

AD-A238 628



MEMORANDUM REPORT BRL-MR-3921

BRL

EXPERIMENTAL HYPERVELOCITY FIRINGS
 USING STICK AND GRANULAR
 PROPELLANT CONFIGURATIONS

CARL R. RUTH
 FREDERICK W. ROBBINS
 ALBERT W. HORST

DTIC
 ELECTE
 JUL 19 1991

JUNE 1991

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
 ABERDEEN PROVING GROUND, MARYLAND

91-05165



NOTICES

Destroy this report when it is no longer needed. DO NOT return it to the originator.

Additional copies of this report may be obtained from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The use of trade names or manufacturers' names in this report does not constitute indorsement of any commercial product.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1991	3. REPORT TYPE AND DATES COVERED Final, Jan 89 - Dec 89		
4. TITLE AND SUBTITLE Experimental Hypervelocity Firings Using Stick and Granular Propellant Configurations			5. FUNDING NUMBERS PR: 1L161102AH43	
6. AUTHOR(S) Carl R. Ruth, Frederick W. Robbins and Albert W. Horst				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) USA Ballistic Research Laboratory ATTN: SLCBR-DD-T Aberdeen Proving Ground, MD 21005-5066			10. SPONSORING/MONITORING AGENCY REPORT NUMBER BRL-MR-3921	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for Public Release - Distribution Unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The suitability of lumped-parameter interior ballistic models for prediction of the interior ballistic performance of very high velocity guns is limited by use of a predetermined pressure gradient which is superimposed on the solution to approximate the relationship between space-mean, breech and projectile base pressures. Even modern two-phase flow interior ballistic models, specifically formulated to address the hydrodynamics of the problem, have not been extensively exercised in this regime. Only recently have limited, large-caliber gun firings with realistic projectile masses been conducted to provide required data in this velocity regime. In this study, firings were conducted in a long 120-mm gun at propellant charge to projectile mass ratios (C/M) of about 3 to 6, yielding muzzle velocities in the 2 - 2.7 km/s range. The tube was instrumented with pressure gages at various locations along its length to provide data for comparison to predictions of various interior ballistic codes.				
14. SUBJECT TERMS Interior Ballistics, Hypervelocity, Pressure Gradients, 120-mm Tank Guns, Resistive Pressure			15. NUMBER OF PAGES 37	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

INTENTIONALLY LEFT BLANK.

- TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES.....	v
LIST OF TABLES.....	v
1. BACKGROUND TO THE PROBLEM.....	1
2. INITIAL TESTING.....	2
2.1 Description of Components.....	2
3. RESULTS AND DISCUSSION.....	6
3.1 Firing Results, Series A, Stick Propellant, Standard Loading.....	6
3.2 Firing Results, Series B, Stick Propellant, Inbore Loading.....	9
3.3 Firing Results, Series C, Granular Propellant.....	12
4. DISCUSSION.....	14
5. CONCLUSIONS.....	16
6. ACKNOWLEDGMENTS.....	16
7. REFERENCES.....	16
APPENDIX A - Propellant Description Sheets.....	19
APPENDIX B - Breech Pressure (Solid Line), Forward Chamber Pressure (Dashed Line), and Pressure Difference Versus Time Plots.....	23
DISTRIBUTION LIST.....	31



Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

INTENTIONALLY LEFT BLANK.

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Locations of Pressure Transducers in the 120-mm, High Velocity Gun.....	2
2. Schematic Layout of the Firing Barricade.....	3
3. Polypropolux Projectile Configuration.....	3
4. Venting Techniques for Different Stick Propellant Geometries.....	4
5. Overall Charge Configuration for Stick Propellant, Standard and Downbore Loading.....	5
6. Overall Charge Configuration for Granular Propellant, Standard Loading.....	5
7. Smear Photograph of Polypropolux Projectile.....	9
8. Typical On-Line Pressure-Time Profiles for Series B, C/M of 5, Stick Propellant at 63° C, Sampling Rate at 50 and 1 us/Sample.....	15

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Gun, Projectile and Charge Characteristics for Series A, B and C.....	6
2. Experimental Firing Results, Series A, Stick Propellant, Standard Loading.....	7
3. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series A).....	8
4. Experimental firing Results, Series B, Stick Propellant, Inbore Loading.....	11
5. Experimental and Simulated Data for a Cartridge with a C/M of 3, 5 and 6 (Series B).....	12
6. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series C).....	13
7. Experimental Firing Results, Series C, Granular Propellant, Standard Loading.....	14

INTENTIONALLY LEFT BLANK.

1. BACKGROUND TO THE PROBLEM

There has always existed substantial interest in high muzzle velocities for academic and both indirect and direct military exploitation (Swift 1979; Baer 1982; Powell 1987; Baer 1987; Hertzberg 1988; Thomkins 1988). Many recent discussions focus on electric gun propulsion alternatives (e.g., rail gun, coil gun, electrothermal gun), many of which are purported to circumvent the supposedly all-important limitation of the speed of sound in the propellant gases. Although research and development is proceeding on the above disciplines at various government and private agencies, the point may be made, from a military perspective, that both the payoffs and the system burdens of very high velocities must be carefully scrutinized when considering the practicality of any of the available concepts, be they chemical or electric. Excessive system weights and/or gun wear rates associated with heavy tubes required to support the very high breech pressures associated with the high C/M ratios required to achieve high velocities with conventional guns versus the currently excessive weights associated with power generation (and perhaps cooling) for electric gun concepts may pose the limits of real concern to the gun designer.

Muzzle velocities as high as 3950 m/s have been achieved by Baldini (1985) using solid propellant guns though admittedly at C/M's and pressures too high for practical military applications. Investigators at the Ballistic Research Laboratory (BRL) demonstrated muzzle velocities at 2500 m/s (Ruth and Horst 1988), a somewhat lower but clearly interesting ballistic level with potentially acceptable system burdens. However, propellant and projectile weights were outside the current range of 120-mm components. The current goal is to enlarge the experimental data base by measuring experimentally, the pressure gradient in a solid propellant gun firing at velocities in the 2 to 3 km/s range. Effects of varying both charge and projectile weight to achieve different C/M's, type of propellant (stick versus granular), and propellant conditioning temperature were all parameters to enlarge on the limited existing data base presently available on high velocity chemical systems (Robbins and Keller 1988). A 120-mm, ballistic tube similar to an XM-25 Cannon (1524 cm longer than the standard 120-mm, M256 Cannon) was available for use in this study. Unfortunately, since existing projectile onboard instrumentation/telemetry packages would not withstand the high-acceleration environment (~100 kg's), determination of the pressure gradient had to be made using discrete location pressure gages mounted in the tube sidewall. Preliminary calculations using a standard lumped-parameter interior ballistics code (Anderson and Fickie 1987) suggested that either a 19-perforated JA2 stick or a granular propellant would launch 1.6 to 3.0 kg projectiles to a velocity in the region of interest. Variations in charge conditioning temperature, projectile weight and projectile seating distance would be the parameters to assure results from this study would be at an acceptable pressure (well under the ~700 MPa pressure limit for the tube), potentially

useful both to the modeling community and to the community more directly interested in any growth potential for the performance of solid propellant guns.

2. INITIAL TESTING

2.1 Description of Components.

All testing was conducted at the Sandy Point Firing Facility (Range 18) located at the Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, Maryland. As previously indicated, a 120-mm, ballistic tube similar in design to an XM-25 Cannon with 6304 mm of inbore travel (1524 mm more than the standard 120-mm, M256 Cannon) was used for all the tests. The gun tube was instrumented with four of the five pressure gages in the chamber: two each, 100 degrees apart at 95 mm, and two each, 70 degrees apart at 489 mm as measured from the rear face of the tube. Redundancy at the breech and forward chamber positions was incorporated into the cannon because of the possibility of losing a gage at the high pressures expected for these firings. The gage at the center of the chamber (286 mm) was not used. To measure pressure at discrete downtube locations, eleven gages were located at 768 mm, 908 mm, 1048 mm, 1289 mm, 1530 mm, 2292 mm, 3054 mm, 3816 mm, 4578 mm, 5340 mm and 6102 mm. An M174 Recoil Mechanism in conjunction with the upper carriage from a 155-mm, M59 Gun was used to mount the APG Medium B Sleigh which housed the 120-mm, ballistic cannon. Projectile displacement was determined by using a 15-GHz doppler radar to measure projectile motion both within and 10 metres beyond the gun muzzle. Projectile in-air velocity was calculated by using the distance between a known time interval just after the projectile exited the gun tube using both the 15-GHz inbore and 10-GHz Weibel radars. Ignition delay was determined by using, as zero time, the application of the firing voltage to either a M125 or a XM123 electrical primer. Generally, the data were recorded in real time by the Ballistic Data Acquisition System (BALDAS) under the control of a PDP 11/45 minicomputer. If the data were not recorded online because of some unusual ignition delay or computer malfunction, they were later digitized from an analog tape recording made of each test firing. A schematic of the 120-mm, ballistic cannon is shown in Figure 1, along with the locations of the 14 axial pressure port locations.

