as Sabot during fire command training. The reason for using Sabot in the fire command is a very important one. The terms AP and HE sound very similar in a noisy environment, and Sabot is substituted for AP to avoid confusion. The same problem exists for the term used to designate a personnel carrier (PC). Students often use the term BMP during a fire command and not PC. These substitutions should be used in other portions of the course besides fire command training, so that they become automatic.

Currently, the commander must state the ammunition type before the target in a fire command. From a logical standpoint, however, the commander must decide on the ammunition after he classifies or identifies the target. In the training environment, when the student tries to use the correct sequence for

ammunition and target, he often hesitates until he can present the command in the recommended sequence or makes a hasty mistake and must correct the order.

Ammunition is given before the target in the current fire command sequence, based on the rationale that ammunition can be selected sooner. However, frequent switching of ammunition is not the typical case when vehicles are assigned a weapons ready posture. Switching ammunition and weapon may occur, but not on every engagement.

The alternative of giving the target before the ammunition may be beneficial when the commander does not use magnification to identify the target. The commander may not have identified the target correctly. Saying the target first in the fire command sequence allows the gunner to locate the target and confirm the commander's identification before the ammunition selection has been made.

Overall, the sequencing of the ammunition and target in the fire command probably makes little difference in the time required to execute the fire command. The current requirement may create unnecessary problems in execution of the fire command.

Recommendation 47. Time standards for execution of a fire command need to be reexamined.

Recommendation 48. Terms used in the fire commands should be used in BFV gunnery training prior to fire command training.

Recommendation 49. Flexibility should be allowed in the sequencing of target and ammunition information in the fire command.

FULL-CALIBER GUNNERY

Introduction

Background

Each of the three turret-bound weapons and the firing port weapons require utilization of different gunnery techniques and principles. Effective teamwork and communication are required to achieve optimal employment of weapons. The gunner and commander are the primary team members, but the contributions of the driver and other squad members are critical.

The 25-mm gun provides the infantry with the capability to destroy enemy personnel carriers and other light-skinned vehicles. First-round hit capability greatly depends on the gunner's capability to select the appropriate range and offset his aiming point to compensate for BFV movement, target movement, and environmental conditions (e.g., wind). Due to the caliber of the ammunition, first-round hits do not necessarily produce kills; obtaining the multiple hits typically required to achieve a kill is facilitated by the automatic modes of fire for the 25-mm gun.

The preferred technique for direct-fire adjustments with the 25-mm gun is burst-on-target (BOT). Single sensing rounds are fired until a hit is achieved. Shot groups of three to five rounds then are fired until the target is immobilized. Ammunition conservation is the primary reason for using the BOT-adjustment technique. The recommended upload of APDS-T ammunition is 70 rounds and these rounds could be quickly expended at a firing rate of 200 rounds/sec, if firing discipline is not exercised.

Direct-fire adjustment with the 7.62-mm coaxial machine gun is achieved using the tracer-on-target technique. Adjustment is made as the gunner "walks" the tracer toward and onto the target. Recommended uses of the coaxial machine gun include engagement of troops (area targets), suppressive fire, reconnaissance by fire, and designation of targets.

Firing the TOW missile is similar, in many ways, to using a fully automated fire control system. The gunner aims at the target, fires and maintains the aiming point until round impact. Considerations must be made for uninterrupted flight to the target, objects and personnel positioned along the flight path, back blast, vehicle orientation, and most critically, target range.

Live-Fire Training

A description of current live-fire training will be provided, using the BFV Commander Course as representative. Of the three courses providing gunnery training, the BFV Commander Course devotes the greatest number of hours to live-fire training. The concepts of training are very similar in all courses and the purpose of live-fire training, as stated in the POI, is "to teach the soldier to effectively engage targets with the BFV turret weapons systems and to develop vehicle team interaction and speed in the employment of the turret

weapons." Table 6 summarizes the tasks, conditions, and standards for live-fire training in the BFV Commander Course.

