ARMY RESEARCH LABORATORY

Comparison Between Simulated and Experimental Results for a Balanced-Breech M256 Cannon System

by Stephen A. Wilkerson, David H. Lyon,
and Larry Rusch

ARL-TR-2335 September 2000

Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

ARL-TR-2335 **September 2000**

Comparison Between Simulated and Experimental Results for a Balanced-Breech M256 Cannon System

Stephen A. Wilkerson and David H. Lyon
Weapons and Materials Research Directorate, ARL

Larry Rusch
Benet Laboratories

Abstract

Numerical simulations indicate that a mass-balanced system, with realistic tolerances and boundary conditions, would drastically reduce the motion of the gun tube during the projectile in-bore cycle. It was further postulated that such a system could significantly reduce projectile dispersion, as well as diminish the computer correction factors for different ammunition types. Several simple devices were designed and manufactured to achieve this desired effect on the actual recoil system. Then, a series of tests was conducted to duplicate what had been observed in the gun dynamics computations. The first set of experimental test firings employed an M256 in a hard-stand mount while following experiments incorporated in the system in an M1A1 Abrams tank. Specifically, a set of steel blocks was attached to the breech, which caused the centroid of the breech to coincide with the barrel centerline in both the vertical and horizontal directions. Additional modifications were made to both the fixed and adjustable kick blocks that guide the breech. The limited results showed that the muzzle-pointing angle at shot exit was reduced when compared to the baseline standard gun. However, later shots from an M1A1 were inconclusive. This report details the modifications and reviews the observations. In addition, some possible explanations as to the outcome are offered.

List of Figures

INTENTIONALLY LEFT BLANK.

List of Tables

INTENTIONALLY LEFT BLANK.

1. Introduction

For the M256 tank cannon, firing-induced gun tube "whip" is attributed to the powder-pressure couple. This couple results in a rotational moment about the trunnions and is produced by an "unbalanced" breech. More specifically, this moment is caused when the centroid of the M256 breech is not coincident with the gun tube centerline. A previous effort to correct this effect utilized a two-dimensional (2-D) gun-dynamics simulation code called Little Rascal [1], in conjunction with an experimental firing program [2]. These simulations indicated that balancing the breech would greatly reduce the magnitude of gun motion; therefore, an experiment to confirm this result was undertaken. A breech was balanced by adding steel blocks to the top and rear of the breech to bring the centroid in line with the geometric center of the gun tube. However, the experimental firings did not agree with the simulation. Instead, they revealed that the breech unbalance was only one contributor to the overall gun tube response. The explanation for these unanticipated results pointed to the asymmetric support conditions of the gun tube driven by the tube expansion. Evidence was offered to support this hypothesis in the form of a comparison between the frequency content of both the breech pressure pulse and the gun tube displacement. Close agreement between these two data indicated support for this possibility.

After examining the data from this prior work and investigating the intricacies of the recoiling parts, it was conjectured that further simple modifications to the gun system might produce the desired effect. As previously stated, the premise behind the balanced breech was to produce a linear recoil stroke that would minimize any out-of-plane motions. From prior data, it was known that the breech initially dropped as the gun system recoiled. However, when the system was balanced, the breech dropped during the initial 2–4 ms of recoil, but thereafter began to rise. Once the system is balanced, the recoil motion should not produce lateral forces significant enough to move the breech in the horizontal or vertical directions during the in-bore cycle (approximately the first inch of recoil travel). Moreover, the breech has two guides, or kick blocks, which help it maintain a uniform recoil (Figures 1 and 2).

