Research Report 1483

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Accuracy of Boresight Equipment for the 25-Millimeter Gun of the Bradley Fighting Vehicle

Mike S. Perkins and Craig S. Wilkinson
Litton Systems, Inc.

ARI Field Unit at Fort Benning, Georgia
Training Research Laboratory

U. S. Army

Research Institute for the Behavioral and Social Sciences

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Observations of zeroing with the 25-mm gun of the Bradley Fighting Vehicle (BFV) indicated excessive ammunition expenditure. Analysis of fielded boresight equipment indicated that 25-mm boresight adapters were generally less accurate than boresight telescopes; however, some telescopes were extremely inaccurate. Data indicated that telescope accuracy decreases with equipment use and abuse. Much inaccurate equipment was not designated for repair or replacement; lack of fielded accuracy standards for either the 25-mm adapter or the 25-mm kit may contribute to this undesirable situation.

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EDGAR M. JOHNSON
Technical Director

WM. DARRYL HENDERSON
COL, IN
Commanding

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Litton Computer Services Division
Litton Systems, Inc.

Technical review by

David W. Bessemer
John A. Boldovici
L. E. Lyons

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Mike S. Perkins and Craig S. Wilkinson
Litton Systems, Inc.

ARI Field Unit at Fort Benning, Georgia
Seward Smith, Chief

Training Research Laboratory
Jack H. Hiller, Director

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

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Training and Simulation

FOREWORD

Since 1975, the U.S. Army Research Institute (ARI) has contributed to a program to determine emerging problems and address critical issues affecting the Bradley Fighting Vehicle (BFV). This report describes accuracy tests conducted on fielded boresight equipment for the 25-mm gun of the BFV and is intended for project and product managers associated with this equipment.

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

The results of these studies provide the foundation for future gunnery research and have been briefed to the Armament Munitions and Chemical Command (AMCCOM), PM Bradley, TSM Bradley, and throughout the 29th Infantry Regiment and USAIS. Findings will be incorporated in the next edition of the Bradley gunnery manual.

EDGAR M. JOHNSON
Technical Director

ACCURACY OF BORESIGHT EQUIPMENT FOR THE 25-MILLIMETER GUN OF THE BRADLEY FIGHTING VEHICLE

EXECUTIVE SUMMARY

Requirement:

Observations of zeroing with the 25-mm gun of the Bradley Fighting Vehicle (BFV) indicated target misses by substantial margins after boresighting. In attempting to adjust the sight, the gunner then used excessive ammunition. Research determined the accuracy of fielded government-furnished boresight equipment.

Procedure:

Boresighting error was defined as the difference (in mils) between the aiming points of the boresight equipment and the centerline of the 25-mm gun bore. Boresight telescopes and 25-mm adapters were obtained at Fort Benning from a Basic Issue Item room and a set of equipment used for institutional training. Testing was conducted on (a) 25-mm boresight kits formed by random pairings of telescopes and adapters, (b) telescopes paired with an accurate adapter, and (c) adapters paired with an accurate telescope.

Findings:

The typical 25-mm boresight kit had a boresighting error of 1.4 mils. The typical 25-mm adapter paired with an accurate telescope had an error of 1.3 mils, while the accuracy of a typical telescope paired with an accurate adapter was 0.8 mils. Adapters generally were less accurate than telescopes; however, some telescopes were extremely inaccurate. Telescope accuracy probably decreases with use and abuse, because errors progressively increased for telescopes classified as new, used, and unserviceable, respectively. Much inaccurate equipment was in use and not designated for repair or replacement; lack of fielded test procedures for the adapter and kit may contribute to this undesirable situation.

Utilization of Findings:

Findings indicate (a) a high level of error in fielded boresight equipment and (b) inadequate field tests to determine equipment accuracy. These results led ARI to develop boresight equipment test procedures that will be included in the BFV Gunnery field manual. These procedures will allow units to identify accurate boresight equipment that will prevent excessive ammunition expenditure during zeroing and increase the accuracy of sight alignment when combat conditions do not allow zeroing.

ACCURACY OF BORESIGHT EQUIPMENT FOR THE 25-MILLIMETER GUN OF THE BRADLEY FIGHTING VEHICLE

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ACCURACY OF BORESIGHT EQUIPMENT FOR THE 25-MILLIMETER GUN
OF THE BRADLEY FIGHTING VEHICLE

INTRODUCTION

Background

The 25-mm gun of the Bradley Fighting Vehicle (BFV) often is referred to as a burst-on-target weapon system not designed to achieve first-round hits. However, when armor-piercing ammunition is used against a BMP-sized target (about 2 meters high), the material need statement for the BFV requires a high first-round hit capability from 0 through 1400 meters when a range control setting of 1200 meters is used (Deparment of the Army, 1978).

Proper sight alignment achieved during boresighting and zeroing increases the first-round accuracy of the 25-mm automatic gun. Boresighting aligns the sight with the aiming point of the gun bore and sighting accuracy is refined by zeroing. The criticality of accurate boresighting in combat is expressed by a BFV battalion commander.