A baseline gunnery exercise is often conducted as familiarization training with the 25-mm gun. About 50 rounds of ammunition are fired at stationary and moving silhouette targets without time limitations.

The first two tasks listed in Table 6 use the coaxial machine gun to simulate the 25-mm automatic gun firing techniques. The first task, firing from a stationary BFV, has been eliminated from current training because the target array of the firing ranges does not adequately support subcaliber firing. Overall, there are a very limited number of targets now located within the maximum effective range of the coaxial machine gun. The coaxial machine gun still is used for subcaliber training when firing from a moving BFV. This exercise is particularly useful for developing crew coordination and fire commands. Training of Task 2 often occurs after the baseline exercise for the 25-mm gun.

Task 3 listed in Table 6 is usually the third exercise conducted during training. With the BFV stationary, the 25-mm gun and coaxial machine gun are used with the day and/or the thermal sight to engage single and multiple targets that are either stationary or moving. Single stationary and moving targets were exposed for 15 to 25 seconds while multiple target exposures ranged from 30 to 45 seconds. Typical moving target speeds were between 10 to 15 km/hr. Task 4 is engagement of stationary and moving targets from a moving BFV. Task 5 is not conducted because, at this point in training, vehicle team skills have not reached the level necessary for performance of a platoon level exercise.

Simulated enemy targets at Fort Benning are wooden (vehicular type) and plastic (troop type) silhouettes painted dark green. Targets can be raised and lowered electronically while automatic scoring systems allow detection of target hits based on target vibration produced by round impact. Personnel (i.e., the target controllers) positioned in elevated control towers raise and lower the targets, adjust the length of target exposure, record number of target hits, and set the number of hits required for a target kill (either 1 or 4 rounds).

Live fire in USAIS courses during the last two years primarily was conducted on Ruth and Ware Ranges. Ruth Range has four adjacent firing lanes with a concrete platform used for firing from a stationary BFV. While the range is designed primarily for target engagement from a stationary BFV, a gravel road weaves through the range for firing on the move. Signs along the road indicate start and stop locations for moving engagements. Ware Range is designed for target engagement from a moving BFV. Firing lanes radiate from a curving gravel road.

Table 6

Listing of Tasks, Conditions, and Standards for Live Fire

Tasks	Conditions			Standards
	Ammunition (Rnds)	Target	Range (m)	
1. Engage targets from a stationary BFV	7.62 mm (160)	BMP	400-900	Engage single targets within 15 sec & multiple targets within 40 sec using 20 rnds/target
2. Engage targets from a moving BFV	7.62 mm (160)	BMP	500-900	Traveling 15 m/hr, kill multiple moving/stationary targets within 40 secs using 20 rnds/target
3. Engage targets from a stationary BFV	TP-T (70)	BMP, BRDM, ZSU-23-4	800-2500	Kill (5 rnds) single stat. targets within 15 secs & moving multiple &/or stat. targets within 30 secs using 10 rnds/target
	7.62 mm (100)	Troops	600-800	Suppress targets within 15 secs using 100 rnds
	TOW (1)	Tank	1500-1800	Launch missile within 15 secs after target exposure/kill target
4. Engage targets from a moving BFV	TP-T (50)	BMP, BRDM	600-2000	Kill (2 hits) single stat. targets 20 secs & mult. moving &/or stat. targets in 40 secs using 10 rnds/target.
	7.62 mm (100)	Troops	600-800	Suppress targets using 100 rnds.
5. Conduct a movement to contact	TP-T	BMP, BRDM	1200-3750	Kill (5 hits) single stat. targets within 20 secs & mult. moving &/or stat. targets in 10 secs using 10 rds/target
	7.62 mm (300)	Troops	150-600	Suppress targets within 20 secs using using 100 rnds.
	TOW (1)	Tank	1200-3750	Kill by launching missile within 15 secs after target exposure.
	5.56 mm (120)	RPG-7	150-600	Suppress targets within 20 secs using 120 rnds.

