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This analysis was conducted to determine if system errors in the Bradley Fighting Vehicle (BFV) negatively affect elevation or range-related aspects of 25mm gunnery accuracy. A Soviet BMP vehicle is about 2.15m high, but the horizontal ranging stadia of the integrated sight unit (ISU) on a fielded BFV was designed to determine range for a target of from 1.5 to 1.7m high (depending on the part of stadia used). For target ranges of 1800m and greater, super elevation (SE) compensation produced by the fire control system for armor piercing and high explosive ammunition was more and less, respectively, than indicated by firing tables. SE compensation of the auxiliary sight unit closely matched data from the firing tables. For a sample of fielded vehicles, ISU backlash was usually no greater than 0.5 miles, while the mean value for the auxiliary sight unit was 1.7 miles. Switching magnification of the ISU caused aiming changes that varied widely among vehicles. (0.5 to 5 mils). With these findings, BFV managers can identify potential system problems and undertake needed modifications.

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Analysis of System Factors Affecting Range-Related Accuracy of the 25mm Gun of the Bradley Fighting Vehicle

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September 1988

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FOREWORD

The Army Research Institute for the Behavioral and Social Sciences (ARI) has contributed to a program to define emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). Consistent with that program, this analysis was designed to determine whether there are BFV system errors that affect elevation or range-related aspects of 25mm gunnery accuracy.

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

The work was conducted in close cooperation with USAIS and the BFV Gunnery Proponency Office of the 29th Infantry Regiment. Results were briefed to the proponent, which led to the development of backlash test procedures and modified procedures for utilizing the horizontal ranging stadia. These developments have been incorporated into the BFV Gunnery field manual (FM 23-1).

ANALYSIS OF SYSTEM FACTORS AFFECTING RANGE-RELATED ACCURACY OF THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

EXECUTIVE SUMMARY

Requirement:

Analysis was performed to determine if there are system factors of the Bradley Fighting Vehicle (BFV) that negatively affect round elevation or range-related aspects of 25mm gunnery accuracy. Specific objectives were to determine the target height that allows accurate range determination with the horizontal ranging stadia, to compare range-dependent superelevation (SE) compensation indicated in the firing tables with actual compensation produced by integrated sight units (ISU) and auxiliary sight units of BFVs, to determine backlash in ISUs and auxiliary sight units, and to determine aiming changes of the ISU when magnification is switched.

Procedure:

The height (mils) of the horizontal ranging stadia was measured at the range markings and trigonometric calculations were used to determine target height (meters) that would allow accurate range determination with the stadia. Drop of the ISU reticle was measured for different range control settings when both armor piercing (AP) and high explosive (HE) ammunition were selected. These data were compared to SE data in the firing tables to determine the accuracy of ballistic correction in fielded BFVs. SE compensation provided by the auxiliary sight unit was also measured and compared to data from the firing tables. Backlash of ISUs and auxiliary sight units was determined by measuring the difference in the aim of the gun after ISU reticle gun lays that ended in opposite directions. Differences in the aim of the ISU reticle were measured for low and high magnification.

Findings:

Data indicated that the horizontal ranging stadia is designed to estimate range for a target about 1.5 to 1.7 meters high, depending on the part of reticle used. For target ranges of 1800 meters and greater, SE compensation produced by the fire control system was more for AP ammunition and less for HE ammunition than was indicated by the firing tables. SE compensation of the auxiliary sight unit closely matched data from the firing tables. ISU backlash was usually no greater than 0.5 mils, while the mean value for the auxiliary sight unit was 1.7 mils. Switching magnification of the ISU caused aiming changes that varied widely between vehicles (range of 0.5 to 5 mils).

Utilization of Findings:

The findings of this analysis will be used by BFV managers to identify potential system problems and modifications.

ANALYSIS OF SYSTEM FACTORS AFFECTING RANGE-RELATED ACCURACY OF THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

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ANALYSIS OF SYSTEM FACTORS AFFECTING RANGE-RELATED ACCURACY OF THE 25MM GUN OF THE BRADLEY FIGHTING VEHICLE

INTRODUCTION

Background

Since September 1983, Litton Computer Services has been under contract to the Army Research Institute (ARI) Fort Benning Field Unit to improve operational effectiveness of the Bradley Fighting Vehicle (BFV). Gunnery research and development focused on techniques and procedures to improve the crews' capability to achieve first-round hits with the 25-mm gun. While it is often stated that the 25-mm gun of the BFV is not designed to achieve first-round hits, the materiel need for the BFV requires the 25-mm weapon system to have a high first-round hit capability against a BMP-sized target (about 2 meters high) from 0 through 1400 meters when armor piercing (AP) ammunition is used (Department of Army, 1978).