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

The 25-mm gun of the BFV is boresighted with a boresight telescope and 25-mm adapter (see Figure 1). The knob of the adapter is inserted into the 25-mm gun barrel until the tapered stop contacts the end of the gun barrel. The telescope stem fits into the tapered receptacle of the adapter. Focusing

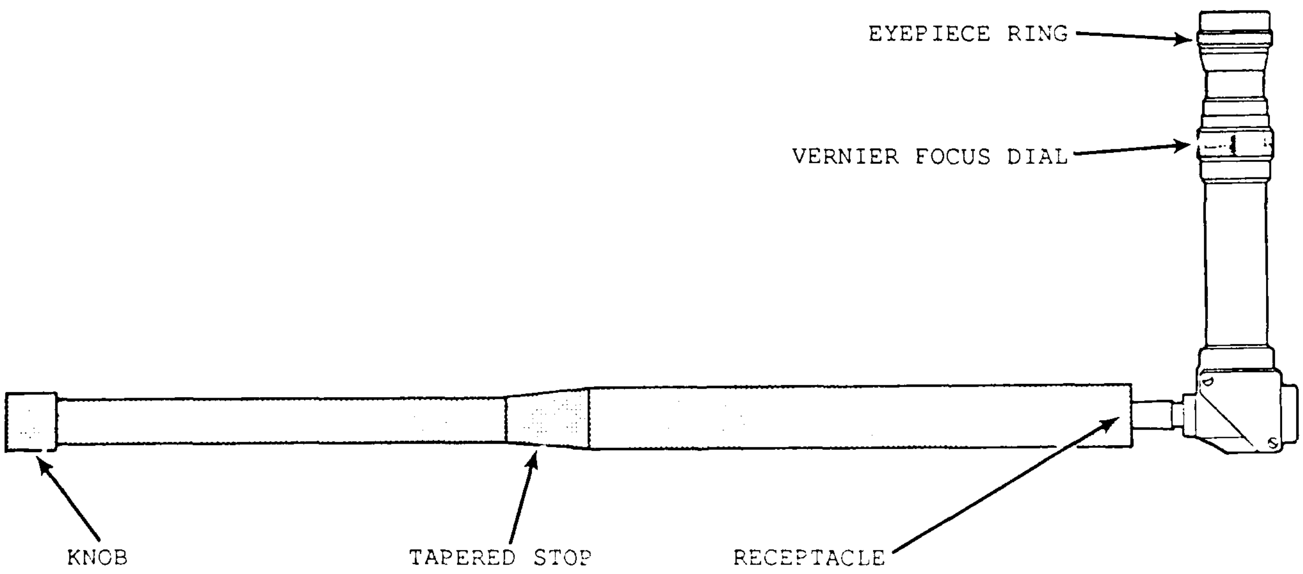

Figure 1. Boresight telescope and 25-mm adapter.

rings on the telescope are used to focus the reticle (eyepiece ring) and the target (vernier focus dial).

Boresight equipment should indicate the centerline of the gun bore. The difference (in mils) between the aiming points of the boresight equipment and centerline of the gun bore is defined as boresighting error. The ideal field test of boresight equipment would determine the amount of boresighting error. However, the user does not have the special equipment required to measure the centerline of the gun bore, so field tests of boresight equipment use an indirect measure of accuracy. These tests determine change in aim of the boresight equipment after it has been rotated. For the boresight telescope, separate tests are described in the turret technical manual (TM 9-2350-252-10-2) and the BFV Gunnery field manual (FM 23-1). There are no fielded accuracy tests for the 25-mm adapter and the 25-mm kit (i.e., combined action of the adapter and telescope).

As described in the test version of the gunnery manual, the telescope accuracy test begins with the boresig t telescope eyepiece facing right and the reticle laid on an aiming point. Following 180-degree rotation of the boresight telescope, the standard is met if the aiming point of the telescope changes no more than 0.5 mils (FM 23-1, 1983). This test assesses an actual boresighting error of 0.25 mils.

A different telescope test is described in the turret technical manual. Testing begins with the telescope eyepiece facing upright and the reticle laid on an aiming point. The telescope is rotated 90 degrees to the right and then 90 degrees to the left; the standard is met if the aim of the telescope shifts no more than 1 mil during either rotation (TM 9-2350-252-10-2, 1986). A boresighting error of 0.7 mils is assessed by this test.

A third accuracy test, used as a turn-in standard for the telescope, has been presented by the Armament Munitions Chemical Command (AMCCOM). The test, which has not been fielded, allows no more than a 1-mil change in the aiming point following 180-degree rotation of the telescope. This change is equivalent to a boresighting error of 0.5 mils (AMCCOM, 1985).

As a result of field reports of inaccurate boresight equipment, the Materiel Testing Directorate (MTD) tested the accuracy of alternative and government furnished equipment (GFE). Tested telescopes had errors considerably smaller than the accuracy standard indicated in the test version of the BFV Gunnery field manual (FM 23-1, 1983). The GFE adapter produced readings that were approximately 0.7 mils from the centerline of the gun bore and the complete GFE kit produced errors of 0.88 mils. Interpretation of inaccuracy associated with the adapter and kit was hindered by the lack of performance standards (Department of the Army, 1984). However, MTD concluded that:

- The GFE kit is incapable of indicating the centerline of the gun bore.
- The major source of error originates from the fit between the adapter and gun bore.
- The alignment (i.e., fit) between the telescope and adapter is generally satisfactory as judged by current standards.

Problem

In September 1983, the Fort Benning Field Unit of the Army Research Institute (ARI) and its resident contractor (Litton Computer Services) initiated research and development on a wide scope of issues related to the BFV. The preliminary problem analysis in gunnery indicated potential problems with boresight equipment. Conversations with students and instructors in the institutional environment indicated negative opinions about boresighting the 25-mm gun. Comments of "useless" and "a waste of time" applied to both equipment and the utility of boresighting. Observations of zeroing conducted at Fort Benning indicated that current equipment was inaccurate. After boresighting, gunners would miss the zeroing target by substantial margins. Target misses led to excessive ammunition expenditure as the gunner attempted to adjust the sight to the point of impact (Perkins, 1987a).