NOTE: From a POI of the BFV Commander Course dated 9 August 1984.

Objectives

The analysis and observation of live-fire training conducted over a two-year period resulted in the identification of a number of unresolved issues. Some of these issues relate to the newly emerging doctrine for BFV tactical gunnery. Others pertain to current training content and practices, and/or to current qualification procedures for establishing student mastery of BFV gunnery. Technical analyses that were summarized elsewhere in this report are relevant in this context as well, and the discussion will be deliberately repetitious to eliminate the need for extensive cross-referencing. Finally, suggestions for future actions and/or directions for further investigation are presented.

Familiarization Versus Qualification

The conditions and standards for Tasks 3, 4 and 5 of the POI closely match those for gunnery qualification. However, the standards specified in the POI often are relaxed to reflect more realistic expectation of student gunnery performance. Furthermore, gunnery qualification is not a graduation requirement for the BFV Gunner, Master Gunner and Commander Courses.

The primary goal of live-fire training is to prepare the soldier to quickly and effectively engage targets. This requires the student to transfer the skills learned during preliminary gunnery training to live-fire performance, and to integrate those skills and techniques that can only be learned when rounds are fired (e.g., BOT adjustment). To reflect this, the live-fire training objectives that closely resemble qualification requirements should be re-written to focus on the fundamental skills and techniques, with the tasks, conditions, and standards structured to allow progressive training in the fundamentals of gunnery.

While many of the critical gunnery skills and techniques for the BFV have been identified, there seems to be a lesser understanding of the nature and frequency of gunner errors contributing to ineffective gunnery performance. An understanding of gunner errors provides critical background information for developing training required to improve performance. One of the best approaches for identifying factors affecting gunnery performance is to sit in the turret with the gunner. Gunner actions and reactions can be observed along with the sight picture of the ISU. However, when both the gunner's and commander's positions in the turret are occupied by students, then the instructor must monitor gunnery performance from on top of the turret. This view is not nearly as good as observing from within the turret.

Technology is now available for recording the gunner's responses during either simulated or actual live fire. A through-the-sight (TSV) video recording system can be used to record the ISU sight picture during gunnery. Verbal exchange between crew members also can be recorded with this system. Through-the-sight video recordings could be used to record gunnery performance as an initial step in determining fundamental skills and techniques that require more extensive gunnery training. Additionally, the Uni-Conduct of Fire (U-COFT) BFV gunnery simulator can be used to display and record gunnery performance. These recordings could be used to determine gunner errors.

Conclusions

Certain tasks of the current POI for live-fire gunnery closely resemble the conditions and standards that exist for gunnery qualification, but standards are often relaxed to allow more realistic expectations of gunnery performance. A more desirable training strategy would be to train fundamental skills and techniques so that gunnery performance could be achieved in a variety of conditions and circumstances. The following section will discuss some of the areas of gunnery in need of improved training. In addition to these areas, research needs to be conducted to determine the fundamentals and techniques that are not being adequately trained. Use of TSV during live-fire performance and U-COFT during simulated gunnery performance are two ways of determining current gunnery weaknesses. Therefore, the following recommendation is presented.

Recommendation 50. Use TSV and U-COFT to determine typical gunner errors as an essential step in determining live-fire training requirements.

Training Considerations for Live-Fire Gunnery

The 25-mm gun often is referred to as a BOT-weapon system and the BOT technique is new for the infantry. The BOT technique requires three primary skills and techniques: (a) trigger control; (b) tracking (when the target and/or BFV is moving); and, (c) adjustment. During a typical sequence with the BOT technique, the gunner aims at the target, fires a single sensing round, continues to track the target if necessary, senses round-impact location relative to the reticle, adjusts the aiming point so that point of impact lies on the target, and fires a three to five round shot group. The technique is called BOT, however, the only burst that comes when firing APDS-T ammunition is when the round hits the target, in which case, no or little adjustment is required. The difficult case is when the round misses the target; the mythical burst is often hard to detect. One subsection will be devoted to training of the BOT-adjustment technique. This section will also have subsections on aspects of live fire related to firing from a stationary position, engagement of moving targets, and firing while on the move. The following subsections examine the critical factors that should be considered when developing strategies for live-fire training.