To achieve first-round hits, the gun must be elevated above line of sight to account for drop of the round caused by gravity. Rounds may hit above or below the target if either gunner or weapon system errors cause the gun to be incorrectly elevated. This report focuses on the identification of system factors that affect elevation or range-related accuracy of the 25-mm gun. Factors analyzed include range estimation accuracy of the reticle (horizontal ranging stadia), range related ballistic correction provided by either the fire control system (range control knobs) or reticles (auxiliary sight unit), and other system operations that cause unexpected errors (backlash) in elevation of the gun.

Underestimation of range causes rounds to fall short of the target, while overestimation causes rounds to fly over the target. The horizontal ranging stadia of the integrated sight unit (ISU) (see Figure 1) allows the gunner to estimate range to a BMP-sized target. The gunner lays the stadia so that the bottom of the target is positioned on the horizontal line while the top of the target touches the scaled, slanted line used to determine range (FM 23-1, 1986).

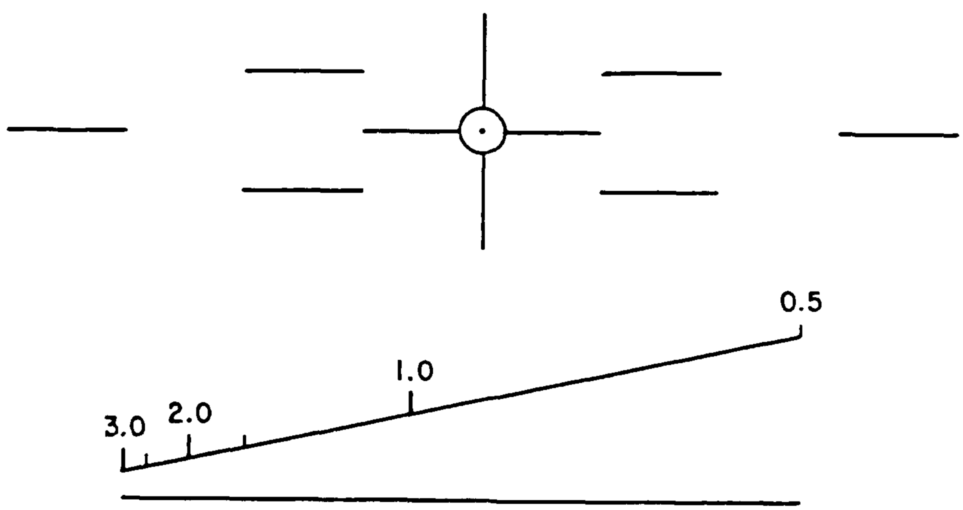

Figure 1. Illustration of the ISU gun reticle and horizontal ranging stadia.

After the gunner determines the target range, the BFV's fire control system is designed to provide the correct superelevation (SE) to the gun. Using a range control knob, the gunner sets the range at even numbered 200-meter increments up to 3000 meters. Computer controlled operations then adjust the sight picture of the ISU based on the setting (the sight picture drops as range increases). After the range is set, the gunner re-lays the reticle on target and fires.

For the fire control system to provide the correct gun elevation, the amount of drop of the sight picture (and gun reticle) for a particular range control setting should equal the SE data in the ballistic firing tables (FT 25-A-1, 1984). SE data from the table indicate the angle (mils) the gun must be elevated above line of sight in order to achieve target hits. The fire control system provides separate ballistic corrections for AP and high explosive (HE) ammunition.

The auxiliary sight unit is used to fire the 25-mm gun when either the ISU is not operational or turret backup power has failed. The auxiliary sight reticle is illustrated in Figure 2. The boresight cross is used to align the reticle and gun during boresighting. The ranging stadia (AP and HE), range scales (AP and HE), and range lines are used (a) to estimate range to BMP-sized targets and (b) to provide the correct SE compensation for target engagement. The vertical distance in mils between the boresight cross and a range line, for a particular type of ammunition, should be the same as SE data listed in the firing tables.

In summary, at least two range-related factors must operate properly in order for the gun to have the correct elevation. The ranging stadia must indicate the correct target range. And secondly, the fire control system for the ISU and the reticle for the auxiliary sight must provide the correct SE compensation based on ammunition and target range. Errors in either range estimation or SE compensation can lead to either low or high rounds.