Field observations by ARI indicated a greater problem with boresight equipment than suggested in the MTD test. The methodology of the MTD test was elaborate and meticulous although the sample size was small (two GFE telescopes and one GFE adapter). Tests of new equipment are necessary but they do not determine the impact of equipment use and abuse.

Purpose

The primary objective of these experiments was to determine the error of fielded 25-mm boresight equipment. In Experiment 1, accuracy testing was conducted on a sample of 25-mm boresight kits from Fort Benning. Because of the high level of inaccuracy in a large portion of kits, further testing examined the contribution of the telescope and adapter to kit inaccuracy. A highly accurate adapter was used to test telescopes while 25-mm adapters were tested with a highly accurate telescope.

Experiment 2 extended the results of the first experiment. A new random sample of telescopes and adapters was tested during pairings with an accurate adapter and telescope, respectively.

EXPERIMENT 1

Method

Equipment

Testing was conducted on a total of 24 telescopes and 22 25-mm adapters (part number 12524010). Telescopes were classified according to prior use and current operational condition. Prior to testing, 4 new telescopes were packed in the original shipping container, 16 used telescopes were stowed in their boresight kit containers, and 4 telescopes were marked by the unit for direct exchange (DX). With one exception, all adapters showed signs of prior use (e.g., scratches, scuffs, and cylindrical grooves where the adapter makes contact with the end of the gun bore).

A boresight assembly manufactured by Wild-Heerbrugg was used to determine the centerline of the gun bore. A collimation feature of this equipment allows adjustment of the reticle so that the assembly can be aligned with the centerline of the gun bore. The caliber bar fits reliably into the gun bore because of springs that maintain pressure between the bore and assembly.

A boresight test panel consisted of a 10 by 10 grid of 1-mil squares to allow estimation of azimuth (horizontal) and elevation (vertical) coordinates for the aiming points of boresight equipment. The panel is described in greater detail and illustrated in Appendix A.

Twenty-five millimeter gun barrels mounted on four vehicles were used during the five days of testing because it was not possible to retain the same vehicle during all testing. Data obtained with the Wild-Heerbrugg boresight assembly indicated that all 25-mm gun barrels were straight.

Procedure

Obtaining and marking equipment. Boresight equipment was obtained by hand receipt from the Basic Issue Item (BII) room of a BFV company at Fort Benning. Boresight telescopes and 25-mm adapters were not stored as a kit in the BII room and there were no preassigned pairings for a particular telescope and adapter. For experimental purposes, each telescope was marked with an assigned number. On adapters, masking tape was placed around the end where the telescope is inserted. An identification number was written on the tape along with Position Marks (A, B, C, and D) placed 90 degrees apart. These marks allowed systematic placement of the adapter into the gun barrel.

Equipment setup. Prior to testing, the boresight test panel was positioned 52 meters from the end of the gun barrel. The gun was laid on the center of the test panel using the Wild-Heerbrugg boresight assembly.

Pretest gun bore aiming point. With the test panel in place, the Wild-Heerbrugg boresight assembly provided baseline data on the aiming point of the gun bore as a reference for determining GFE equipment accuracy. With the gun laid on or very close to the center of the test panel, azimuth and elevation readings of the aiming point were taken by two experimenters.

GFE testing. Kit tests were conducted first. An adapter and telescope were arbitrarily designated as a kit if each component had the same experimental identification number. A total of 18 kits were tested as described below; 16 of the kits involved used telescopes and 2 kits had new telescopes.

Following kit testing, telescopes and adapters with different identification numbers were paired. One pair (Telescope #6 and Adapter #12) had a high degree of accuracy (boresighting error of 0.34 mils) so its components were called the Good Telescope and Good Adapter. These components then were used to determine the accuracy of telescopes and adapters. The Good Telescope was paired with adapters to determine their accuracy while the Good Adapter was paired with telescopes. Telescopes and adapters selected for testing usually were from a previously tested kit having a moderate to high level of inaccuracy. Details on the pairings will be presented in the Results section.

Each GFE test (for either a kit, adapter, or telescope) consisted of 24 readings collected as two subsets of 12 readings each. Each subset allowed all possible combinations of four adapter positions (A, B, C, and D) and three telescope positions (right, up, and left). The two subsets differed in their sequence of testing. The first 12 readings were taken using the Telescope-Rotation Technique. With Mark A of the adapter positioned upright, the telescope was sequentially placed in right, upright, and left positions. The adapter was then rotated throughout all untested adapter positions performing telescope rotation at each one. The last 12 readings were collected using the "Adapter-Rotation" Technique. The adapter was rotated through its four positions with a set telescope position (e.g., right) before the telescope was rotated to the next position. For a test, data readings were taken and announced by one experimenter as the other recorded data. Experimenters reversed reading and recording roles on successive tests to minimize eye fatigue associated with prolonged testing.

Posttest gun bore aiming point. The Posttest, identical to the Pretest, confirmed the aiming point of the gun following GFE testing. The Posttest for one GFE test served as the Pretest data for the next GFE test.

Accuracy Measures

Data collected during Pretests, GFE Tests, and Posttests were used to calculate the following accuracy measures.

- Boresighting error. The distance (mils) between the aim of GFE boresight equipment and the centerline of the gun bore.

- Telescope rotational change. The change (mils) in aiming point of the GFE telescope after being rotated 180 degrees in a stationary adapter.

- Adapter rotational change. The change in aiming point of GFE equipment after 180-degree rotation of the adapter with the direction of the telescope remaining unchanged (i.e., either right, left, or up).