The BOT Technique

There are currently no tasks or training objectives in Fort Benning POIs that are specifically designed to prepare the gunner for use of the BOT technique. One of the critical skills required for effective gunnery using the BOT-adjustment technique is trigger control or fire discipline. Use of the BOT adjustment technique is preferred over the tracer-on-target adjustment technique because of the need to conserve ammunition with the 25-mm gun. Current live-fire training does not provide systematic training for trigger control with the 25-mm gun. Instruction in trigger control has been primarily at the discretion of the instructor; the primary impetus for effective fire discipline has been individual instructors that insisted on proper use of fire discipline.

Moving target engagement requires target tracking after the sensing round is fired if accurate BOT adjustments are to be achieved. Currently, there are no systematic procedures for determining whether the gunner effectively tracks the target during the engagement sequence.

Finally, the quickest adjustment can be made when the gunner observes the location of round impact. Current training does not systematically determine whether a gunner can actually adjust aiming point based on round-impact location. The commander and gunner also require training in the procedures for giving and receiving adjustment instructions (e.g., 1 target from right), in the event the gunner fails to locate the impact point of a sensing round.

Many of the current inadequacies in BOT-adjustment training, particularly in the BFV Commander Course, is a result of using two students in the turret during live-fire training. This does not allow the instructor to observe critical aspects of gunnery performance. However, TSV recordings of gunner performance could be used for feedback to the student and as information for critiquing gunnery performance. Students having problems with the BOT-adjustment technique could receive additional instruction to include use of the U-COFT.

The U-COFT now provides the instructor with the capability to observe critical aspects of both gunner and commander performance. The instructor could use specific exercises focusing on the gunner's employment of the BOT-adjustment technique. Such a training strategy would not use necessarily the scoring system of U-COFT as currently designed. The present scoring system does not reinforce use of the BOT technique; in fact, in many cases it works against use of the technique. A critical factor in the current scoring is how quickly the target is killed; and a kill can be obtained with up to 20 rounds before a penalty is given for excessive ammunition expenditure. Twenty rounds per kill would be far too many in a combat situation. Use of the U-COFT for BOT training would require feedback and guidance provided by the instructor, and not just the information from the computer printouts.

In conclusion, the BOT technique is fundamental for BFV gunnery, but it is not emphasized as a training objective in current instruction. The live-fire portion of the BFV gunnery POI should include training in both the component parts of the technique and the teamwork required between commander and gunner.

Engaging Stationary Targets from a Stationary BFV

Employment of the horizontal ranging stadia is recommended for estimating range from a defensive or stationary position. Use of this technique is the basis for precision gunnery with the 25-mm gun. The technique requires full exposure of the height of the target. If the vehicle has taken a stationary fighting position, it will probably be partially concealed. This will preclude accurate range estimation with the stadia.

If the horizontal ranging stadia cannot be effectively used for range estimation from a stationary fighting position, in every case, then other techniques are required. Measurement of vehicle width (mils) used with the quick reference table is one technique; use of a range card is another.

The range card is not emphasized for range estimation from defensive positions, by institutional training or the units. Use and construction of the range card is covered in gunnery manuals and in instruction. However, actual use of the range card is more restricted. Current training in target engagement from stationary firing positions in USAIS courses does not require use of the range card. Furthermore, it is not required during gunnery qualification. The range card can be effectively employed in both unobscured and limited visibility conditions to provide ranging data. The range card would not necessarily be referenced on each target engagement, but in the process of making the range card, the gunner becomes familiar with the terrain so that ranges to prominent terrain features are known prior to target engagement.