Another weapon system error that can affect projectile accuracy is backlash, which is caused by an imprecise linkage between the sight and gun. Backlash is measured by taking the difference in the aim of the gun (using a boresight telescope) after laying the gun reticle on a given aiming point, first from low to high, then from high to low. The maximum allowed backlash between the gun reticle and gun bore is 2 mils (Department of Army, 1980).

Potential Problems

During the problem identification phase for gunnery research (Perkins, 1987a), the following information was obtained:

- There is little confidence in the range determination accuracy of the horizontal ranging stadia,
- The horizontal ranging stadia was not based on a BMP that was 2.2 meters high,

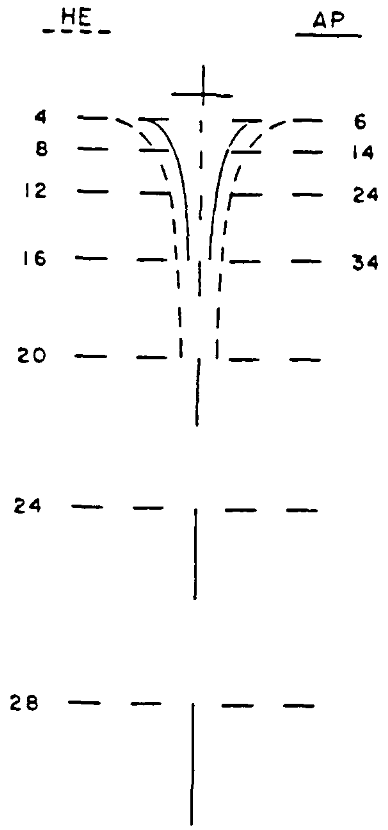

Figure 2. Illustration of the auxiliary sight unit reticle.

- Several very experienced BFV gunners indicated that AP rounds tended to be high on long-range target engagements,

- A senior BFV instructor indicated that the aiming point of the ISU gun reticle moved when magnification was shifted between low and high.

While some or all of these potential problems may result from human errors, it is also possible that certain fire control and weapon system errors exist.

Purpose

The overall research objective was to determine if there are fire control and weapon system errors that affect elevation or range-related aspects of 25-mm gunnery accuracy. Specific test objectives were:

- To determine the size of target that is accurately ranged by the horizontal ranging stadia;

- To compare SE compensation provided by the range settings of the ISU with SE data in the firing tables;

- To compare the SE compensation provided by the auxiliary sight reticle with the SE data in the firing tables;

- To determine aiming changes of the ISU gun reticle when magnification is switched;

- To determine backlash in the ISU and the auxiliary sight unit.

Experiment 1 tested the first four objectives while backlash was tested in Experiment 2. Backlash was tested separately because it was not recognized as a potential problem during the planning and execution phases of Experiment 1.

EXPERIMENT 1

Method

Materials and equipment. Six BFVs from a company at Fort Benning were used. Vehicles were available for a four-hour period on 19 September 1985 during another scheduled ARI test. Data collection was facilitated by a special score sheet (see Figure 3) and test panel. The test panel had a four-by-four grid and a vertical mil scale (see Figure 4). The grid and scale were on a white board that was 1-foot wide and 6.5 feet high. One-eighth-inch-wide lines were produced by dado cuts "filled" with black tape. The side of each square on the grid was 2 inches (1 mil at 52 meters). The distance between long and short tick marks on the vertical mil scale was 1 inch (0.5 mils at 52 meters).

Determination of SE compensation provided by the ISU. All six vehicles were tested. For each test, the test panel was placed 52 meters from the ISU. Testing preparation consisted of turning on turret power and turret drive, placing the ammunition select switch in the ARM position, selecting AP ammunition, and setting the ISU in the day mode and high magnification. Reticle drop (i.e., SE compensation) for each range control setting was measured using high rather than low magnification to allow better interpolation of readings. However, one vehicle was tested in low magnification because a reticle was not displayed in high power.

The gunner's control station was then used to aim the center dot of the ISU gun reticle on the center of the four-by-four grid; the center of the grid represents 0 mils on the vertical mil scale. Reticle position on the mil-scale of the test panel was recorded (to the nearest 0.1 mils) at each range control setting up to 28 (2800 meters). The range control was re-set to 0 prior to each reading to ensure that the reticle had not changed its position on the grid during testing. After data were collected for an ammunition selection of AP, HE was selected. The position of the reticle on the vertical mil scale on the test panel was recorded for each range control setting up to 2400 meters.