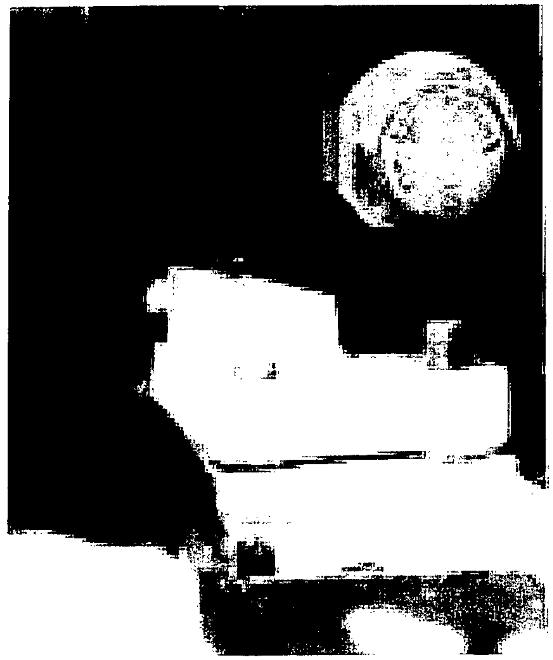

Figure 1. Left-Side Kick Block.

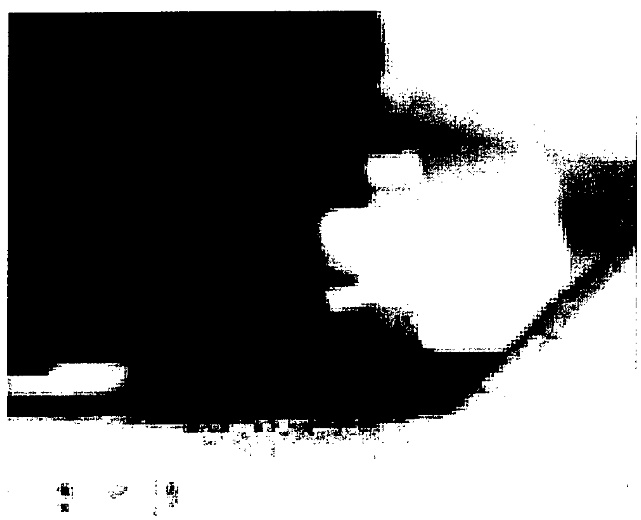

Figure 2. Right-Side Kick Block.

Therefore, the resultant breech motion was unexpected. Experimental observation revealed that the breech would initially drop, then rise. Numerical simulations using the Little Rascal code showed the correct drop of the breech for the unbalanced case, but predicted that the balanced case would reduce vertical and horizontal movement in the system to a minimum [2]. To help explain the phenomena, a three-dimensional (3-D) transient finite element model of the M256 gun and recoil system was developed [3]. When that model was initially used to predict the movement, it also produced results similar to the Little Rascal model. For the unbalanced case, the breech dropped; for the balanced case, the breech traveled nearly straight back. Figure 3 shows a comparison between the experimental and numerical simulations for the unbalanced breech case.

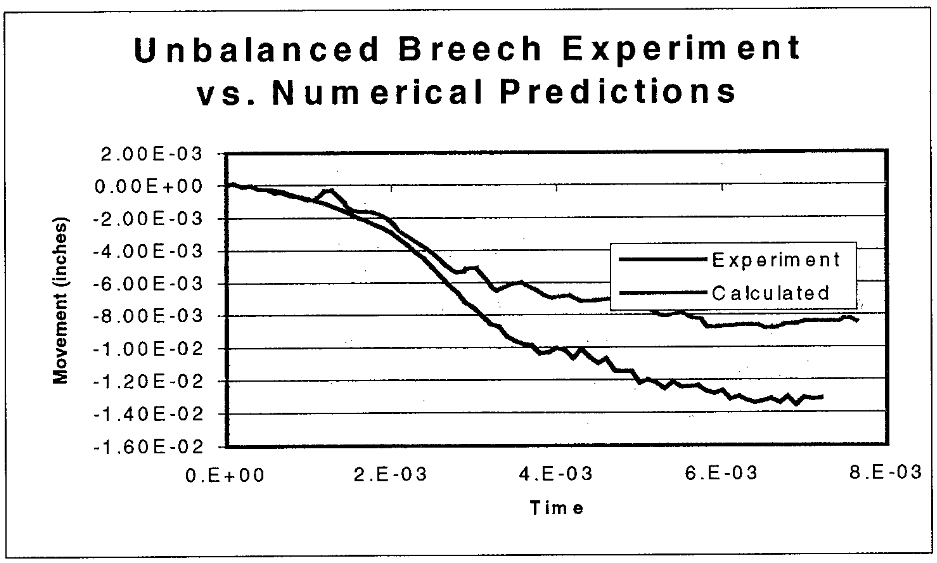

Figure 3. Unbalanced-Breech Comparison Between Experiment and Numerical Predictions.