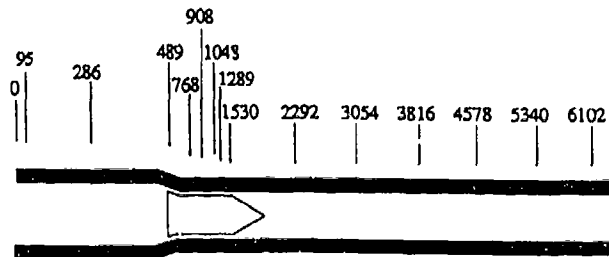


Figure 1. Locations of Pressure Transducers in the 120-mm High Velocity Gun.

Two Photec high-speed cameras and one smear camera were used to record the initial free flight of the projectiles for selected firings. The schematic layout of the firing barricade in Figure 2 shows the positions of the three cameras, the inbore and downrange radar units and the reflector mediums for both radar systems. Primary concern was in optimizing the 15-GHz doppler signal from the projectile to the radar unit so that accurate muzzle velocity could be calculated. The downrange Photec and smear cameras were to determine if unburnt propellant was expelled from the cannon and if the projectile survived the high velocity environment.

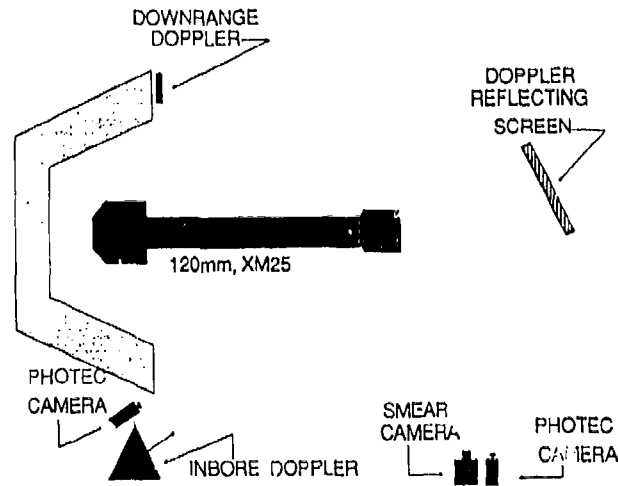


Figure 2. Schematic Layout of the Firing Barricade.

Although several projectile configurations were used during the course of this program, the projectile shown in Figure 3, with length modifications depending on C/M ratio, was chosen as the standard because it consistently withstood the inbore forces during the crucial portion of the ballistic cycle. The

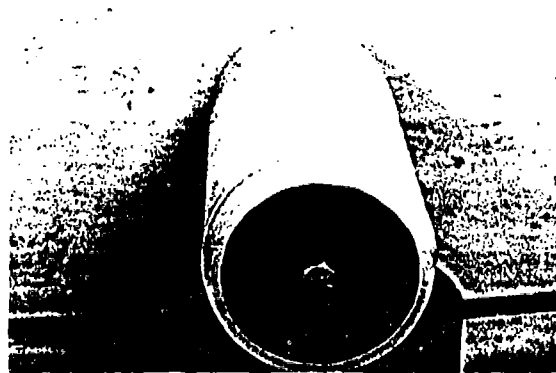


Figure 3. Polypropolux Projectile Configuration.

projectiles were made of a polypropolux plastic. This choice of material provided an inexpensive approach to meeting the low weight requirement as well as facilitating incorporation of a standard obturator configuration into the projectile design.

The propelling charges employed the conventional JA2 formulation used in the 120-mm tank gun. The propellant configuration for Series A and B used a high progressivity/high density (HPD) concept known as partially cut (PC) stick propellant. Use of nearly any stick geometry results in a higher loading density and provides natural flow channels to minimize pressure gradients within the charge during flamespread. However, the use of the traditional, slotted-stick geometry (Figure 4, left) provides a slightly regressive burning profile, not allowing efficient use of the higher loadable charge weight. Unslotted stick configurations, usually necessary for more progressive, multiperforated geometries, suffer from problems with overpressurization within the perforation leading to stick fracture (Robbins 1984; Robbins 1988). The PC configuration circumvents this problem by providing lateral venting of the perforations at the required spacing to avoid pressure build-up (Figure 4, right). Very likely, the sticks separate into short segments sometime early in the interior ballistic cycle, but all testing to date indicates that this occurs after flamespreading is complete, thereby not compromising the high longitudinal permeability required for use of a simple base ignition system.

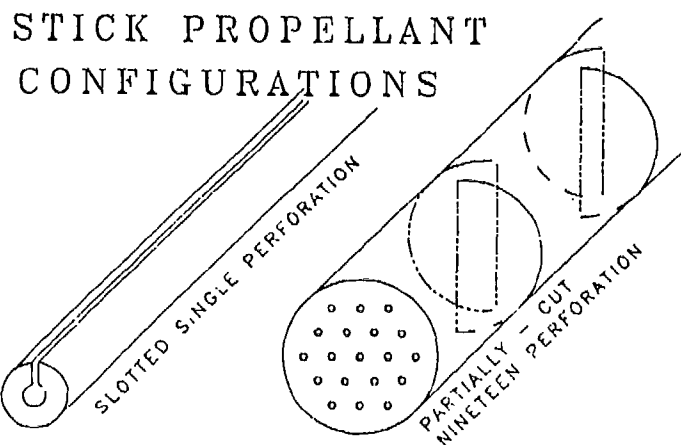


Figure 4. Venting Techniques for Different Stick Propellant Geometries.

The overall charge for Series A employed a BRL-designed charge of axially-aligned JA2 stick propellant and a projectile seated in the forcing cone in the standard manner; for Series B the same base charge was used, but one of three additional charge increments, depending on the final initial seating distance of the projectile, was added after the projectile was forcibly seated forward of the forcing cone in the gun. Both charge configurations are represented by the schematic in Figure 5. Both series employed a standard 120-mm stub base for holding an ignition system consisting of the XM123 stub primer surrounded by

a cloth donut containing 100 g of Class 1 black powder. No combustible or inert case was used to hold the propellant. The projectile and charge were separately loading into the gun.

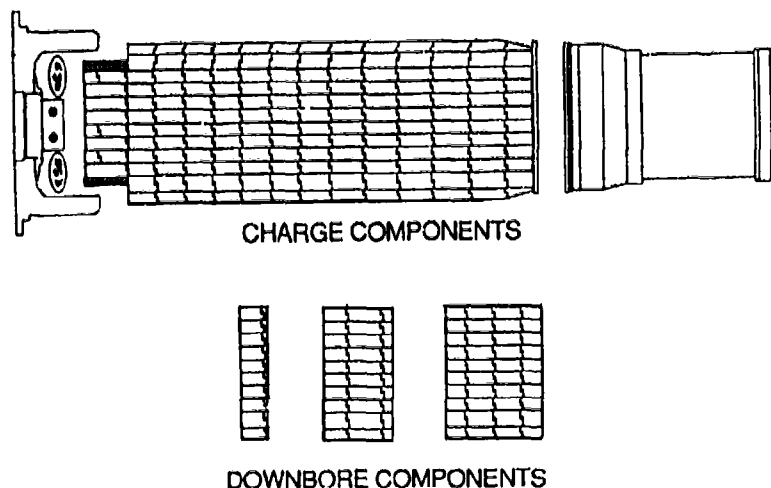


Figure 5. Overall Charge Configuration for Stick Propellant, Standard and Downbore Loading.

The propellant used for Series C was granular, hexagonal, 19-perforated JA2 contained in a noncombustible cartridge case (Figure 6). Although the pressure loss incurred by using an inert cartridge case was significant, the necessary pressure needed to impart sufficient energy to a low mass projectile and still achieve velocities in the 2.0 - 2.7 km/s range was obtainable by conditioning the propellant at a high temperature. Nitrocellulose cases were not used so as to minimize unknown or poorly defined case parameters as input to the interior ballistic code. Experiments are ongoing to better defined these parameters for systems using nitrocellulose containers. To eliminate the possibility of pressure wave formation, ignition of the highly compacted granular charge was accomplished with a M125 primer extending well into the charge.