INTEGRATED SIGHT UNIT DATA SHEET

VEHICLE: ______________

DATE: __________ TIME: __________

25 MM RETICLE POSITION DURING MAGNIFICATION CHANGE

DATA READER				
ISU SETTING	Day / Night	Day / Night	Day / Night	Day / Night
MAGNIFICATION	Low / High	Low / High	Low / High	Low / High
RETICLE AZ				
RETICLE EL				
RET. SHIFT (MIL)				

25 MM RETICLE SHIFT (SUPERELEVATION) DURING RANGE INDEXING

DATA READER				
0 M				
200 M				
400 M				
600 M				
800 M				
1000 M				
1200 M				
1400 M				
1600 M				
1800 M				
2000 M				
2200 M				
2400 M				
2600 M				
2800 M				

Figure 3. A sample score sheet.

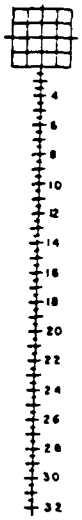

Figure 4. Illustration of the grid and vertical mil scale on the test panel.

Data from all vehicles were used to calculate the mean and standard deviation SE compensation (reticle drop) for each range control setting. SE data from the firing tables (FT 25-A-1, 1984) were used to determine the amount of ballistic correction that should be applied for accurate gunnery performance; the firing tables were assumed to provide the most valid indicator of required SE compensation. The tables used in this analysis have undergone several live-fire iterations for validation. Ideally, validated data for the firing table should then be specified as a production requirement for the vehicle. This requirement should then serve as a means of quality control and assurance for vehicle operation. Vehicle specifications for providing SE compensation were determined from the product function specification document (Department of the Army, 1978).

Difference scores for a given range were used to determine the following SE compensation errors.

- Function specification error: SE from the product function specification minus SE from the firing tables.

- Production error: mean measured SE minus the SE from the product function specification.

- Actual functional error: mean measured SE minus SE data from the firing tables.

For a given target range, the function specification error plus the production error equalled the actual functional error.

Determination of reticle changes during magnification switching. After each vehicle was tested for SE compensation, reticle change caused by magnification switching was measured. Only the five BFVs that displayed a reticle in high magnification were tested.

Testing began with the range control knob set on 0, magnification set on high, and AP ammunition selected. Using the gunner's control station, the reticle was then aimed at the center of the grid on the panel. Magnification was then switched to low and the position of reticle aim was determined. The panel matrix was treated as a cartesian coordinate system with the center being defined as azimuth = 2 and elevation = 2. The azimuth and elevation coordinates were recorded for reticle aim in low and high magnification. The Pythagorean Theorem was then used to compute the change in aim caused by switching magnification.

Determination of SE compensation provided by the auxiliary sight unit. Because of time constraints, only one vehicle was tested. Using the gunner's control station, the boresight cross on the upper portion of the sight was aligned with the center of the grid on the test panel. The distance in mils from the boresight cross to the top of each range marking was measured. The indicated range for each range line was obtained for the AP and HE range scales on the reticle. The measured SE for indicated ranges was then compared to SE data from the firing tables (FT 25-A-1, 1984).

Determination of target size accurately ranged by the horizontal ranging stadia. The vehicle used to test the auxiliary sight was also used for the test of the horizontal ranging stadia. The panel was used to measure the vertical distance (mils) between the baseline of the stadia and the 500-, 1000-, 1500-, 2000-, 2500-, and 3000-meter-range marks of the stadia. This information was used to determine the target size in meters that could be accurately ranged on the stadia at each range mark. The formula used for this conversion was: target size (meters) = range on stadia (meters) X TAN (vertical distance in mils).

Results

SE compensation provided by the ISU. Table 1 presents the amount of SE compensation for AP ammunition that the vehicle (a) should produce for accurate gunnery performance (SE from firing tables), (b) is required to produce (SE from product function specification), and (c) actually produced (mean measured SE). Data indicated that vehicle requirements and actual SE compensation produced by the fire control system were very similar. However, for increasing range, SE indicated in the firing tables was less than (a) required of the fire control system (SE from product function specification) and (b) for actual vehicle operation (mean measured SE).

The trends noted in Table 1 are supported by derived error measurements (see Table 2). Function specification error increased with range indicating that vehicles are required to produce more SE than indicated by the firing tables. Production error was low; in 93% of target ranges, mean measured SE was no greater than 0.1 mils from that required of the vehicle. Actual functional error, which paralleled production specification error, got progressively higher with range.