After some simplistic static load tests were performed on the M256 system, it was observed that the gun, piston, and cradle components had asymmetric clearances between them. Once the clearances were incorporated into the 3-D transient model, the model was then able to accurately simulate the behavior observed during the original balanced-breech experiments.

Figure 4 shows the same comparison for the balanced system. It was originally many of the individual components, leading to dispersion, are influenced by prior events. It was originally hoped that the modified alignment blocks alone would force the system to recoil without vertical or horizontal movement. However, the incorporation of the balanced breech was also required to achieve an optimal result. Furthermore, reducing the gun and muzzle movement could improve the overall accuracy of the gun system because many of the individual components leading to dispersion are influenced by prior events.

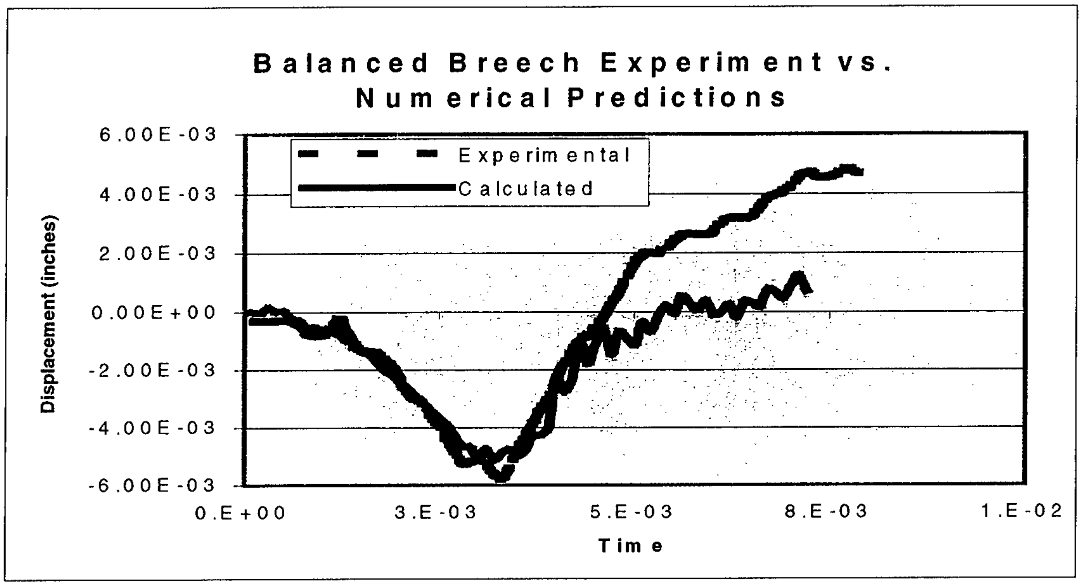

Figure 4. Balanced-Breech Comparison Between Experiment and Numerical Predictions.

2. Hard-Stand Experimental Firings

Encouraged by the prospect of reducing system motion by balancing the breech and guiding the recoiling parts, an experimental validation test was undertaken. Upon concluding the initial balanced-breech firing test, it was discovered that the additional holes, drilled into the breech to secure the balancing blocks, had produced cracks in the breech. Therefore, a balanced breech was designed by Benet Laboratories to use existing holes for securing the weights. In addition, Benet designed and manufactured a set of adjustable kick blocks with increased length. A simple firing series was conducted to verify the robustness of these new components on a hard stand. This was done as a precursor to a tank test for safety precautions. It also allowed researchers the opportunity to examine possible problems where they had easy access to the gun system prior to conducting the test in the close confines of an M1A1 tank turret. This series of shots was conducted at the U.S. Army Research Laboratory (ARL) Transonic Range Facility, Aberdeen Proving Ground, MD. Figures 5 and 6 show the components that were used to balance the M1A1 breech block. The larger block sits on the top of the breech and the smaller two blocks sit on the aft sloping ramps on the rear of the breech. The main block attaches to the breech through a modified breech pin, and the other two blocks attach to the main block at the top using threaded holes. They are then held in place with a bolt that utilizes existing threaded holes on either side of the top of the breech. Finally, a small flat plate is attached to the right side of the breech, rear facing front, to balance the system left to right.