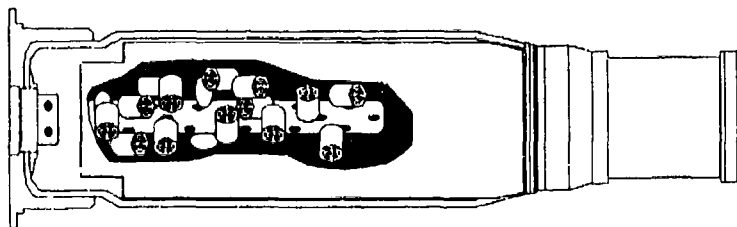


Figure 6. Overall Charge Configuration for Granular Propellant, Standard Loading.

Further details of the gun, projectile, and charges for each of the three series are tabulated in Table 1.

Table 1. Gun, Projectile and Charge Characteristics for Series A, B and C

Characteristics	C/M	Temp (°C)	Series		
			A	B	C
Gun Caliber	(-----120 mm-----)				
Inbore Travel (mm)			6304	varies	6304
Chamber Volume (cc)			9631	varies	9631
Nominal Projectile Weights (kg)	3	21	3.25	3.35	2.66
	5	21	1.98	2.27	1.65
	6	21	N.A.	1.98	N.A.
Stick Propellant Weight (kg)	3	21	9.85	9.85 + 0.23	N.A.
	5	21	N.A.	9.85 + 1.09	N.A.
	5	63	9.85	N.A.	N.A.
	6	21	N.A.	9.85 + 1.57	N.A.
Granular Propellant Weight (kg)	3	21	N.A.	N.A.	8.05
	5	63	N.A.	N.A.	8.05
Sidewall Type	((conditioned at		None	None	Inert
Primer Type	the temperature		XM123	XM123	M125
Basepad Type	of the propellant))		--Black powder--		None

Stick propellant (RAD-792-38) web was 1.82 mm; granular propellant (RAD-792-43) web was 1.40 mm; black powder basepad was 100 g of Class 1

3. RESULTS AND DISCUSSION

3.1 Firing Results, Series A, Stick Propellant, Standard Loading.

Before any rounds were fabricated, a loading assessment was made for the maximum amount of stick propellant that could be loaded into the chamber of the ballistic tube without affecting system integrity (9.85 kg). Since no nitrocellulose (NC) or

inert case was used with the stick configurations, considerably more stick propellant could be loaded into the chamber than with a standard 120-mm charge. Prior to fabricating the charge, chamber length measurements were taken to insure that charge length would be slightly less than the chamber length when a projectile was seated in the forcing cone. As shown in Table 1, the loading weight compatible for both temperature conditions was 9.85 kg. Firing results for the series are listed in Table 2.

Table 2. Experimental Firing Results, Series A, Stick Propellant, Standard Loading.

ROUND NO.	1	2	3	4	5	6
Projectile Weight (kg)	1.98	1.98	1.98	3.25	3.24	3.24
Projectile Temperature (°C)	63	63	63	21	21	21
Projectile Seating* (cm)	52.1	52.1	52.1	52.1	52.1	52.1
Propellant Weight (kg)	9.85	9.85	9.85	9.85	9.85	9.85
Propellant Temperature (°C)	63	63	63	21	21	21
C/M Ratio	5.04	5.04	5.04	3.07	3.08	3.08
Ignition System	----XM123 Primer plus 100 g--- of Black Powder, Class 1					
Sidewall Case	-----No Case used-----					
Maximum Pressures at Gun Ports (see Figure 1 for port positions)						
P1	680	681	668	548	551	561
P3	680	679	664	548	547	559
P4	662	671	660	543	542	544
P4A	650	659	651	515	520	527
P5	594	612	585	515	520	515
P5A	551	566	543	464	495	470
P6	529	522	495	451	488	445
P7	287	359	343	298	312	304
P8	237	253	288	222	236	239
P9	212	230	191	197	203	193
P10	145	167	175	153	141	150
Pressure Ratios (breech/base) at Downgage Positions						
P4	2.60	2.14	2.75	2.06	1.74	1.35
P4A	2.56	2.37	2.15	1.94	1.99	1.99
P5	3.38	3.87	3.39	2.79	2.76	2.67
P5A	3.78	2.78	3.67	2.04	2.91	2.28
P6	3.32	3.37	3.06	2.42	2.96	2.54
P7	3.13	3.42	4.11	3.53	3.45	3.24
P8	3.07	3.19	3.37	2.90	2.93	2.89
P9	3.73	4.63	3.53	2.96	2.87	2.68
P10	3.70	3.56	3.17	2.63	2.96	2.40
Doppler Velocity** (m/s)	2686	2678	2666	2278	2272	2273
Time to 7 MPa (ms)	1.8	3.0	8.8	5.3	14.1	4.9
Time to Muzzle (ms)	6.9	8.2	14.2	11.3	19.9	10.9

*Projectile seating is from rear face of tube

**Velocity in air one meter from the gun muzzle

The desired goal was for the experimental peak pressure to be around 650 MPa for the rounds built with both a C/M ratio of 3 and 5. Based on initial computer simulations using data from past firings and the charge data from Table 1, conditioning temperatures that would meet this pressure goal were estimated to be 21° C and 63° C, respectively, for the C/M of 3 and 5. Rounds were conditioned for at least 24 hours prior to firing. All projectiles were conditioned at 21° C to insure proper seating in the gun forcing cone interface.

A summary of averaged firing results for the C/M of 3 and 5, along with best post firing simulations provided by BRL ballisticians is shown in Table 3. The simulations are from the IBRGA, a modified lumped-parameter code using both the standard Lagrange gradient (Anderson and Fickie 1987) and a new pressure gradient to account for the effects of chambrage and two-phase flow effects (Robbins and Keller 1988), and XNOVAKTC, a two-phase flow code (Gough 1980). For all simulations, input data were based on parameters shown in Table 2.

Table 3. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series A).

Type of Data	C/M	Breech Pressure (MPa)	Muzzle Velocity (m/s)	Displacement at Peak Pressure (mm)
Ballistic Tube (Experimental)*	3	553	2274	1270
	5	676	2677	1183

IBRGA - Lagrange Gradient	3	767	2371	579
	5	1028	2745	683

IBRGA - RGA Gradient	3	562	2219	1058
	5	697	2524	1249

XNOVAKTC	3	553	2266	1364
	5	674	2648	1191

*Chamber volume for these rounds was 9631 cc

Experimental results for the two series with a C/M of 3 and 5 yielded a maximum pressure average of 553 MPa and 676 MPa, respectively. The experimental pressure of 553 MPa for the series at 21° C was much lower than anticipated from calculations done previously on IBRGA. As a result, the desired goal of comparing results at the same overall peak pressure for the two different C/M ratios was not realized.

The smaller than expected experimental pressure for the 21° C firings from that originally predicted demonstrates the importance of enlarging upon the experimental data base to define which parameters affect ballistic performance. Apparently, small changes in propellant weight, initial

charge positioning in the gun, lack of accurate temperature burning rate data, information on the effects of PC on propellant functioning, etc., all affect the experimental pressure not yet accurately simulated by the ballistic codes. How the codes handle these variables at high C/M ratios is especially important since the codes seem to be more sensitive to small changes in initial input than at lower C/M ratios.

One of the major concerns from this and the following two firing series was accurate measurement of inbore pressures, projectile position and muzzle velocity, all highly dependent on projectile integrity. Smear photographs (Figure 7) taken 15 meters in front of the gun revealed no sign of breakup for most of the projectiles tested. For the firings at 63° C, severe attenuation of the radar signal believed to be caused by propellant gases leaking by the projectile significantly limited the ability to determine projectile position. Whether the magnitude of gas blowby was sufficient to significantly alter downbore resistance and thus projectile displacement from that predicted by the codes has not been ascertained.



Figure 7. Smear Photograph of Polypropolux Projectile.

3.2 Firing Results, Series B, Stick Propellant, Inbore Loading.

Since the same stick charge as in Series A was used for Series B, the maximum amount of stick propellant that could be put in the chamber of the ballistic tube was 9.85 kg. To change the C/M ratios and not compromise system integrity, adjustments were made to both the initial seating distance of the projectile and the projectile weight, as well as the amount of additional charge that could be placed in the gun bore. Since changing projectile seating and adding more propellant were of a high risk nature, all firings were done at 21° C. From loading studies, a cylinder of propellant slightly less than bore diameter weighed 0.150 kg per cm. Using the loading data and the ballistic code predictions based on the standard input data base from Series A, the additional inbore propellant weight and inbore length needed for the propellant could be calculated. Projectile inbore initial seating was then fixed by these calculations. Thus, loading compatibility for each round was predetermined by assuring that the propelling charge axial dimension was slightly less than projectile seating distance. As in Series A, no

nitrocellulose or inert case was used with the stick configurations. The projectile was seated in the gun bore by pushing it forward using a hydraulic cylinder instrumented with a pressure indicator. As the projectile moved forward into the bore, the pressure was monitored and recorded. From these readings, as indicated for the simulations done previously in Series A, a measured but very limited static bore resistance/displacement profile could be determined.