Table 1

Required and Measured SE Compensation (mils) for AP Ammunition

Range (meters)	SE from firing tables	SE (S.D.) from product function specification	Mean (S.D.) measured SE (n = 6)
200	0.6	0.7 (0.59)	0.8 (0.10)
400	1.1	1.2 (0.63)	1.2 (0.05)
600	1.7	1.8 (0.63)	2.0 (0.08)
800	2.4	2.5 (0.63)	2.6 (0.10)
1000	3.0	3.2 (0.63)	3.1 (0.08)
1200	3.7	4.0 (0.67)	4.0 (0.14)
1400	4.4	4.7 (0.67)	4.8 (0.20)
1600	5.1	5.5 (0.71)	5.5 (0.23)
1800	5.9	6.4 (0.71)	6.4 (0.21)
2000	6.7	7.3 (0.75)	7.4 (0.20)
2200	7.5	8.4 (0.75)	8.4 (0.21)
2400	8.4	9.4 (0.79)	9.3 (0.20)
2600	9.3	10.5 (0.79)	10.5 (0.23)
2800	10.2	11.7 (0.82)	11.7 (0.25)

Table 2

SE Compensation Errors (mils) for AP Ammunition

Range (meters)	Function specification error[a]	Production error[b]	Actual functional error[c]
200	0.1	0.1	0.2
400	0.1	0.0	0.1
600	0.1	0.2	0.3
800	0.1	0.1	0.2
1000	0.2	-0.1	0.1
1200	0.3	0.0	0.3
1400	0.3	0.1	0.4
1600	0.4	0.0	0.4
1800	0.5	0.0	0.5
2000	0.6	0.1	0.7
2200	0.9	-0.1	0.8
2400	1.0	-0.1	0.9
2600	1.2	0.0	1.2
2800	1.5	0.0	1.5

Note. [a] Production function specification minus firing table data. [b] Measured SE minus product function specification. [c] Measured SE minus firing table data

Actual functional error was at least 0.5 mils beginning at 1800 meters. Figure 5 illustrates the predicted impact of actual functional error on a BMP-sized target. The figure illustrates predicted round-impact location relative to a 2-m high target at ranges from 0 through 2800 meters; a center of mass aim is indicated by the broken line centered in the shaded area. For the prediction, it was assumed that the 25-mm gun was perfectly zeroed, the projectile trajectory was correctly specified in the firing tables, the correct target range was set in the fire control system, the gunner achieved a perfect center of mass aim, and the target was fully exposed. With these assumptions it was predicted that rounds would begin to fly over the target at about 1800 meters which is just beyond tracer burn out.

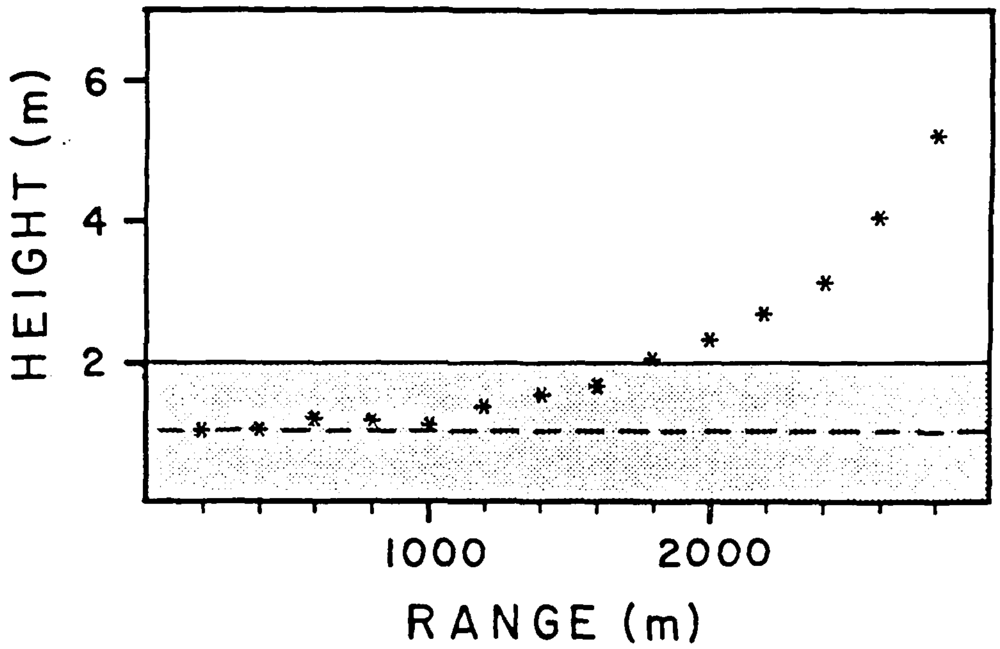

Figure 5. Predicted location of an AP round relative to a 2-meter high target when using a center of mass aim. (Each star indicates where the round would hit the target or pass over it when the range control setting equals target range.)