Boresighting error was the primary measure. For each GFE telescope and adapter pair that was tested, the Pythagorean Theorem was used to calculate the boresighting error between each of 24 GFE aiming points and the aiming point of the gun bore. The latter was the average aiming point of the Wild- Heerbrugg assembly as determined by both experimenters during the Pretest and Posttest.

The telescope rotational change is an indirect measure of telescope accuracy. Theoretically, the value of the telescope rotational change should be twice that of the boresighting error during the test of a telescope. The measure also can indicate an adapter that has an inaccurate fit with the telescope. The rotational change for a test was the average deviation between right and left aiming points (telescope rotated 180 degrees) of the telescope taken from each of the four adapter positions while using the Telescope Rotation Technique (the adapter position remained unchanged in the gun bore during right and left readings).

Ideally, inaccuracy associated with the adapter's fit with the gun bore is indicated by the measure of adapter rotational change. This measure is valid only when the fit of the adapter with the telescope is accurate. This condition always was not met during tests of GFE equipment because of (a) a loose fit between the adapter and telescope in some cases and (b) difficulty in rotating the adapter in other cases which made it necessary to remove the telescope before rotating the aoapter.

Results

The Results will be presented in four subsections: Kit Tests, Telescopes Paired with the Good Adapter, Adapters Paired with the Good Telescope, and Boresight Telescope Equipment Problems.

Kit Tests

The median boresighting error for all 18 kits was 1.42 mils; Figure 2 presents data for each kit. The following summarizes the distribution of boresighting error in these kits: 2 kits (11%) were less than 0.5 mils., 2 kits (11%) were between 0.5 and 1.0 mils, 7 kits (39%) were between 1 and 2 mils, while 7 kits (39%) had values greater than 2 mils. For a particular kit, there was a substantial difference in boresighting error from one reading to the next; the mean standard deviation for a kit was 0.51 mils (see Appendix B).

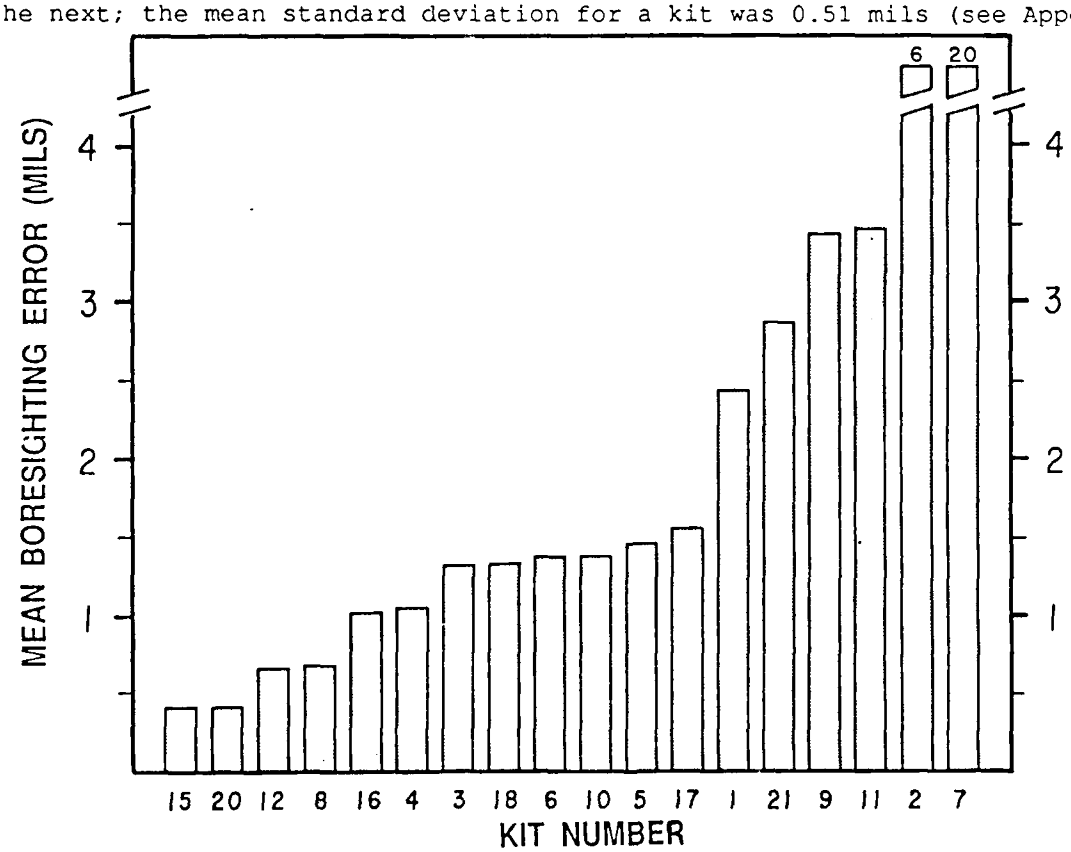

Figure 2. Mean boresighting error (mils) for each 25-mm boresight kit.

Telescopes Tested with the Good Adapter

Good Adapter #12 was tested with a total of 16 telescopes (4 New, 8 Used, and 4 DX). The median boresighting error for all telescopes was 0.78 mils. As shown in Figure 3, only 2 Used Telescopes had values less than 0.5 mils; however, half of the telescopes had values either less than or reasonably close to 0.5 mils (range of 0.34 to 0.69 mils). Several telescopes had extremely high errors (e.g., Telescope #7), and surprisingly, the two worst telescopes were Used, and not DX, telescopes.