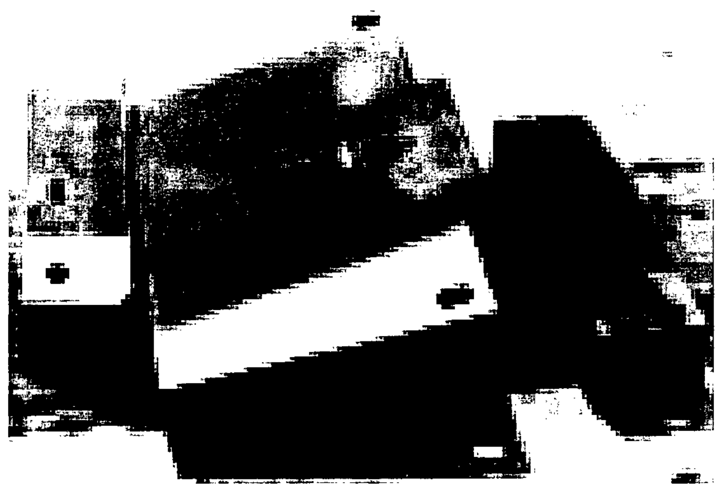

Figure 5. Balancing Blocks Before Installation.

Figure 6. Balancing Blocks Installed on Breech.

Additional instrumentation included noncontact proximity-sensor (eddy probe) stations at selected positions along the gun tube [4]. The most critical of these were the muzzle and breech locations. Figure 7 shows the double-eddy-probe rosette used to record the muzzle motion and determine the muzzle pointing angle. Figure 8 shows a typical eddy-probe arrangement to record the breech movement in the plane perpendicular to the direction of recoil. The firing test consisted of four DM13 kinetic energy cartridges. Two were shot with an unbalanced breech (unmodified), and two were shot with a balanced breech. The second of the two balanced shots incorporated an additional 0.002 in of shim under the adjustable kick block on the left side. This clearance might be critical in controlling breech motion. Table 1 summarizes the results from this series. The balancing blocks withstood the stress induced by recoil, and neither the blocks nor the breech developed cracking or damage.

This very limited data shows a marked reduction in the muzzle pointing angle for both of the balanced breech shots. Furthermore, the second balanced shot with the additional shim produced a pointing angle almost 1 order of magnitude smaller than the unbalanced case of shot 2. In addition to the reduced muzzle pointing angles, the breech motion was significantly diminished.

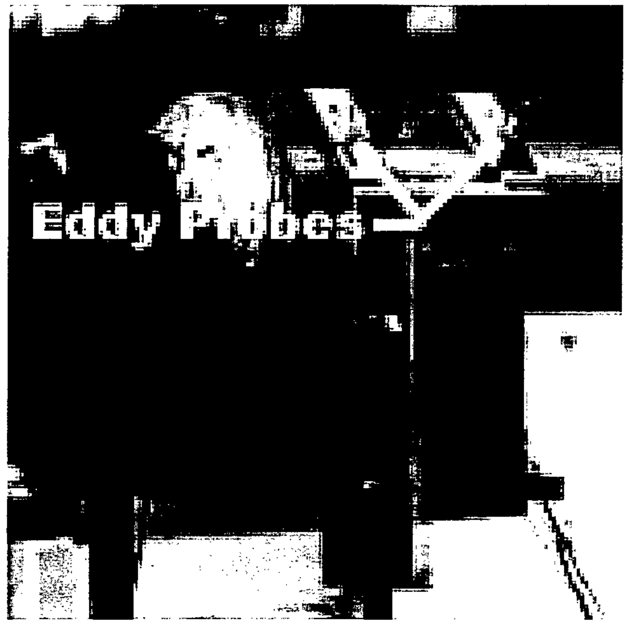

Figure 7. Eddy-Probe Rosettes at Muzzle.