Table 3 indicates that for HE ammunition vehicle requirements (SE from product function specification) and actual SE compensation (mean measured SE) were very similar. However, beginning at a range of 1600 meters, SE indicated in the firing tables was more than (a) required of the fire control system and (b) for actual vehicle operation.

Table 4 (see page 13) summarizes the error data. As with AP ammunition, there was minimal production error for HE ammunition. Actual functional error, which was similar to product specification error, indicated that the fire control system was required to have, and actually had, less SE compensation than indicated by the firing tables.

Reticle Aim Change During Magnification Switching. Reticle aim change during magnification switching varied considerably between the five tested vehicles. The reticle aim change for tested vehicles was 0.5, 0.8, 0.8, 1.8, and 5.0 mils (mean = 1.8 mils, S.D. = 1.87 mils).

Table 3

Required and Measured SE Compensation (mils) for HE ammunition

Range (meters)	SE from firing tables	SE (S.D.) from product function specification	Mean (S.D.) measured SE (n = 6)
200	0.9	0.9 (0.63)	1.0 (0.00)
400	1.9	1.9 (0.63)	2.0 (0.05)
600	3.1	3.2 (0.67)	3.2 (0.15)
800	4.5	4.6 (0.67)	4.5 (0.11)
1000	6.1	6.1 (0.71)	6.2 (0.24)
1200	8.1	8.0 (0.75)	8.2 (0.22)
1400	10.5	10.4 (0.79)	10.3 (0.20)
1600	13.5	13.1 (0.87)	13.2 (0.15)
1800	17.1	16.5 (1.02)	16.5 (0.26)
2000	21.7	20.7 (1.24)	20.6 (0.29)
2200	27.3	25.7 (1.48)	25.6 (0.31)
2400	33.9	31.7 (1.79)	31.8 (0.36)

Table 4

SE Compensation Errors (mils) for HE Ammunition

Range (meters)	Function specification error [a]	Production error [b]	Actual functional error [c]
200	0.0	0.1	0.1
400	0.0	0.1	0.1
600	0.1	0.0	0.1
800	0.1	-0.1	0.0
1000	0.0	0.1	0.1
1200	-0.1	0.2	0.1
1400	-0.1	-0.1	-0.2
1600	-0.4	0.1	-0.3
1800	-0.6	0.0	-0.6
2000	-1.0	-0.1	-1.1
2200	-1.6	-0.1	-1.7
2400	-2.2	0.1	-2.1

Note. [a]Production function specification minus firing table data. [b]Measured SE minus product function specification. [c]Measured SE minus firing table data.

SE Compensation for the Auxiliary Sight Unit. As indicated in Table 5 (see page 14), SE indicated in the firing tables closely matched that measured on the test vehicle. Actual functional error was no more than 0.5 mils except for a range of 2400 meters for HE ammunition.

Table 5

SE Compensation (mils) for the Reticle of the Auxiliary Sight Unit

Range (meters)	SE from firing table	Measured SE	Actual functional error
		AP Ammunition	
600	1.7	2.0	0.3
1400	4.4	4.5	0.1
2400	8.4	8.4	0.0
		HE Ammunition	
400	1.9	2.0	0.1
800	4.5	4.5	0.0
1200	8.1	8.3	0.2
1600	13.5	13.3	-0.2
2000	21.7	21.3	-0.4
2400	33.9	32.9	-1.0

Size of target accurately ranged with the horizontal ranging stadia. For each range marking on the stadia, Table 6 (see page 15) presents (a) the vertical distance (mils) between the baseline and scaled line of the stadia and (b) the estimated size of target that would be accurately ranged at each range marking. Measurements of the reticle indicate that the stadia was calibrated for a target height of about 1.5 to 1.7 meters. In general, the target size that could be accurately ranged decreased as range increased.

Table 6

Vertical Height (mils) of the Horizontal Ranging Stadia at Marked Ranges and Predicted Height (meters) of Target Allowing Accurate Range Determination

Range marking (meters)	Vertical height of stadia (mils)	Predicted target height (meters)
500	3.50	1.72
1000	1.65	1.62
1500	1.10	1.62
2000	0.85	1.67
2500	0.60	1.47
3000	0.50	1.47

EXPERIMENT 2

Method

Materials and equipment. Nine BFVs from a support company for the BFV Commander Course at Fort Benning were used to test backlash from 21 through 30 January 1987. Seven of the BFVs had auxiliary sight units. A backlash score sheet was designed and prepared for data collection purposes (see Figure 6). A boresight kit (Wild Heerbrugg Instruments, Inc.) was used to aim the gun and to determine changes in the aim of the gun during testing. The reticle of the boresight telescope had horizontal and vertical cross hairs marked at 1-mil increments.