All charges were conditioned at 21° C for at least 24 hours prior to firing; all projectiles were conditioned at 21° C to insure that material expansion due to temperature was not an issue in proper seating in the gun forcing cone interface. Firing results for the series are listed in Table 4. The goal, as in Series A, was to have the peak pressure for the three different C/M's be at 650 MPa.

A summary of averaged firing results for the C/M of 3, 5 and 6, along with predictions provided by the interior ballistics, is provided in Table 5. As in Series A, input parameters for the gun and charges are listed in Table 1.

Experimental results with a charge mass of 10.08 kg (C/M of 3) were essentially the same, with breech pressures of 585 MPa and 584 MPa and in-air velocities of 2283 m/s and 2284 m/s. Projectile seating for the two firings differed by 2 cm; interior ballistic simulations were performed using the average of the two, leading to a predicted maximum chamber pressure of 650 MPa. As in the case of Series A, the experimental pressure was somewhat lower (approximately 10% this time) than the prediction.

Experimental results for a charge mass of 10.94 kg (C/M of 5) were not as consistent. Projectile seating distances for the two rounds again differed by 1.5 cm. Maximum chamber pressures, 627 MPa and 624 MPa, agreed quite well; however, the corresponding in-air velocities were measured to be 2522 m/s and 2480 m/s. It is noted that six of the nine downtube pressure gages yielded higher values for the faster round, suggesting more area under the pressure-travel curve and consistent with a higher overall acceleration profile; however, normal variability in gage response may account for these differences.

At a C/M of 6, only one round was fired because the hydraulic device used for seating the projectile ruptured. The peak pressure of 659 MPa was in the range of the experimentally-planned pressure level of 650 MPa. Muzzle velocity at 2584 m/s was consistent with the higher pressure.

The summary of averaged firing results along with the BRL firing simulations (Table 5), which had the same input data for

the gun/projectile interface as that done for Series A, reflects the variability between the codes. Only inputs to reflect projectile seating, charge weight, etc., were modified.

Table 4. Experimental Firing Results, Series B, Stick Propellant, Inbore Loading.

ROUND NO.	1	2	2a	3	3a
Projectile Weight (kg)	1.97	2.27	2.27	3.35	3.35
Projectile Temperature (°C)	21	21	21	21	21
Projectile Seating* (cm)	65.9	63.7	62.2	57.2	55.2
Propellant Weight (kg)					
In Chamber	9.85	9.85	9.85	9.85	9.85
In Bore	1.56	1.09	1.09	0.23	0.23
Propellant Temperature (°C)	21	21	21	21	21
C/M Ratio	5.84	4.86	4.86	3.04	3.04
Ignition System	-----XM123 Primer plus 100 g----- of Black Powder, Class 1				
Sidewall Case	-----No Case used-----				
Maximum Pressures at Gun Ports (see Figure 1 for port position)					
P1	659	627	624	587	584
P3	640	621	604	587	572
P4	633	604	604	580	565
P4A	623	592	597	580	545
P5	588	580	570	550	536
P5A	606	568	525	511	512
P6	540	516	525	511	480
P7	332	335	340	326	310
P8	223	263	284	226	223
P9	248	196	189	145	150
P10	200	196	189	145	150
Pressure Ratios (breech/base) at Downgage Positions					
P4	1.77	2.47	2.53	2.40	1.89
P4A	2.10	3.35	1.73	2.93	3.09
P5	2.15	3.01	2.07	3.42	2.93
P5A	2.48	2.44	2.67	2.60	3.05
P6	2.25	4.00	2.49	2.92	2.50
P7	2.72	4.12	3.11	4.49	3.45
P8	2.47	3.40	2.88	3.97	2.92
P9	2.00	2.89	3.28	3.25	2.91
P10	2.16	4.02	3.89	2.08	2.04
Doppler Velocity** (m/s)	2584	2522	2480	2284	2283
Time to 7 MPa (ms)	5.8	4.9	3.7	16.9	11.3
Time to Muzzle (ms)	11.3	10.4	8.9	22.9	17.2

*Projectile seating is from rear face of tube

**Velocity in air one meter from the gun muzzle

Table 5. Experimental and Simulated Data for a Cartridge with a C/M of 3, 5 and 6 (Series B).

Type of Data	C/M	Breech Pressure (MPa)	Muzzle Velocity (m/s)	Displacement at Peak Pressure (mm)
Ballistic Tube (Experimental)*	3	586	2284	1230
	5	626	2501	1240
	6	659	2584	1255

IBRGA - Lagrange Gradient	3	744	2332	714
	5	757	2524	746
	6	768	2610	767

IBRGA - RGA Gradient	3	591	2209	1208
	5	594	2392	1276
	6	616	2457	1378

XNOVAKTC	3	616	2312	1189
	5	616	2492	1361
	6	639	2581	1343

*Chamber volume for these rounds was 10281 cc for C/M of 3, 11019 cc for C/M of 5, and 11556 cc for C/M of 6

3.3 Firing Results, Series C, Granular Propellant.

As in the previous two series, before any rounds were fabricated, a loading assessment was made for the maximum amount of granular propellant that could be reasonably loaded into an inert 120-mm cartridge case having the same overall dimensions as that of the standard NC case. Components were separately loaded as in the stick configuration so that the seating distance for the projectiles could be measured. After a projectile was seated in the gun, the charge was placed in the chamber to insure system compatibility. As shown in Table 1, the loading weight compatible for both temperature conditions was 8.05 kg. During loading into the gun, the propellant was contained in the inert case with a thin piece of paper taped over the forward cap opening.

Interior ballistic simulations (usually quite reliable for conventional granular propellants) suggested that the desired maximum pressure of 650 MPa was unattainable using available granular propellants for the desired test conditions (C/M's of 3 and 5). However, the use of temperature conditioning appeared feasible to at least bring the maximum pressures for the two C/M levels into the same regime.

All charges for the C/M of 3 and 5 were conditioned at 21° C and 63° C respectively for at least 24 hours prior to firing;

all projectiles were conditioned at 21° C to insure that material expansion due to temperature was not an issue in proper seating of the projectile in the gun forcing cone interface.

A summary of averaged firing results for the C/M of 3 and 5, along with simulations provided by the interior ballistic codes, is provided in Table 6. The detailed firing results for the two C/M ratios are shown in Table 7. For these simulations, input data were based on parameters shown previously in Table 2 for the ambient charges. As noted in Table 6, the simulations agree closely with the experimental data for the two codes that include chambrage in their modeling.

The round-to-round variations (Table 7) for pressure and velocity, both at a C/M of 3 and 5 were very small. As previously indicated, pressure was well below the desired goal of 650 MPa, a result that could only have been achieved if the propellant web could have been changed.

Table 6. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series C).

Type of Data	C/M	Breech Pressure (MPa)	Muzzle Velocity (m/s)	Displacement at Peak Pressure (mm)
Ballistic Tube (Experimental)*	3	440	2294	1297
	5	471	2587	1333

IBRGA - Lagrange Gradient	3	575	2327	674
	5	631	2601	728

IBRGA - RGA Gradient	3	444	2186	951
	5	454	2394	1092

XNOVAKTC	3	438	2305	1067
	5	465	2589	1158

*Chamber volume for these rounds was 9631 cc

Table 7. Experimental Firing Results, Series C, Granular Propellant, Standard Loading.

ROUND NO.	1	2	3	4	5	6
Projectile Weight (kg)	1.65	1.65	1.65	2.66	2.66	2.65
Projectile Temperature (°C)	21	21	21	21	21	21
Projectile Seating* (cm)	52.1	52.1	52.1	52.1	52.1	52.1
Propellant Weight (kg)	8.05	8.05	8.05	8.05	8.05	8.05
Propellant Temperature (°C)	63	63	63	21	21	21
C/M ratio	4.88	4.88	4.88	3.03	3.03	3.03
Ignition System	-----XM125 Primer-----					
Sidewall Case	-----Inert Case used-----					
Maximum Pressures at Gun Ports (see Figure 1 for port positions)						
P1	478	466	468	442	439	440
P3	445	438	441	416	402	417
P4	367	364	371	354	352	357
P4A	350	344	346	338	337	338
P5	327	323	322	317	315	313
P5A	292	305	304	292	299	308
P6	274	274	268	270	267	270
P7	174	178	172	184	182	184
P8	124	127	118	136	134	135
P9	81	86	85	91	90	91
P10	78	75	77	93	92	84
Pressure Ratios (breech/base) at Downgage Positions						
P4	2.66	3.29	3.09	2.27	2.09	2.37
P4A	2.31	2.40	2.73	1.87	2.17	1.89
P5	2.62	3.71	3.12	2.69	2.34	2.16
P5A	2.58	3.56	2.28	1.87	2.69	2.06
P6	3.19	2.85	4.40	2.51	2.84	2.64
P7	3.34	4.14	4.89	3.03	2.95	3.32
P8	2.98	2.84	3.38	2.59	2.91	2.49
P9	2.93	3.84	3.15	2.37	2.43	2.63
P10	2.14	2.95	2.77	2.26	1.99	2.01
Projectile Velocity** (m/s)	2595	2579	2586	2291	2292	2300
Time to Muzzle (ms)	13.5	13.0	14.9	16.4	15.9	21.9
*Projectile seating is from rear face of tube						
**Velocity in air one meter from the gun muzzle						

4. DISCUSSION

Experimental pressure-time data for discrete locations along the gun tube are shown for all rounds in Tables 2, 4 and 7. All rounds fired are shown plotted in Appendix B. Two pressure ports nearest the muzzle could not be used because the gages were consistently destroyed during the firing cycle. Strain gage measurements at these same axial locations to calculate a

pressure were not successful. Very high-frequency, superimposed noise on top of the strain records impeded the reduction of the data.