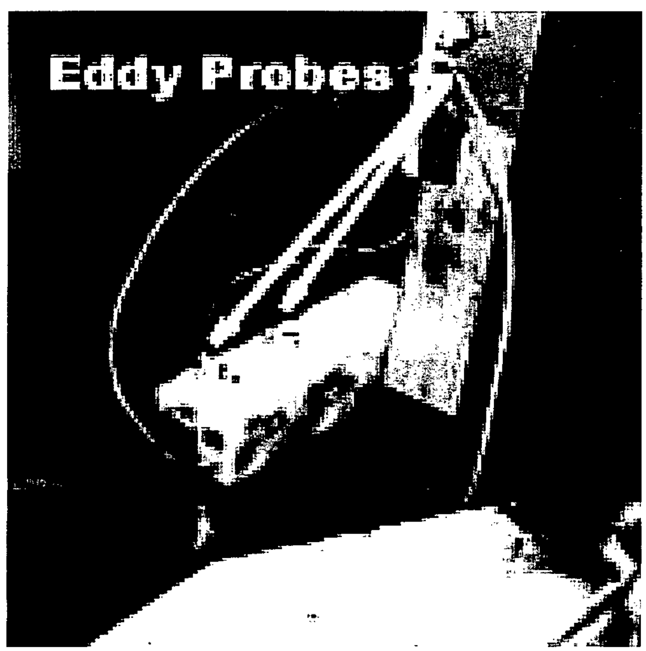

Figure 8. Eddy-Probe Stations at Breech.

Table 1. Hard-Stand Experimental Results

Shot No.	Description	Ammunition	Pointing Angle at Shot Exit (mrads)
1	Unbalanced (no mods)	DM13 at ambient temperature	0.64
2	Unbalanced (no mods)	DM13 at ambient temperature	1.10
3	Balanced	DM13 at ambient temperature	0.40
4	Balanced with 0.002 in extra shim	DM13 at ambient temperature	0.14

Coincident with the smaller muzzle pointing angles was a reduction in the out-of-plane motions of the breech. Here again, shot no. 4 resulted in the smallest breech displacements. Figure 9 shows a direct comparison between one of the balanced shots and one of the unbalanced cases. Another interesting outcome was that nearly all of the unbalanced (baseline) shots gave nearly identical results, whereas the balanced shots contained significantly more variability. In fact, during the remaining experimental firings, the results observed during shot no. 4 were never recreated.

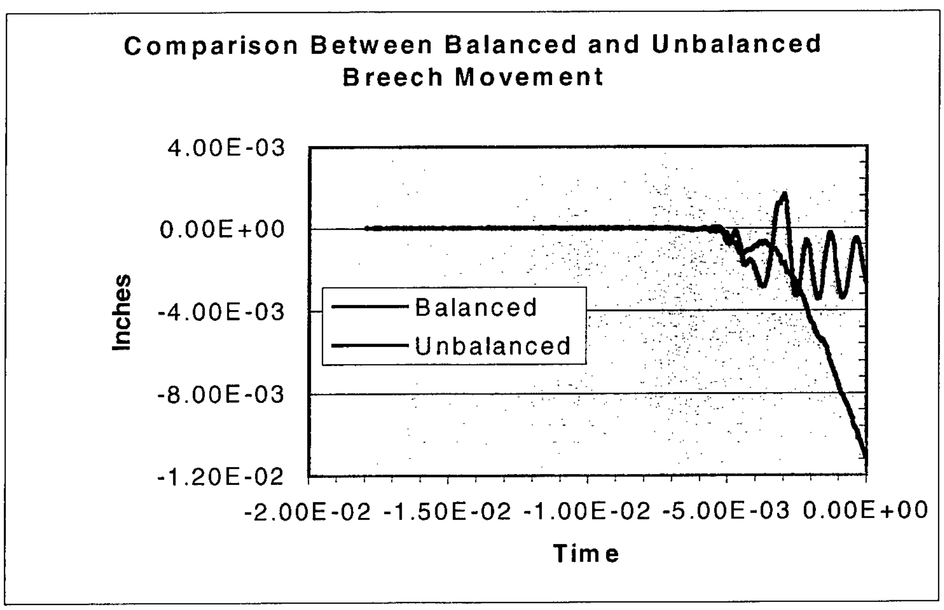

Figure 9. Comparison Between Balanced- and Unbalanced-Breech Displacements.