Two types of test panels were used. A specially designed 52-meter panel had separate aiming points for the ISU reticle (a black cross), the auxiliary sight unit reticle (a black cross), and the 25-mm gun (an orange cross). The 2.5-mil long upper and lower arms of the 25-mm aiming cross had tick marks at 1 and 2 mils from the cross hair center. A second target was a 1200-meter white, boresight panel. The 1200-meter target was used in the latter stages of testing when it was found to require less preparation time for each vehicle.

Procedure. During each test, one experimenter occupied the gunner's position in the turret while another experimenter was positioned at the end of the 25-mm gun barrel. Vehicle conditions prior to testing were turret power and turret drive turned on, the turret traverse and gun elevation drive set in power mode, the ammunition select switch in the ARM position, AP ammunition selected, and the ISU set in day mode with high magnification. The only exceptions to this setup procedure was that two vehicles were tested in manual mode.

The ISU day reticle was boresighted to the 25-mm gun prior to testing. The boresight kit was inserted into the 25-mm gun barrel. With a gun lay ending with at least 5 mils of elevation as determined by the boresight telescope, the gun was laid on the aiming point of the target (the 25-mm cross hair on the 52-meter target or the upper left-hand corner of the 1200-meter target). The day boresight adjustment knobs were then used to align the ISU reticle with the designated aiming point (the ISU cross hair on the 52-meter target or the upper left-hand corner of the 1200-meter target). The auxiliary sight unit was boresighted after completion of backlash testing for the ISU.

The procedure for testing backlash was the same for the ISU and auxiliary sight unit. Table 7 summarizes the procedure. The gun lay pattern refers to the action taken by the experimenter within the turret. Using the gunner's control station, the experimenter either depressed or elevated (at least 5 mils) the gun as described in the table and then elevated or depressed the gun, respectively, until the reticle (either the ISU center dot or the auxiliary sight unit boresight cross hair) was aiming at the designated aiming point on the target.

Table 7

Test Procedure for Backlash

Gun lay pattern	Data reading	Backlash determination (mils)
Down then up to aimpoint	Gun aimpoint 1	
Up then down to aimpoint	Gun aimpoint 2	Gun aimpoint 1 - gun aimpoint 2
Up then down to aimpoint	Gun aimpoint 3	
Down then up to aimpoint	Gun aimpoint 4	Gun aimpoint 3 - gun aimpoint 4
Down then up to aimpoint	Gun aimpoint 5	
Up then down to aimpoint	Gun aimpoint 6	Gun aimpoint 5 - gun aimpoint 6
Up then down to aimpoint	Gun aimpoint 7	
Down then up to aimpoint	Gun aimpoint 8	Gun aimpoint 7 - gun aimpoint 8

Data readings were taken using the boresight telescope reticle. The data reflected the distance in mils between the cross hair of the boresight telescope and the aiming point on the target. Readings were interpolated to the nearest 0.25 of a mil. Backlash was then determined by subtracting gun aiming points that followed gun lay patterns ending in opposite directions. Four backlash determinations were made for each test of both the ISU and auxiliary sight unit test. The mean backlash was determined for each sight.

Eight BFVs were used to test ISU backlash; the ISU on one vehicle was not tested because of a faulty sight. Auxiliary sight unit backlash was tested on six vehicles. When both ISU and auxiliary sight unit backlash were tested on the same vehicle, the ISU was tested first.

Results

Backlash results are presented in Table 8. All ISUs had backlash that met the 2-mil standard. The mean backlash for all sights was 0.53 mils while most ISUs (75%) had backlash of 0.5 mils or less. The mean backlash for all auxiliary sight units was 1.69 mils with values generally being between 1 and 2 mils; one sight had backlash greater than 2 mils.

Table 8

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

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

SUMMARY AND DISCUSSION

The overall research objective was to determine if there are equipment or system related errors on the BFV that affect elevation or range-related accuracy of 25-mm gunnery. One factor examined was the accuracy of SE compensation produced by the ISU. Analyses examined range-related SE compensation that is (a) indicated by firing tables, (b) required of the vehicle by the production function specification document, and (c) produced by the ISU of fielded vehicles. SE compensation of fielded vehicles closely matched vehicle production requirements; however, compensation produced by vehicles differed from the firing tables. For both AP and HE ammunition, SE compensation by the vehicle differed from the firing tables by at least 0.5 mils beginning at 1800 meters and error increased with range.