Engaging Moving Targets from a Stationary BFV

Currently there is no standardized strategy in USAIS courses for training moving-target engagements. Students engage moving targets as part of live-fire scenarios, but there is no particular training program to insure progressive development of the gunner's skills for engaging moving targets.

The current design of firing ranges creates problems in training for moving-target engagements. Targets at Fort Benning move virtually at right angles to the firing lane so students do not obtain experience in engaging targets moving at oblique angles. Also, the targets travel at speeds in training (10 to 15 km/hr) that are less than the speeds expected in combat. The gunnery manual (FM 23-1, 1983) indicates that typical target speeds will be about 32 km/hr. Special range-operation procedures are required for target speeds of 25 km/hr or greater.

Finally, the characteristics of the training ammunition will contribute to non-realistic training conditions even if range design can be improved. The greater ranging accuracy and greater aiming-point lead required by TP-T ammunition can make moving-target engagements difficult. Even though current moving targets at Fort Benning move at approximately 90-degree angles to the firing platform, there are changes in target ranges (50 to 100 meters) along the movement path. These relatively small changes in ranges have been observed to cause target misses. BOT adjustments correctly performed at the range of the sensing round were inaccurate on the first shot group because the target had changed range after the sensing of the first-round.

The U-COFT could be used to minimize many of the problems associated with moving-target engagements on live-fire ranges. Moving vehicular targets are usually engaged with APDS-T ammunition, and this ammunition is simulated by the U-COFT. Furthermore, the U-COFT presents a variety of moving targets that travel at varied speeds, angles to the BFV, and at different ranges. Like for BOT training, effective moving-target engagement training could be designed using a particular sequence of exercises that progressively trains moving-target engagements.

Engaging Stationary Targets from a Moving BFV

The stabilization system of the BFV is designed to produce a steady gun and sight during BFV movement; the gunner can maintain a constant aiming point

over rough terrain. Despite this capability, there are a number of factors that can have a negative impact on gunnery effectiveness when firing on the move. These include:

- o The commander must control the driver as well as the gunner;
- o The enemy will probably fire first;
- o The target will probably be partially covered and concealed;
- o The gunner may have difficulty detecting target location;
- o Accurate range estimation may be difficult.

If a BFV is engaged while moving, the commander must split his attention between the driver, gunner, and the enemy. The commander must make decisions on both avoiding hits and hitting or suppressing the enemy.

During an offensive operation (e.g., movement to contact), it is likely that the enemy will both detect the BFV and fire on it before the BFV crew has detected the target. If the commander detects the firing signature, he must then lay the gun and be able to indicate the target location to the gunner. If the gunner's sight picture did not allow detection of the firing signature, then the firing signature may have dissipated by the time the commander lays the gun for the gunner. The commander may then need to engage the target, making command and control of the vehicle difficult.

Once target location is detected by the gunner, target hit probability will be reduced dramatically if the target is not fully exposed. The smaller exposed surface will decrease hit probability. Compared to a fully exposed frontal view (2-m high by 3-m wide), the placement of a vehicle in partial defilade (1-m high by 2-m wide) results in a target hit probability that is 25 to 35 percent lower (see Perkins 1987c).

If the height of the vehicle is not totally exposed, then the horizontal stadia lines cannot be used for accurate estimation of range. In fact, it is doubtful that time would exist for use of the stadia even if the target were fully exposed.

In general, firing on the move will probably be much more difficult in combat than it is during training. BFV speed during training is often slow (5 to 10 miles/hr), targets are usually fully exposed, and targets do not initiate the firing engagement. The first two conditions make it easier to hit targets while the latter condition does not force the commander to decide on the relative importance of returning fire versus avoiding fire.

The U-COFT generally does allow target engagement with faster BFV and target speeds, than on the live-fire range. However, U-COFT does not have conditions in which a BFV is ambushed by a target that is partly covered and concealed, and has had more time to acquire the BFV and estimate range than does the BFV.