3. M1A1 Experimental Firings

3.1 Phase I. After reviewing the results from the first firing series, there was some speculation that the breech could be forced to recoil straight back using the modified kick blocks only. Therefore, the first series of tank firings included three shots with no modifications, three shots with the improved kick blocks, and three shots with the kick blocks and the balancing blocks.

Again, DM13 ammunition was fired at ambient temperature. Table 2 compares the eddy-probe gauges used to measure the tube movement. The first rosette was located 13.6 in from the muzzle, while the second rosette was located 19.6 in from the muzzle. Both of these locations can be seen in Figure 6. The third rosette was located 64 in from the muzzle and the fourth rosette was located 124 in from the muzzle.

Table 2. Gun Tube Displacement at Shot Exit

Rosette No.	Configuration 1 No Modifications			Configuration 2 Modified Kick Blocks Only			Configuration 3 Kick Blocks and Balancing Blocks		
	Shot No. 1	Shot No. 2	Shot No. 3	Shot No. 1	Shot No. 2	Shot No. 3	Shot No. 1	Shot No. 2	Shot No. 3
1	0.008	0.008[a]	0.006	0.008	0.008	0.010	0.006[b]	0.007	0.006
2	0.016	0.010[b]	0.014	0.012	0.010	0.010	0.012	0.014	0.010
3	0.012	0.012	0.012	0.014	0.014	0.016	0.010	0.010	0.010
4	0.040	0.040	0.040	0.030	0.030	0.030	0.014	0.014	0.014

[a]Two gauges failed; data unreliable.
[b]One gauge in rosette failed.

Table 3 summarizes the muzzle pointing angle at shot exit for the three configurations. These results show no overall difference in muzzle displacement or muzzle pointing angle. Also, the values were within the normal M1A1 operating parameters. Although the muzzle

Table 3. Pointing Angle Summary at Shot Exit

	Configuration 1 No Modifications			Configuration 2 Modified Kick Blocks Only			Configuration 3 Kick Blocks and Balancing Wedges		
	Shot No. 1	Shot No. 2	Shot No. 3	Shot No. 1	Shot No. 2	Shot No. 3	Shot No. 1	Shot No. 2	Shot No. 3
Pointing Angle (mrad)	0.810	—[a]	0.753	0.865	0.825	0.865	0.854	0.785	0.531
Average	0.78			0.85			0.72		

[a]Loss of data.

displacement seems unaffected by the modifications, these tables indicate there was a consistent reduction in the gross movement of the gun tube. This is especially evident during the last series of balanced-breech test shots (configuration 3) at the fourth eddy-probe station.

During these experiments a number of issues developed concerning the experimental setup of the breech gauges. One issue was how precisely the surfaces used to measure the recoil were coincident with the line of recoil. The majority of breech displacement data gathered was unreliable. This could be due to alignment problems, or it could have been due to alignment problems, or it could have been due to overshimming of the alignment blocks. To overcome these difficulties, a new measurement technique was adopted for any firings thereafter. The alignment problem was eliminated by adding an adjustable measurement bar to the right side of the breech and aligning it to be coincident with the muzzle reference sensor (MRS) upstand, using a gunner's quadrant. The gun was then hydraulically pumped through the recoil stroke, and the breech displacement measurements were recorded. This method allowed the observation and correction of any gross alignment errors before a firing test. Also, careful attention was paid to the kick blocks between shots. Their displacement was checked several times during this procedure to assure the proper shimming.

In addition to the eddy-probe data, target impact locations were also recorded on a target cloth located 985 m from the gun. Upon analysis, there was no statistically significant difference between any of the shot groupings. It is quite possible that improvements in the gun system would not reveal themselves as an obvious reduction in dispersion, especially for a well-behaved ammunition such as the DM13, over such a limited number of firings.