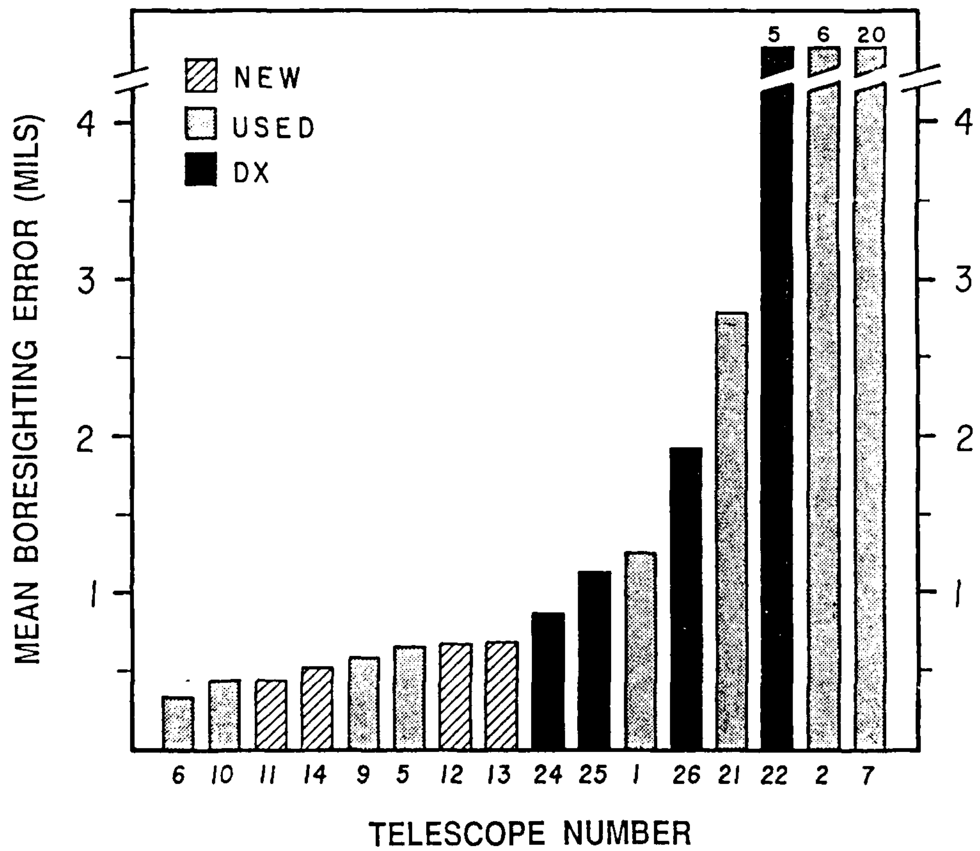

Figure 3. Mean boresighting error for New (n=4), Used (n=8), and DX (n=4) Telescopes paired with Good Adapter #12.

The median telescope rotational change (1.44 mils) was noticeably higher than boresighting error (0.78 mils). Six of 16 telescopes had a telescope rotational change less than 1 mil (i.e., the AMCCOM standard). The Good Adapter and the Good Telescope pair had the lowest rotational change with a value of 0.15 mils.

Table 1 summarizes boresighting error and telescope rotational change for telescopes in various conditions. Results for both measures indicate that the level of error progressively increased for telescopes classified as New, Used, and DX.

Table 1

Median Boresighting Error (mils) and Telescope Rotational Change (mils) of Telescopes Paired with the Good Adapter

	Telescope condition			
Measure	Good	New	Used	DX
Boresighting error	.34	.60	1.25	1.52
Telescope rotational change	.15	.70	2.21	2.90
Number of pairs	1	4	7	4

The telescope end of the adapter can dramatically affect the apparent accuracy of the telescope. New Telescope #11 had a much higher telescope rotational change when paired with Adapter #11 (3.62 mils) than Adapter #12 (0.83 mils).

Overall, when a telescope was in error, the direction of error during 180-degree rotation of the telescope was very consistent. When the telescope was facing to either the right or left, the azimuth error generally was in the same respective direction. Median azimuth readings for right and left readings for all tested telescopes were 0.98 and -0.59 mils, respectively, from the centerline of the gun bore. Median elevation errors for right and left readings were 0.51 and 0.48 mils, respectively.

Adapters Tested with the Good Telescope

The median boresighting error for all adapters was 1.27 mils. Error for all tested adapters is presented in Figure 4. Only the Good Adapter and Good Telescope pairing had boresighting errors less than 0.5 mil. Surprisingly, the adapter (#13) with no signs of prior use had the largest error (3.1 mils).

For adapters tested with an accurate telescope, the telescope rotational change indicates the accuracy of the telescope end of the adapter. The median rotational change for all adapters was 1.32 mils. The scores were distributed as follows: 6 adapters (54%) had values less than 1 mil, 1 (9%) had a value between 1 and 2 mils, and 4 adapters (36%) had values greater than 2 mils.

Median boresighting error (1.27 mils) was very similar to telescope rotational change (1.32 mils) and adapter rotational change (1.58 mils). Boresighting error was more highly correlated with adapter rotational change (r = 0.88) than telescope rotational change (r = 0.36) as indicated by data presented in Appendix C.