Typical of the pressure-time data are the selected plots of Figure 8 for Series B, C/M of 5, projectile at 21° C and stick propellant at 63° C, with sampling at fifty microseconds per sample (BALDAS) and one microsecond per sample (TAPE), respectively. Pressure data in the chamber (P1 and P3) are not compromised at either sampling rate. For the downtube gages (P6 and P10), the time at which the projectile passes and exposes the gage to gun pressure and the character of the rise is somewhat compromised because of the minimum number of points defining this time interval. However, the absolute value of pressure for these downtube positions is approximately the same.

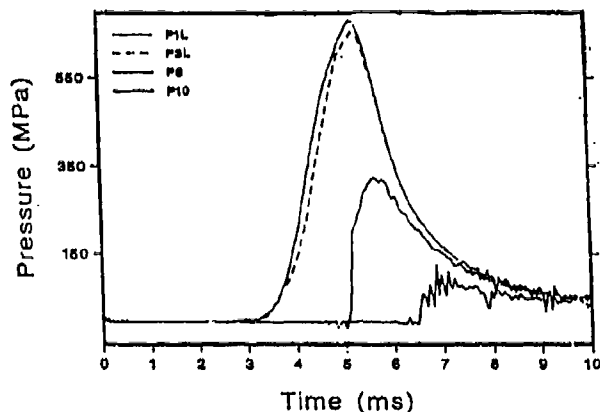


Figure 8a. Fifty (50) microseconds per sample

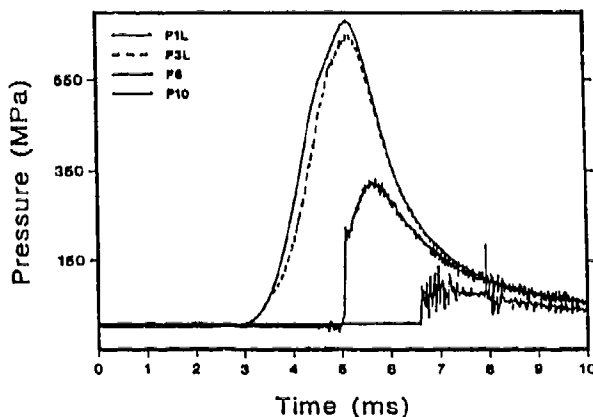


Figure 8b. One (1) microsecond per sample

Figure 8. Typical On-Line Pressure-Time Profiles for Series B, C/M of 5, Stick Propellant at 63° C, Sampling at 50 and 1 us/Sample.

Efforts are being made to improve the techniques for measuring and reducing inbore radar data to provide an online computer comparison of predicted and observed inbore trajectories. From hand-read records of doppler output from analog tape, projectile inbore position can be laboriously determined but not easily compared to that indicated by the data-time record of a downtube pressure and/or strain station which is recorded online. Techniques for obtaining pressures at locations close to the gun muzzle have not been successful, thus limiting the accuracy of the breech to base pressure ratios that are calculated for comparison to simulations. Finally, an effort is ongoing to do an experiment to obtain onboard pressure and acceleration measurements in the regime of C/M's well above unity. However, survivability of onboard gages and electrical components are still a major problem.

5. CONCLUSIONS

The current study reinforces the view that chemical propulsion is a viable option for a hypervelocity system. Firings were done that demonstrated that velocities as high as 2.68 km/s with launch masses in the 2 kg range can be obtained with conventional stick propellant gun techniques at conventional pressures in the 120-mm gun. Launch masses of 1.6 kg were in the 2.2 - 2.6 km/s range at pressures below 500 MPa in a 120-mm gun. These results were accomplished using current Army 120-mm gun and charge components.

6. ACKNOWLEDGMENTS

The authors wish to acknowledge Mr. W. Donovan for designing the projectiles; Messrs. J. Bowen, J. Hewitt, E. Mark, and J. Tuerk of the Applied Ballistics Branch and R. May and D. Meier of Applied Concepts Corporation for their usual high level of cooperation and support at the branch's Sandy Point Firing Facility; Messrs. A. Pfliegel and E. Stilson, Benet Weapons Laboratory, for instrumenting the front of the gun tube with strain patches; Ms. K. Meyers for the technical illustrations used in the paper; and Messrs. R. Mudd and I. Stobie for incisive comments and suggestions in their review of the report.

7. REFERENCES

Anderson, R. D. and K. D. Fickie. "IBHVG2 - A User's Guide." BRL-TR-2829, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1987.

Baer, P. G., C. F. Banz, I. W. May, and W. F. Morrison. "A Propulsion System Comparison Study for the 120-mm Anti-Armor Cannon." BRL-TR-2842, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, August 1987.

Baer, P. G. and I. W. May. "An Analysis of a Tapered-Bore Gun Concept." ARBRL-TR-02427, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, October 1982 (AD B069074L).

Baldini, L. F. "High Velocity (13,000 feet/second) Propellant Gun." 36th Meeting of the Aeroballistic Range Association, San Antonio, TX, October 1985.

Gough, P. S. "The Nova Code: A User's Manual, Volume 1. Description and Use." IHCR 80-8, Naval Ordnance Station, Indian Head, MD, December 1980.

Hertzberg, A., A. P. Bruckner, and D. W. Bogdanoff. "Ram Accelerator: A New Chemical Method for Accelerating Projectiles to Ultrahigh Velocities." AIAA Journal, Vol. 26, No. 2, February 1988.

Powell, J. R. "The Thermal Hypervelocity Launcher (THL)." Presentation to DARPA, Department of Nuclear Energy, Brookhaven National Laboratory, Upton, NY, January 1987.

Robbins, F. W. and A. W. Horst. "Continued Study of Stick Propellant Combustion Processes." BRL-MR-03296, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1983.

Robbins, F. W. and G. E. Keller. "Studies Supporting Development of a Modified Gradient Equation for Lumped-Parameter Interior Ballistic Codes." BRL-MR-3678, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1988.

Ruth, C. R. and A. W. Horst. "Detailed Characterization of Hypervelocity Firings in a Long 120-mm Gun." BRL-TR-3190, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1991.

Swift, H. F. and E. R. Larrison. "Feasibility of Hypervelocity Ordnance (Estimate of the Usefulness and Feasibility of Hypervelocity Weapons in Modern Combat)." Contractor Report ARSCD-CR-79003, Fire Control and Small Caliber Weapon Systems Laboratory, USA ARRADCOM, Dover, NJ, July 1979 (AD B040244).

Thomkins, R. E., K. J. White, and W. F. Oberle. "Combustion Diagnostics and Ballistic Results of Proposed Traveling Charge Propellant." BRL-TR-2902, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1988.

INTENTIONALLY LEFT BLANK.

APPENDIX A - Propellant Description Sheets

INTENTIONALLY LEFT BLANK.