Conclusions

There are a number of combat conditions that cannot be reproduced realistically in a live-fire training environment. For example, operational characteristics of moving targets do not allow speeds expected in combat, the length of firing lanes makes it difficult to conduct target engagement from a BFV moving at combat speeds, there is no cost effective training ammunition for the TOW, time and equipment restrictions often preclude training with the auxiliary sight, and the thermal nature of targets on the range can make target engagement difficult at night. The U-COFT may have the capabilities to fulfill many of these requirements. In any case, live-fire training would be enhanced by the development of needed strategies or improvement of current training strategies.

Recommendation 51. Training strategies are required for BOT adjustments, engaging moving targets, firing from a moving BFV, using the auxiliary sight, firing the TOW, and engaging targets under limited visibility conditions.

Recommendation 52. Construction of range cards should be a requirement for target engagement from a stationary BFV during training and qualification.

The Role of TP-T Ammunition in Training for AP-Type Engagements

APDS-T ammunition is costly and imposes severe range restrictions. Therefore, TP-T ammunition is used as a substitute during training for target engagements that would employ APDS-T under combat conditions. Range requirements preclude the use of APDS-T for training at Fort Benning and in Germany.

As discussed in previous sections, TP-T is ballistically matched with HEI-T, which is designed for area targets, while APDS-T is designed for point-type target engagements. Differences between the two types of ammunition (dispersion level and flight trajectory) have a negative impact on gunnery training and performance compared to APDS-T. Compared to APDS-T ammunition, the characteristics of TP-T substantially decrease both first-round hit capability and hit probability on subsequent rounds. For example, the greater dispersion of TP-T can decrease zeroing accuracy by about one-half, unless special zeroing procedures (i.e., use of three-round shot groups) are employed.

Independent of zeroing procedures, TP-T can result in substantially lower target hit probabilities once the correct aiming point is obtained. Even more critically, it is much more difficult to obtain a correct aiming point with TP-T when the BOT-adjustment technique is used because a single round of TP-T may not provide an accurate indication of the typical impact location. Consequently, direct-fire adjustments based on a single sensing round may be highly inaccurate with TP-T.

Additionally, the amount of elevation correction required to compensate for a range estimation error is considerably greater for the training ammunition. For target ranges between 1000 to 1600 m, ranging errors require elevation corrections for TP-T that are three to six times greater than required for APDS-T. Thus, range estimation errors will have greater consequence in training than in combat.

Engagement of moving targets with TP-T requires a greater aiming-point lead than for APDS-T. Overall, the lead requirements for TP-T are nearly twice that of APDS-T ammunition. To achieve first-round hits during live-fire training, the gunner must use the lead rule suitable for TP-T ammunition rather than the APDS-T lead rule that he will need to use in combat, unless target speed in training is slower than expected combat speeds.

The Role of TP-T Ammunition in Gunnery Qualification Standards

The known ballistic differences between TP-T and APDS-T ammunition make it unrealistic to expect identical gunnery performance with these two types of ammunition. (See Perkins (1987c) for the predicted effect of varied projectile dispersion levels on target-hit probability.) For example, on a frontal silhouette of a BMP sized target at 1600 m, the hit probability for TP-T ammunition dispersion is only about 50 percent for that of APDS-T.

The increasingly low hit probability with TP-T as target range increases has implications for establishing the maximum effective engagement range for TP-T ammunition, particularly when used against vehicular targets. Gunnery standards need to reflect this consideration. Use of long-range engagements (e.g., 1600 m or greater) in training can result in excessive ammunition utilization per engagement. The use of shot groups of 3 to 5 rounds may be abandoned by the gunner in an effort to achieve hits. This type of experience would foster gunner habits that are counter to the fire discipline required for optimal ammunition utilization with the 25-mm gun.

Given the above considerations, it would seem that gunnery standards for target ranges beginning at 1000 m should compensate for predicted differences in hit probabilities. No such adjustment or compensation is currently provided in gunnery qualification tables. Therefore, the following recommendation is presented.