Analysis of the horizontal ranging stadia of the ISU indicated that it was calibrated for a target height of about 1.5 to 1.7 meters depending on the point of measurement on the stadia. Analysis of the auxiliary sight unit indicated that SE compensation provided by range lines closely matched data from the firing tables. Backlash for the ISU was usually no greater than 0.5 mils while mean backlash for the auxiliary sight unit was about 1.6 mils. There was wide variability (0.5 to 5 mils) in the amount of reticle shift occurring during magnification switching with the ISU.

SE compensation by the ISU. The SE data from the firing tables was assumed to be the most valid indicator of SE compensation required for accurate gunnery performance. Differences in SE compensation produced by the vehicle and shown in the firing tables indicates a system error in the fire control system. The direction of potential error differed for AP and HE ammunition.

As was shown in Figure 5, it is predicted that the amount of SE compensation error for AP ammunition in fielded BFVs would cause rounds to fly over a fully-exposed BMP beginning at ranges of 1800 meters, even with perfect range determination and the correct range control setting. Because rounds are predicted to be high, it would be difficult to determine where the round passed the plane of the target. This increases the probability of error during direct-fire adjustment.

The current version of the BFV gunnery field manual (FM 23-1, 1987) indicates an AP maximum effective range equal to tracer burn out of about 1800 meters. For engagements up to this range, it is doubtful that measured SE compensation errors in tested vehicles would have a significant impact on gunnery accuracy.

The results for HE ammunition suggest that, beginning at about 1600 to 1800 meters, rounds would hit about 75 meters short of the target. Although rounds would be short, direct-fire adjustment should be relatively accurate because round-impact location could be determined.

The horizontal ranging stadia. When the stadia is used as recommended in earlier versions of the gunnery manual (FM 23-1, 1983, 1986), it should be possible to determine the range to a target the height of a BMP. Its height varies according to weapons attached to the turret, but a commonly referenced height is 2.15 meters (DDB-1100-255-80, 1980; FM 100-2-3, 1984). Based on the current analysis, it is predicted that the stadia would underestimate target range by 20 to 42% for a BMP-sized target when used as previously recommended (FM 23-1, 1983, 1986).

Given the current design of the stadia, it has been recommended that the top of the hull be used as the reference for ranging to BMP-sized targets (Perkins, 1987 & 1988). Because the hull of the BMP is standard for the BMP, the BMP-2, and for different turret-mounted weapon configurations, it should be possible to obtain accurate range estimation for vehicles of different design and configuration. The latest version of the gunnery manual (FM 23-1, 1987) has adopted the recommendation for measuring only the hull of a BMP-sized target.

SE compensation by the auxiliary sight unit. SE compensation provided by the range lines of the auxiliary sight unit was measured. Generally, there was less than 0.5 mils difference between SE compensation provided by the sight and that indicated by the firing tables. The results of the test suggest that the range markings on the auxiliary sight unit closely approximate that indicated in the firing tables (FT 25-A-1, 1984).

Backlash. Backlash between the sight (ISU or auxiliary) and gun can cause elevation errors in gunnery even when range has been perfectly determined and the correct range control setting is made. A 2-mil standard exists for the ISU. The ISUs tested in this analysis had backlash that was much less than the requirement. Backlash for auxiliary sight units was about three times greater than for ISUs.

As discussed in a previous report (Perkins, 1988), backlash less than the 2-mil standard can have a negative impact on gunnery accuracy. However, the effects of backlash can be minimized if a standardized gun lay pattern is used during sight alignment (boresighting and zeroing) and target engagement. As a result of the earlier development of backlash-related operating and test procedures (Perkins, 1988; Perkins and Roberson, 1988), the latest gunnery manual includes a test that can be conducted by the user to determine backlash in fielded vehicles (FM 23-1, 1987), and the turret technical manual (TM 9-2350-252-10-2) will include a standardized gun lay pattern as part of boresighting and zeroing.

ISU aiming changes caused by magnification switching. Switching ISU magnification caused a change in the aim of the reticle. Because of potential variation in the aim of the sight as a result of magnification setting, it is critical that the 25-mm gun be boresighted and zeroed in the magnification used for target engagement. Because targets are usually engaged in high magnification, the turret technical manual recommends use of high magnification during boresighting and zeroing (TM 9-2350-252-10-2, 1986). The wide variability in reticle shift between vehicles suggests that the scope and implications of these findings should be further investigated.

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