PROPELLANT DESCRIPTION SHEET

EXEMPT-PARA 7-2a
AR 395-15

COMPOSITION PROPELLANT, JA-2, 19 PERFORATION, HEX	DA LOT NUMBER RAD-PE-792-43
SPECIFICATION DDO-P-44035, COR LTR SMCRA-EN DTD 11/13/87	PACKED AMOUNT 800 LB
AT ADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	CONTRACT NUMBER DAAA09-86-7-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS B5248, B95252, B95253, B95254	NITROGEN CONTENT	KI STARCH (65.5°C)	STABILITY (134.5°C)
	MAX _____ %	_____ MIN	_____ MIN
	MIN _____ %	_____ MIN	_____ MIN
	AVG 13.06 %	45+ MIN	30+ MIN
			EXPLOSION NR

MANUFACTURE OF SOLVENTLESS PROPELLANT

FROM	TO		MAIS	TIME	ROOM
145	155	CARPET ROLL AT EXTRUSION			
160	170	EXTRUSION DIE			
105	115	FORCED AIR DRY			4

PROPELLANT COMPOSITION CONSTITUENT	TEST OF FINISHED PROPELLANT			STABILITY AND PHYSICAL TESTS		
	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	TESTS	FORMULA	ACTUAL
NITROCELLULOSE	59.50	+/- 2.00	59.88	HEAT TEST @ 120°C	MCC 40'	MCC 60'+
NITROGLYCERIN	14.90	+/- 1.50	15.54	NO FUMES	NF 1 h	NF 1 h
DIETHYLENE GLYCOL DINITRATE	24.80	+/- 1.50	24.79			
AKARDIT II	0.70	+/- 0.20	0.72	TALIANI:		
MAGNESIUM OXIDE	0.05	- 0.02	0.04	SLOPE AT 100 mmHg	<1 mmHg/min	0.350
GRAPHITE	0.05	- 0.02	0.03	HCE, cal/g	1120 NOM.	1122
TOTAL	100.00		100.00			
				ABSOLUTE DENSITY, g/cc	1.56 MIN	1.57
MOISTURE CONTENT	0.5	+/- 0.3	0.39	BULK DENSITY, LB/FT ³	INFO	58.65
ASH CONTENT	0.3	MAX	0.07	FORM		HEX
METHYLENE CHLORIDE SOLUBLES	40.4	+/- 3.0	41.67	NUMBER OF PERFS		19

CLOSED BOMB

PROPELLANT DIMENSIONS (INCHES)

TEST	NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE	SPECIFICATION	DIE	FINISHED	SPEC	ACTUAL	UNIFORMITY BY MEAN VARIATION, %
	792-43	90	136.59	100.62	LENGTH (L)	0.650	0.650	0.656	N/A	1.39
		145	149.36	101.68	DIA (D)	0.430	0.453	0.434	N/A	0.84
		-40	130.39	100.12	PERF (d)	0.020	0.019	0.022		DATES:
STD	PE-472-138	90	100.00%	100.00%	WEB AVG	0.055	0.060	0.054		
REMARKS					INNER	N/A	0.063	0.056		PACKED 7/88
					MIDDLE	N/A	0.062	0.053		SAMPLED 7/88
					OUTER	N/A	0.054	0.053		TEST FINISHED
					DIFF, %	N/A		0.32		8/88
										OFFERED
					L:D	1.51		1.51		DESCRIPTION SHEETS
					D:d	21.50		21.50		FORWARDED 23 Aug 88

TYPE OF PACKING CONTAINER FIBER DRUM, DWG 9342857

REMARKS

THIS LOT MEETS SPECIFICATION REQUIREMENTS.

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE

SIGNATURE OF GOVERNMENT ASSURANCE REPRESENTATIVE

[Signature]
ARROOM FORM 214R 10 AUG 77

[Signature: Charles N. Hall]

12314

PROPELLANT DESCRIPTION SHEET

EXEMPT-PARA 7-2a
AR 335-15

COMPOSITION	DA LOT NUMBER
PROPELLANT, JA-2, 19 PERFORATION STICK	RAD-PE-792-38
CLASSIFICATION	PACKED AMOUNT
DD-P-64035 AND 5MCRA-EN DTD 8-6-87	1400 LB
MFG AT	CONTRACT NUMBER
RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.	DAAO9-96-7-0003

PRELIMINARY

NITROCELLULOSE	
ACCEPTED BLEND NUMBERS	NITROGEN CONTENT
895191, 895192, 895193, 895194, 895195, 895197	MAX _____ %
	MIN _____ %
	AVG 13.08 %
KI STARCH (65.5°C)	STABILITY (134.5°C)
_____ MIN	_____ MIN
_____ MIN	_____ MIN
45+ MIN	30+ MIN
	EXPLOSION HR

MANUFACTURE OF SOLVENTLESS PROPELLANT

TEMPERATURES, °F		PROCESS	TIME	
FROM	TO		DAYS	HOURS
150	155	CARPET ROLL AT EXTRUSION		
165	165	EXTRUSION DIE		
102.5	107.5	DRYING		32

PROPELLANT COMPOSITION	TEST OF FINISHED PROPELLANT			STABILITY AND PHYSICAL TESTS		
	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	TESTS	FORMULA	ACTUAL
NITROCELLULOSE	59.50	+/- 2.00	59.64	HEAT TEST @ 120°C	INFO	NO CC 60'+
NITROGLYCERIN	14.90	+/- 1.00	15.26	NO FUMES	INFO	MF 1 H
DIETHYLENE GLYCOL DINITRATE	24.80	+/- 1.50	24.33			
AKARDIT II	0.70	+/- 0.20	0.58	TALIANI:		
WESLUM OXIDE	0.05	- 0.02	0.15	SLOPE AT 100 mmHg	<1 mmHg/min	0.297
WHITE	0.05	- 0.02	0.04	HOE, cal/g	1120 NOM.	1115
TOTAL	100.00		100.00			
				ABSOLUTE DENSITY, g/cc	1.56 MIN	1.59
MOISTURE CONTENT	0.5	+/- 0.3	0.3			
ASH CONTENT	0.3	MAX	0.09	FORM	CYL.	CYL.
METHYLENE CHLORIDE SOLUBLES	40.4	+/- 3.0	40.14	NUMBER OF PERFS	19	19

CLOSED BOMB					PROPELLANT DIMENSIONS (inches)						
TEST	LOT NUMBER	TEMP °F	RELATIVE QUICKNESS	RELATIVE FORCE	SPECIFICATION	DIE	FINISHED	SPEC	ACTUAL	UNIFORMITY BY MEAN VARIATION, %	
	PE-792-38	+90	120.38	99.81	LENGTH (L)	21.4 NOM	21.4	21.4	N/A	N/A	
		+145	135.34	99.91	DIA (D)	0.567 NOM	0.572	0.561	N/A	1.49	
		-40	101.65	97.46	PERF (d)	0.039 NOM	0.037	0.036	DATES		
STD	PE-472-138	+90	100.00%	100.00%	WEB						
					INNER	0.062 NOM	0.071	0.061	PACKED 11/87		
					MIDDLE	0.062 NOM	0.071	0.060	SAMPLED 10/87		
					OUTER	0.062 NOM	0.056	0.072	TEST FINISHED		
					AVG.	0.062 NOM	0.066	0.064	11/87		
					DIFF.	N/A	N/A	8.06	OFFERED		
									12/87		
					L:D	N/A	N/A	38.15	DESCRIPTION SHEETS		
					D:d	N/A	N/A	15.58	FORWARDED		