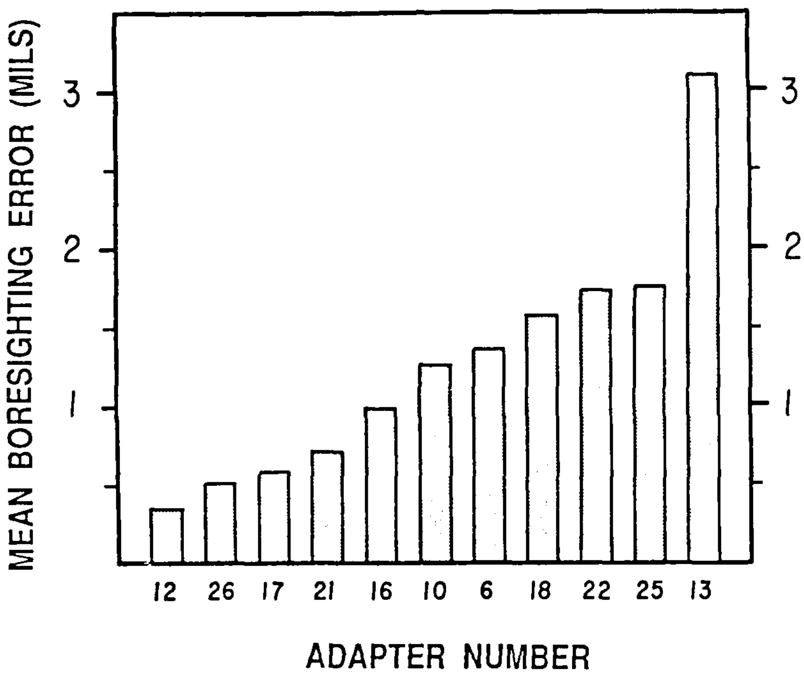

Figure 4. Mean boresighting error (mils) for adapters paired with the Good Telescope #6.

Boresight Telescope Equipment Problems

Equipment was inspected for aberrations existing prior to testing. Table 2 lists problems noted with the telescopes and the frequency of occurrence of these problems according to condition of the telescope. Of the problems listed in Table 2, the three considered the most critical in affecting accuracy are the light-refracting prism, the telescope stem, and the attachment of the telescope extension tube to the base. The prism, glued to and enclosed in the base of the telescope, serves to refract light at a 90-degree angle between the telescope and the line-of-sight for the gun bore. The stem attaches to the telescope base and inserts into the adapter. The telescope extension tube screws into the telescope base and has two set screws positioned 90 degrees apart.

None of the 4 New Telescopes had notable equipment-related problems. One of the 17 Used Telescopes had a severely bent adapter rod, a cracked eye piece, and the reticle rotated with focus and diopter adjustments; these problems prevented testing, but interestingly, the telescope had not been withdrawn from use. Other problems noted with Used Telescopes probably contributed little to inaccuracy. Two telescopes had the eye piece lenses reversed. These were removed and correctly inserted prior to testing.

Table 2

Equipment Problems with New, Used, and DX Telescopes

Problem	Telescope condition (n)		
	New (4)	Used (17)	DX (5)
Detached prism	0	0	2
Bent tapered stem	0	1	0
Loose telescope extension tube	0	0	3
Missing focus ring screws	0	1	0
Incorrectly positioned eyepiece lens	0	2	0
Cracked eyepiece lens	0	1	0
Poor image resolution	0	0	3
Reticle rotates with diopter and/or focus adjustment	0	2	0

Of 5 DX telescopes, one was not tested because the prism had broken loose. Twenty-two of the 24 readings in another DX telescope had been taken before the prism became detached. The other three DX telescopes had loose extension tubes. These were tightened prior to testing, but accuracy still tended to be less than for Used Telescopes.

EXPERIMENT 2

The median boresighting error during Experiment 1 was less for telescopes (0.78 mils) than for adapters (1.27 mils) suggesting that typical telescopes are more accurate than typical adapters. However, a statistical comparison was precluded by a nonrandomized sampling procedure. A tested component (i.e., telescope or adapter) often was chosen from a kit that was found to be noticeably inaccurate. Experiment 2 compared the accuracy of randomly selected telescopes and adapters.

Method

The GFE telescopes and adapters were obtained from a set of equipment different from that for Experiment 1. Ten telescopes and 10 adapters were obtained from equipment used for institutional gunnery training at Fort Benning. Telescopes and adapters were paired with the Good Adapter and Good Telescope, respectively. Equipment labelling, Pretest, GFE Testing, Posttest procedures, and data analysis were identical to Experiment 1. In addition, a one-tailed t-test was conducted on the average boresighting error for Telescope and Adapter Groups.

Results

The difference between the mean boresighting error for telescopes (0.82 mils) and adapters (1.30 mils) was statistically significant ($t(18) = 2.08$, $p<.05$, one-tailed test). The difference also is indicated by the distribution of scores (see Table 3).

Table 3

Distribution of Boresighting Error for Telescopes and Adapters

Component	Boresighting error (mils)				
	0-.5	.51-.75	.76-1.0	1.01-2.0	>2.0
Telescopes	0	5	3	2	0
Adapters	0	2	1	6	1

Half of the telescopes had boresighting errors between 0.5 and 0.75 mils; by contrast, the majority of adapters had values between 1 and 2 mils. As in Experiment 1, there was an adapter with an error greater than 3 mils. Appendix D presents the boresighting errors, telescope rotational change, and adapter rotational change for individual pieces of equipment.

The distribution of telescope rotation change for adapters and telescopes is presented in Table 4. While 50% of adapters and telescopes had changes less than 1 mil, adapters had a high proportion of scores over 2 mils.

Telescopes had a slightly higher median telescope rotational change (1.02 mils) than boresighting error (0.75 mils). Median boresighting error and telescope rotational change for adapters were 1.21 and 0.73 mils, respectively.

Table 4

Distribution of Telescope Rotational Change for Telescopes and Adapters

Component	Telescope rotational change (mils) Less than 1	1.01 to 2	Greater than 2
Telescopes	5	4	1
Adapters	5	1	4

Median telescope rotional change (1.57 mils) and adapter rotational change (1.37 mils) were similar for adapters. However, there was no systematic relationship between the two measures as illustrated by comparison of data for Adapters #29 and #31 presented in Appendix C.