3.2. Phase II. This was the final firing test conducted during this program. Due to its piggyback status, only minimal instrumentation was possible. Five shots were made with full gun modifications, immediately followed by five similar shots with no modifications. Again, DM13 ammunition was fired at ambient temperature. After firing the first shot, the kick blocks were determined to be slightly undershimmed. They were adjusted, and shot nos. 2–6 were fired as a single occasion. To speed the data acquisition process, the continuous muzzle reference system (CMRS) was used, instead of the eddy-probes, to observe the muzzle pointing angle. The particular CMRS unit used during the first two shots was found to be faulty and was replaced with a spare unit. This negated the muzzle data for those shots. However, the breech motion data appeared reasonable throughout this test series.

For direct comparison, the second configuration employed no gun modifications. All five rounds were fired within a 2-hr period, which was considered a single occasion. It was concluded that this particular gun and ammunition combination shot with such low dispersion, the difference in gun motion did not produce a detectable difference on the target. A final test series was conducted with minimal instrumentation. Eleven shots were fired, and all of the shots were made on the same day. In every case, the gun shot better than average, and 7 of the 11 bullet holes were keyholed in the target cloth.

4. Conclusions

A previous test series had shown that balancing the M256 breech alone did not reduce the magnitude of gun motion to that observed in simple 2-D dynamic simulations. Specifically, the direction of vertical breech motion did not agree between the simulation and experiment. It was conjectured that asymmetric support conditions, acting in conjunction with tube expansion, were also contributing factors. A more complex 3-D model was then developed and applied to the same problem. This detailed model included realistic clearances between the various recoiling components in addition to time-dependent tube expansion. The results of this model mimicked the experimental breech motion in the vertical plane, while still indicating a significant reduction in the overall motion of the gun tube. It was conjectured that if the recoiling parts could be forced or guided to produce little out-of-plane motion, the gun tube would respond identically to the simulations. A detailed examination of the gun components revealed that the breech block slid free of the kick blocks after only approximately 5/8 in of recoil while the projectile is still in-bore, thereby indicating that the breech is then not constrained in as robust a fashion. A set of modified kick blocks were then designed and manufactured, along with an improved balanced breech, and test fired. Although test data were not consistent across all conditions, the results indicate a significant reduction in the muzzle pointing angle and absolute muzzle motion. Such a reduction in gun tube motion could increase the performance of projectiles that are more sensitive to transverse motions.

5. References

1. Erline, T. F., M. D. Kregal, and M. Pantano. "Gun and Projectile Flexural Dynamics Modeled by the Little Rascal-A User's Manual." BRL-TR-3122, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1990.

2. Held, B. J., and T. F. Erline. "Dynamics of the Balanced Breech System for the 120-mm Tank Main Gun." BRL-TR-3186, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1991.

3. Wilkerson, S. A., and D. A. Hopkins. "Analysis of a Balanced Breech System for the M1A1 Main Gun System Using Finite Element Techniques." ARL-TR-608, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 1994.

4. Bornstein, J., I. Celmins, P. Plostins, and E. M. Schmidt. "Techniques for the Measurement of Tank Cannon Jump." BRL-MR-3715, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, 1988.

INTENTIONALLY LEFT BLANK.

NO. OF COPIES	ORGANIZATION
2	DEFENSE TECHNICAL INFORMATION CENTER DTIC OCA 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
1	HQDA DAMO FDT 400 ARMY PENTAGON WASHINGTON DC 20310-0460
1	OSD OUSD(A&T)/ODDR&E(R) DR R J TREW 3800 DEFENSE PENTAGON WASHINGTON DC 20301-3800
1	COMMANDING GENERAL US ARMY MATERIEL CMD AMCRDA TF 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
1	INST FOR ADVNCD TCHNLGY THE UNIV OF TEXAS AT AUSTIN 3925 W BRAKER LN STE 400 AUSTIN TX 78759-5316
1	US MILITARY ACADEMY MATH SCI CTR EXCELLENCE MADN MATH THAYER HALL WEST POINT NY 10996-1786
1	DIRECTOR US ARMY RESEARCH LAB AMSRL D DR D SMITH 2800 POWDER MILL RD ADELPHI MD 20783-1197
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CI AI R 2800 POWDER MILL RD ADELPHI MD 20783-1197