REMARKS

FIRED IN NOMINAL SIZE 700cc CLOSED BOMB AT 0.2 g/cc LOADING DENSITY

TYPE OF PACKING CONTAINER BOX, FIBERBOARD, PPP-8-636J; BAG, BARRIER, MIL-B-117E; BOX, WOOD, MIL-B-2427G

REMARKS

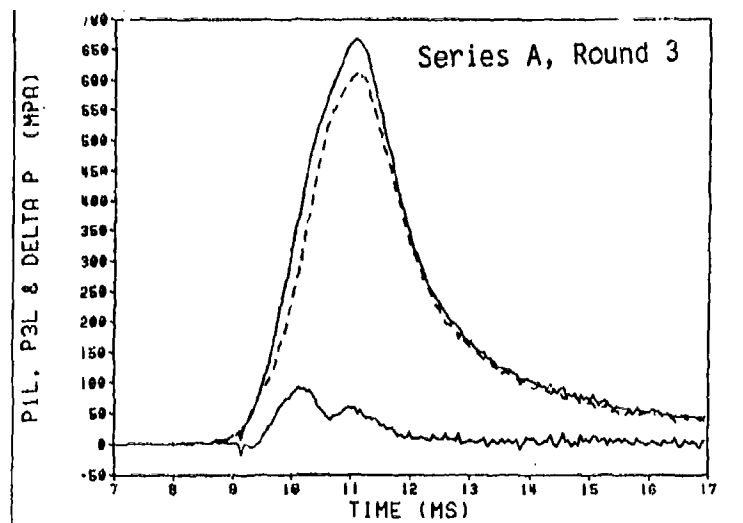
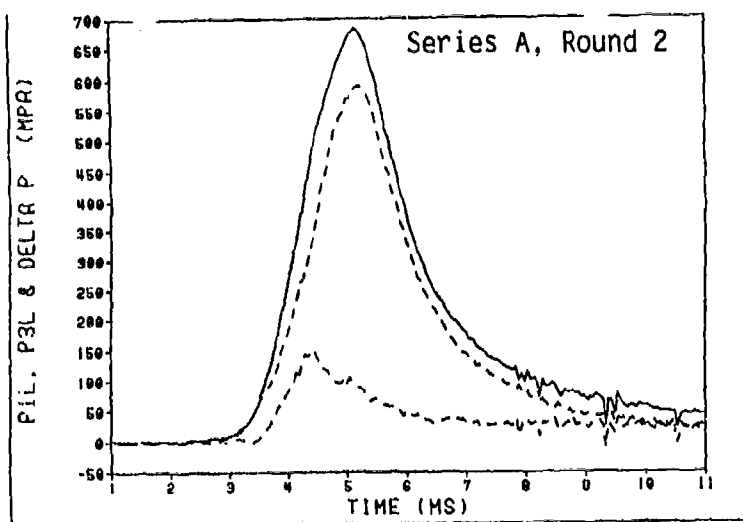
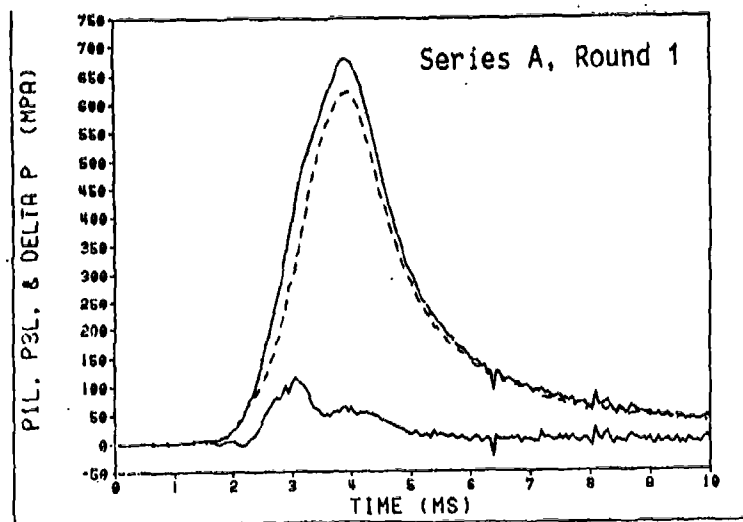
SIGNATURE OF CONTRACTOR'S REPRESENTATIVE

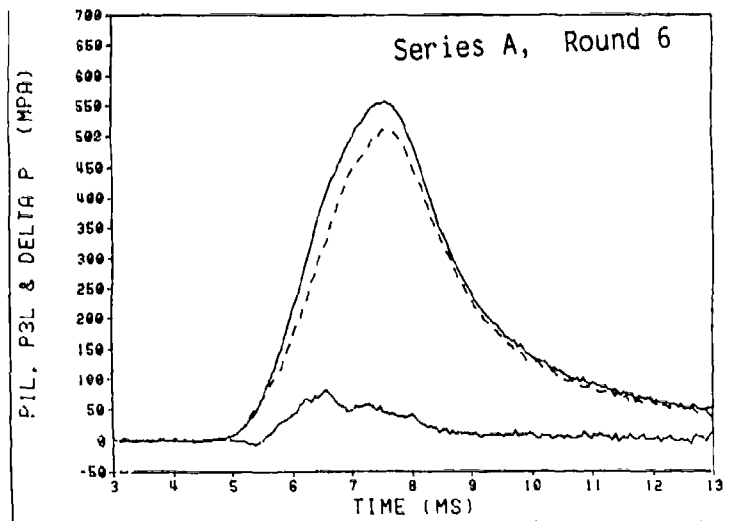
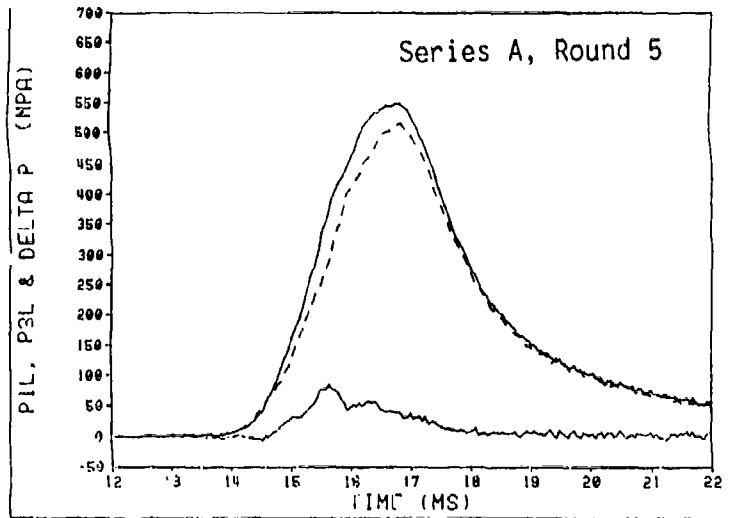
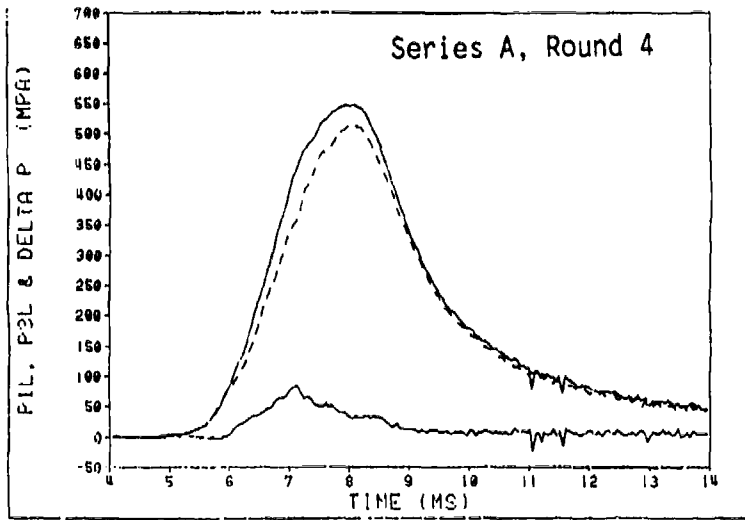
SIGNATURE OF GOVERNMENT ASSURANCE REPRESENTATIVE

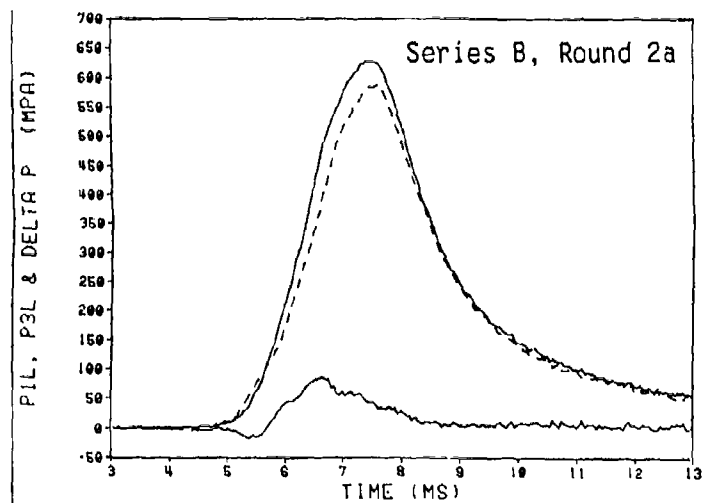
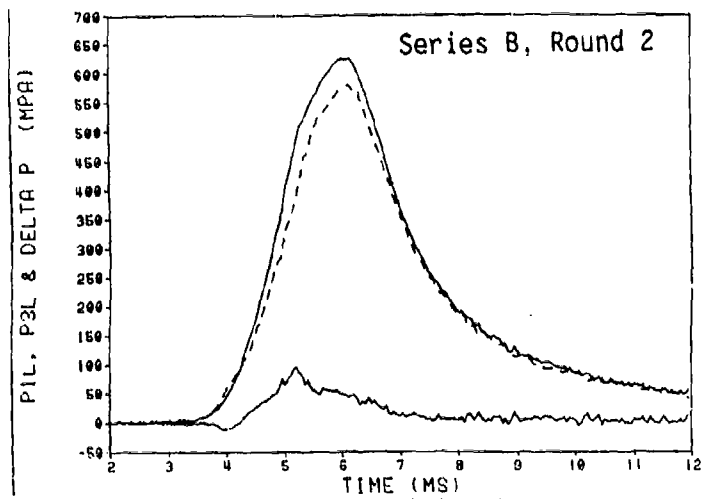
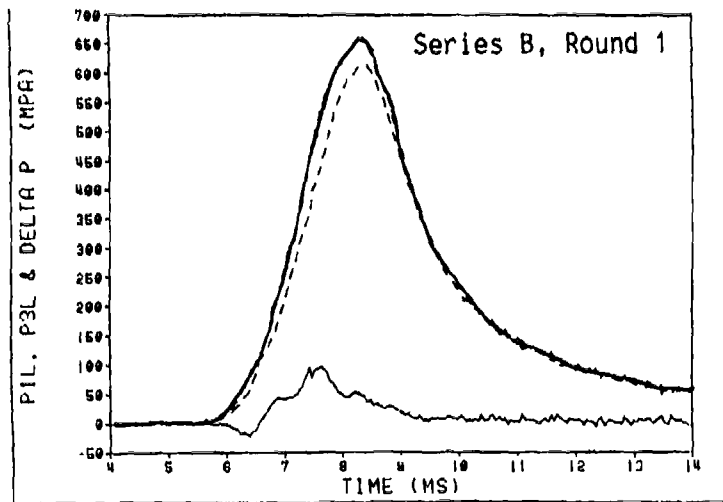
D. W. KIRKPATRICK
ARJCOM FORM 2148 1A