Standard deviations were calculated on boresighting errors for each adapter and telescope. The mean standard deviation of all telescopes was 0.37 mils with a range from 0.26 to 0.71 mils. The mean standard deviation for adapters was 0.46 mils (range from 0.26 to 0.73 mils).

SUMMARY AND DISCUSSION

These experiments determined the accuracy of fielded 25-mm boresight kits, 25-mm adapters, and boresight telescopes. The typical kit had a boresighting error of 1.4 mils. Typical telescopes and adapters had errors of 0.8 and 1.3 mils, respectively. Error in the fielded kits and their components in these experiments was greater than reported for a small sample of new equipment (Department of the Army, 1984).

Telescopes

Different turn-in standards for telescopes are presented in the test version of the BFV Gunnery field manual (0.25 mils), in the turret technical manual (0.7 mils), and by AMCCOM (0.5 mils) (AMCCOM, 1985; FM 23-1, 1983; TM 9-2350-252-10-2, 1986). AMCCOM also stated that the standard for new telescopes (0.25 mils) is less than the turn-in standard (0.5 mils). For the following discussion, it is assumed that the valid accuracy standards are those presented by AMCCOM; however, it must be recognized that the user only has access to those standards provided in the gunnery and turret manuals.

The 4 New Telescopes tested in Experiment 1 had boresighting errors ranging from 0.41 to 0.69 mils. No telescope passed the 0.25-mil standard required for new telescopes while two of four passed the 0.5-mil turn-in standard. The low passing percentage for new equipment may be partially caused by the interaction between the telescope and adapter. The Good Adapter was highly accurate when paired with the Good Telescope, but the same adapter may interact differently with other telescopes because of machining characteristics of the stem of the telescope and the taper of the adapter.

Telescope accuracy deteriorates with use, and possibly abuse. This is indicated by the progressively higher boresighting error in New (0.60 mils), Used (1.25 mils), and DX (1.52 mils) Telescopes. Of the 17 Used and 4 DX Telescopes, only 2 Used Telescopes passed the 0.5 mil turn-in standard of AMCCOM (1985). Surprisingly, many inaccurate Used Telescopes were still in use and not marked DX.

It was not possible to determine the amount and type of use and abuse that produced deterioration in telescope accuracy. Overall, the telescope is constructed with a number of removable components (e.g., screws, eye-piece) making it relatively easy for curious personnel to investigate and disassemble the telescope. Furthermore, the telescope stem is vulnerable to bending with repeated use and abuse.

Adapters

There are no accuracy standards for the 25-mm adapter so a standard equal to that of the telescope was used as a criterion in the analysis. Only 1 of 21 adapters had a boresighting error of 0.5 mils or less. The typical adapter paired with the good telescope produced an error of 1.3 mils. A couple of adapters had boresight errors of about 3 mils, and one of these had no visible signs of prior use. Data from another study of boresight equipment indicates that unused and used 25-mm adapters (part number 12524010) have similar levels of boresighting error (Perkins, 1987).

Data obtained during adapter rotation and telescope rotation indicate accuracy problems with (a) the fit of the adapter into the gun bore and (b) the fit of the adapter with the telescope, respectively. These two problems occurred independently; that is, a particular adapter may have been inaccurate at either the telescope end, the gun-bore end, or both ends. The MTD study (Department of the Army, 1984) reported accuracy problems associated with only the adapter fit into the barrel.

Kits

The term "25-mm boresight kit" is misleading. The telescope is stowed in a container while there is no stowage container or protection for the adapter. The two components are made by separate manufacturers, and the telescope and 25-mm adapter issued with a vehicle are never pretested as a kit. Informal conversations with program and product managers associated with BFV boresight equipment indicate that omission of an accuracy standard for the 25-mm boresight kit was unintentional. In fact, it is possible that the 0.5 mil turn-in standard for the telescope, was meant to apply to the kit. None of the

18 randomly selected kits had a boresighting error equal to or less than 0.5 mils. A total of 22% of the kits had an error close to 0.5 mils (i.e., 0.51 to 0.75 mils), however, 88% of the kits had errors over 1.33 mils.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions on boresight equipment accuracy are confounded by absence of standards for the kit and the 25-mm adapter and the multiple standards that exist for the telescope. However the following is concluded:

- For fielded boresight equipment, both the boresight telescope and 25-mm adapter (part number 12524010) contribute to identified 25-mm boresight kit inaccuracy.

- The typical 25-mm adapter is less accurate than the typical boresight telescope.

- Adapters are inaccurate because of an imprecise fit with both the gun and the telescope.

- Use and abuse of the boresight telescope can lead to a high level of inaccuracy.

- A large percentage of inaccurate telescopes at Fort Benning are still in use and are not being reported.

- Lack of accuracy standards and tests for the 25-mm adapter and kit prevent the field from reporting a boresight equipment problem.

Problems with the adapter are best summarized by a BFV battalion commander:

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

Boresight equipment problems have not been reported using the quality deficiency report (QDR). As indicated by conversations with BFV instructors and student gunners at Fort Benning, this seems largely due to ignorance on the existence of and use of the QDR. This suggests the need for an improved education program on use and preparation of the QDR.

Because of the absence of testing procedures for the 25-mm adapter and kit, and the fielding of the incorrect accuracy standard for the boresight telescope (see the gunnery and turret manuals), the Fort Benning Field Unit of ARI has produced a handbook entitled Boresight Equipment Testing Procedures (Perkins, 1987b). The contents of this handbook will be incorporated into the next version of the BFV Gunnery field manual (FM 23-1). Once boresight equipment testing procedures are fielded, units will be able to report inaccurate equipment using the QDR. The handbook and gunnery manual describe now to prepare the QDR for both telescopes and 25-mm adapters. QDRs should be prepared for inaccurate and inoperative equipment to indicate the existence of boresight equipment problems in the field.