Recommendation 53. Develop gunnery qualification standards for TP-T ammunition that are realistic in view of its known target hit capability.

The Role of HEI-T Ammunition

The role of HEI-T ammunition in target engagement is not well defined in manuals, training literature, or current training practices. There are a number of inconsistencies and omissions in current practices involving HEI-T ammunition. For example, neither the gunnery qualification tables nor the training objectives for instruction at USAIS include area-type engagements for HEI-T. On the other hand, the gunnery qualification tables do include target engagements of light-skinned vehicular targets (e.g., BRDM) with HEI-T even though this ammunition was designed for area targets. While a HEI-T round would undoubtedly damage such a vehicle, it is first necessary to hit it. Target hit probabilities are lower for HEI-T than APDS-T at a given range, and yet the number of rounds allowed for vehicular target engagement in gunnery qualification tables for HEI-T is the same as for APDS-T. There is no allocation specified for area and suppressive fire engagements. The omission of training for target engagements for which HEI-T was specifically designed, and the inclusion of qualification requirements with target engagements for

which it was not designed, result in the presentation of a confusing picture to the novice gunner.

The gunnery field manual describes engagement techniques with the coaxial machine gun, but no discussion is provided for target engagement techniques with HEI-T. It is not clear why techniques for use of the coaxial machine gun should receive more treatment than use of HEI-T with the 25-mm gun, when the techniques described for the coaxial machine gun are very similar to well-established infantry procedures that are not BFV specific.

The tactical (FC 7-7J) and gunnery (FM 23-1) manuals recommend use of HEI-T ammunition when the target range exceeds the maximum effective range of the coaxial machine gun (i.e., 900 m). Given this, HEI-T has potential use from ranges of about 1000 m to its tracer burnout range of 2400 m. However, because HEI-T provides a definite signature upon impact, it is conceivable that it could be used beyond 2400 m. Despite the long-range capability for providing support fire for dismounted infantry, suppressive fire on ATGM and other positions, and area-type engagements, it should be recognized that effectiveness of HEI-T is very dependent on either accurate range estimation or sufficient time and ammunition to allow direct-fire adjustments.

Another questionable area concerns the current ammunition upload recommendations. These specify that the larger compartment of the ready box (230 round capacity) is to be uploaded with HEI-T and the smaller compartment (70 round capacity) is designated for APDS-T. The reason for this substantial imbalance is not clearly stated in either the tactical manual (FC 7-7J, 1985) or the gunnery field manuals (FM 23-1, 1983, 1986). The BFV often is referred to as a "BMP-killer" at Fort Benning, and yet less ammunition is uploaded for vehicular type targets than for area engagements.

It is possible to reverse the uploading so that there are 230 rounds of APDS-T and 70 rounds of HEI-T. While this provides a substantial improvement for engagement of vehicular targets, it would place restrictions on the use of HEI-T. Seventy rounds of HEI-T would allow only restricted use for area and suppressive fire engagements. Firing techniques used to conserve HEI-T ammunition would be as critical as is currently the case for APDS-T ammunition.

Also, it is not clear whether ammunition conservation requirements for HEI-T dictate the same engagement techniques as used with APDS-T ammunition. The HEI-T ammunition is ballistically designed for area-type engagements so the utility of a single sensing round is questionable in certain circumstances (e.g., an ambush while on the move). Guidance on selection of either low or high rate of fire also is closely related to considerations for ammunition conservation with HEI-T ammunition.

In combat, the BFV crew will encounter numerous situations that call for the selection and effective employment of HEI-T ammunition. Currently, the role of HEI-T ammunition is not clearly defined for the gunner, and the need exists to develop guidance for this ammunition in the areas of techniques for target engagement, strategies for training, and ammunition conservation. Therefore, the following recommendation is presented.

Recommendation 54. Undertake work to further develop and refine firing techniques and training strategies for HEI-T ammunition.

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