NO. OF COPIES	ORGANIZATION
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI LL 2800 POWDER MILL RD ADELPHI MD 20783-1197
3	DIRECTOR US ARMY RESEARCH LAB AMSRL CI IS T 2800 POWDER MILL RD ADELPHI MD 20783-1197
	ABERDEEN PROVING GROUND
2	DIR USARL AMSRL CI LP (BLDG 305)

NO. OF COPIES	ORGANIZATION
1	DIRECTOR US ARMY RESEARCH LAB AMSRL CP CA D SNIDER 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TA 2800 POWDER MILL RD ADELPHI MD 20783-1145
3	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TL 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	DIRECTOR US ARMY RESEARCH LAB AMSRL OP SD TP 2800 POWDER MILL RD ADELPHI MD 20783-1145
2	DIRECTOR US ARMY RESEARCH LAB AMSRL OP CI AD TECH PUB BR RECORDS MGMT ADMIN 2800 POWDER MILL RD ADELPHI MD 20783-1145
1	HQDA DAMI FIT NOLAN BLDG WASHINGTON DC 20310-1025
1	DIRECTOR DA OASARDA SARD SO 103 ARMY PENTAGON WASHINGTON DC 20310-1003
1	DEPUTY ASST SCY FOR R&T SARD TT RM 3EA79 THE PENTAGON WASHINGTON DC 20301-7100

NO. OF COPIES	ORGANIZATION
1	COMMANDER US ARMY MATERIAL CMD AMXMI INT 5001 EISENHOWER AVE ALEXANDRIA VA 22333-0001
2	US ARMY ARDEC AMSTA AR AE WW E BAKER J PEARSON PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR TD C SPINELLI PICATINNY ARSENAL NJ 07806-5000
1	COMMANDER US ARMY ARDEC AMSTA AR FSE T GORA PICATINNY ARSENAL NJ 07806-5000
6	COMMANDER US ARMY ARDEC AMSTA AR CCH A W ANDREWS S MUSALLI R CARR M LUCIANO E LOGSDEN T LOUZEIRO PICATINNY ARSENAL NJ 07806-5000
4	COMMANDER US ARMY ARDEC AMSTA AR CC G PAYNE J GEHBAUER C BAULIEU H OPAT PICATINNY ARSENAL NJ 07806-5000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 2000

3. REPORT TYPE AND DATES COVERED
Final, 1993–1995

4. TITLE AND SUBTITLE
Comparison Between Simulated and Experimental Results for a Balanced-Breech M256 Cannon System

5. FUNDING NUMBERS
TGAD

6. AUTHOR(S)
Stephen A. Wilkerson, David H. Lyon, and Larry Rusch*

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WM-BC
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-2335

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
*Benet Laboratories, Watervliet Arsenal, NY 12189-4050

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Numerical simulations indicate that a mass-balanced system, with realistic tolerances and boundary conditions, would drastically reduce the motion of the gun tube during the projectile in-bore cycle. It was further postulated that such a system could significantly reduce projectile dispersion, as well as diminish the computer correction factors for different ammunition types. Several simple devices were designed and manufactured to achieve this desired effect on the actual recoil system. Then, a series of tests was conducted to duplicate what had been observed in the gun dynamics computations. The first set of experimental test firings employed an M256 in a hard-stand mount while following experiments incorporated in the system in an M1A1 Abrams tank. Specifically, a set of steel blocks was attached to the breech, which caused the centroid of the breech to coincide with the barrel centerline in both the vertical and horizontal directions. Additional modifications were made to both the fixed and adjustable kick blocks that guide the breech. The limited results showed that the muzzle-pointing angle at shot exit was reduced when compared to the baseline standard gun. However, later shots from an M1A1 were inconclusive. This report details the modifications and reviews the observations. In addition, some possible explanations as to the outcome are offered.

14. SUBJECT TERMS
M1A1, balanced breech, M256, 120-mm cannon

15. NUMBER OF PAGES
20

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

INTENTIONALLY LEFT BLANK.