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APPENDIX A

BORESIGHT TEST PANEL

The boresight test panel is illustrated in Figure 5. The panel was a 10 x 10 matrix of 2 inch squares with mil markings to allow estimation of azimuth (x-coordinate) and elevation (y-coordinate) of boresight telescope aiming points. The background for the panel was white illustration board with press-on 0.25 in flat-black lines. A grey 1-mil square was centered on the panel to serve as a reference to facilitate reading. One-by-two inch press-on numbers served as mil markers. The grided panel was enclosed in a frame made of a plexiglass front and a dadoed frame made from two-by-two inch pine.

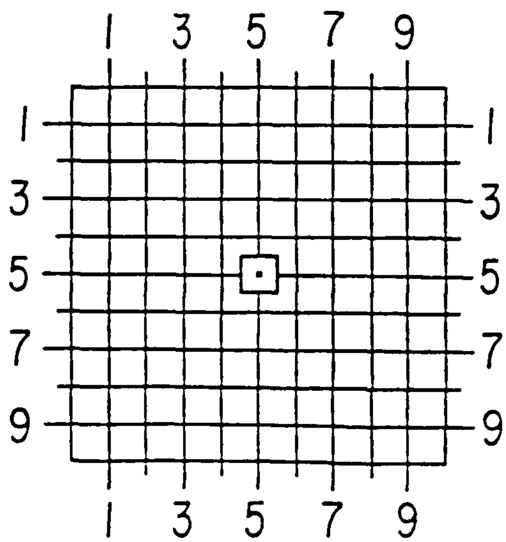

Figure 5. Illustration of the boresighting test panel.

APPENDIX B

VARIANCE DATA FOR BORESIGHTING ERROR

The standard deviation (S.D.) for each piece of equipment (i.e., telescope or adapter) or kit was calculated based on 24 measurements of boresighting error. Table 5 presents variance data for equipment tested during Experiments 1 and 2. The mean S.D. in the table represents the average standard deviation for all equipment within a particular group. The S.D. is the standard deviation of standard deviations within a group. The range is the lowest and highest standard deviation for equipment within a group.

Table 5

Variance Data for Boresighting Error

Group	n	Mean S.D.	S.D.	Range
		Experiment 1		
Kits	17	.51	.26	.20 - 1.36
New Telescopes	4	.26	.05	.21 - .32
Used Telescopes	6	.33	.12	.15 - .52
DX Telescopes	4	.37	.09	.30 - .50
Adapters	10	.51	.26	.20 - 1.36
		Experiment 2		
Telescopes	10	.37	.36	.26 - .71
Adapters	10	.46	.47	.26 - .73

APPENDIX C

DATA FOR ADAPTERS DURING EXPERIMENT 1

Table 6 presents boresighting error, telescope rotational change, and adapter rotational change for adapters paired with Good Telescope #6 during Experiment 1. Data were rank ordered according to boresighting error.

Table 6

Boresighting Error, Telescope Rotational Change, and Adapter Rotational Change for Adapters Paired with the Good Telescope in Experiment 1

Adapter number	Boresighting error	Telescope rotational change	Adapter rotational change
12	.34	.15	.31
26	.52	.58	.49
17	.59	.57	.52
21	.72	.58	1.15
16	.98	2.11	1.19
10	1.26	1.36	.70
6	1.37	2.12	1.05
18	1.58	.88	2.79
22	1.73	2.84	.72
25	1.76	2.47	2.59
13	3.10	.81	5.85

Correlations were calculated for the three measures. The values were: boresighting error and telescope rotational change, r = 0.36; boresighting error and adapter rotational change, r = 0.88; and telescope rotational change and adapter rotational change, r = -0.01.

APPENDIX D

DATA FOR EXPERIMENT 2

Table 7 presents boresighting error, telescope rotational change, and adapter rotational change for all adapters and telescopes of Experiment 2. Adapters and telescopes were paired with Telescope #6 and Adapter #12, respectively. Data were rank ordered for each component according to boresighting error.

Table 7

Boresighting Error, Telescope Rotational Change, and Adapter Rotational Change for Adapters and Telescopes in Experiment 2

Component	Component number	Boresighting error	Telescope rotational change	Adapter rotational change
Telescope	30	.66	.71	.59
	28	.66	.94	.54
	27	.69	.75	.83
	31	.70	.86	.58
	35	.73	1.10	.90
	36	.76	1.15	.82
	29	.76	1.19	.71
	32	.81	.65	.58
	33	1.13	1.66	.58
	34	1.28	2.74	.65
Adapter	33	.56	.34	.35
	32	.73	.44	.93
	28	.83	.80	.73
	30	1.01	2.30	.48
	36	1.17	2.21	.98
	34	1.25	.76	2.28
	27	1.31	1.06	1.77
	29	1.54	.72	3.05
	31	1.55	3.10	.97
	35	3.06	3.99	2.15

Correlations for telescope data were as follows: (a) boresighting error and telescope rotational change, $r = 0.91$, (b) boresighting error and adapter rotational change, $r = -0.18$, and (c) telescope rotational change and adapter rotational change, $r = -0.02$. Correlations for adapter data were: (a) boresighting error and telescope rotational change, $r = 0.77$, (b) boresighting error, and adapter rotational change, $r = 0.57$, and (c) telescope rotational change and adapter rotational change, $r = 0.02$.