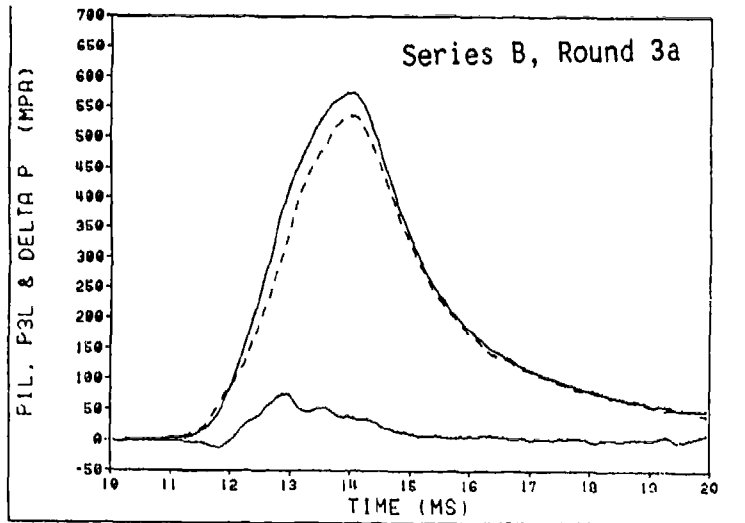
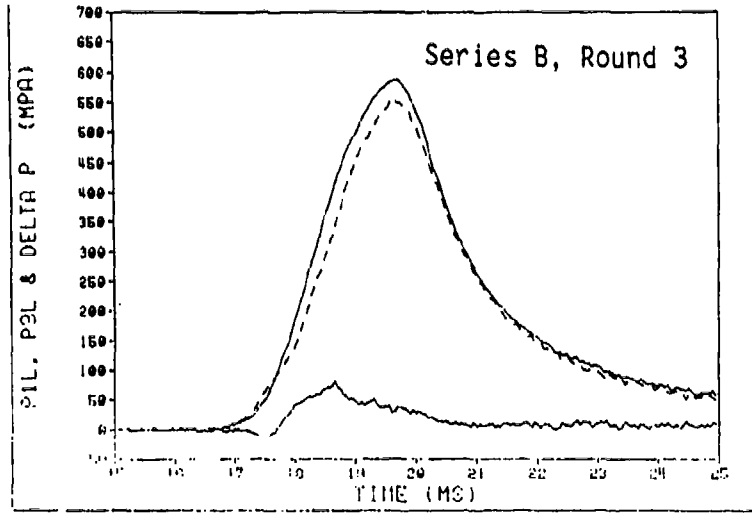
D. W. Kirkpatrick

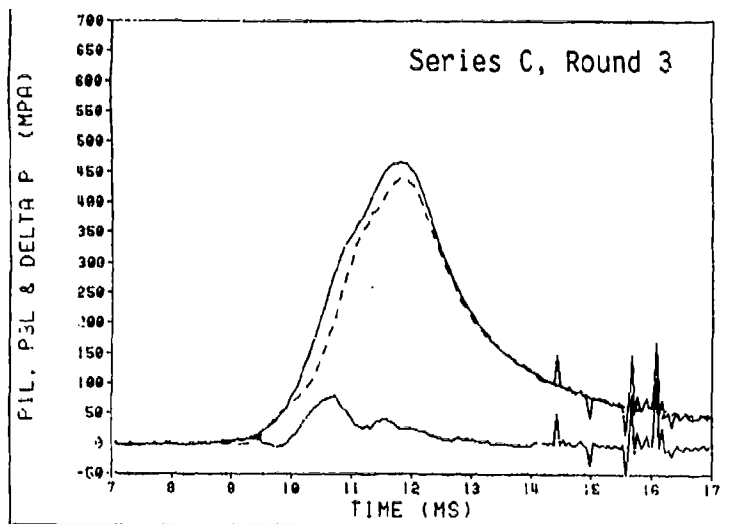
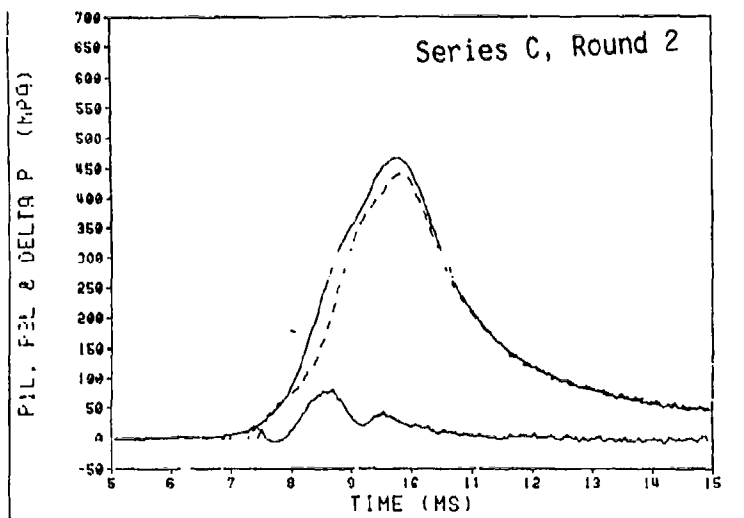
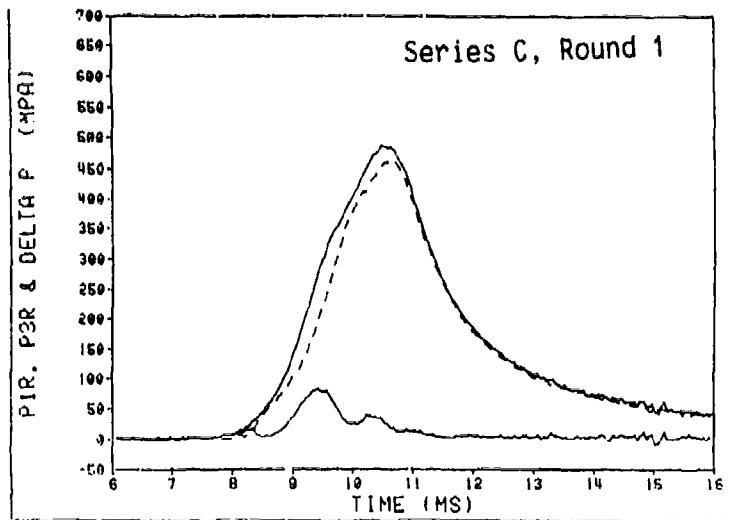
APPENDIX B - Breech Pressure (Solid Line), Forward Chamber Pressure (Dashed Line), and Pressure Difference Versus Time Plots

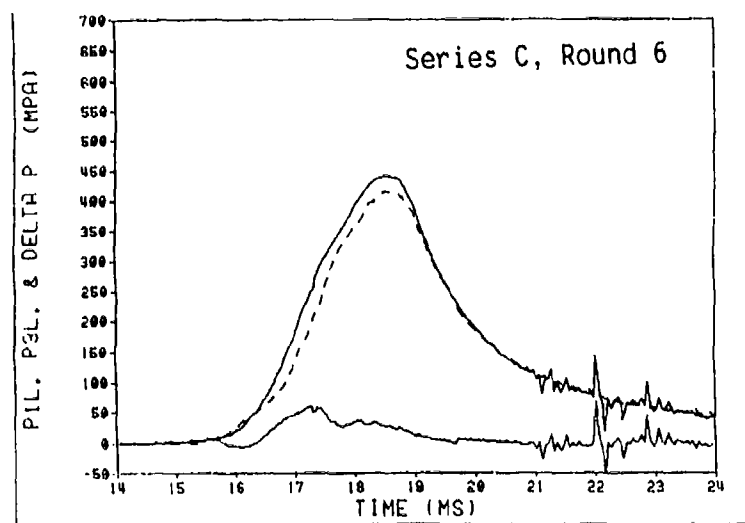
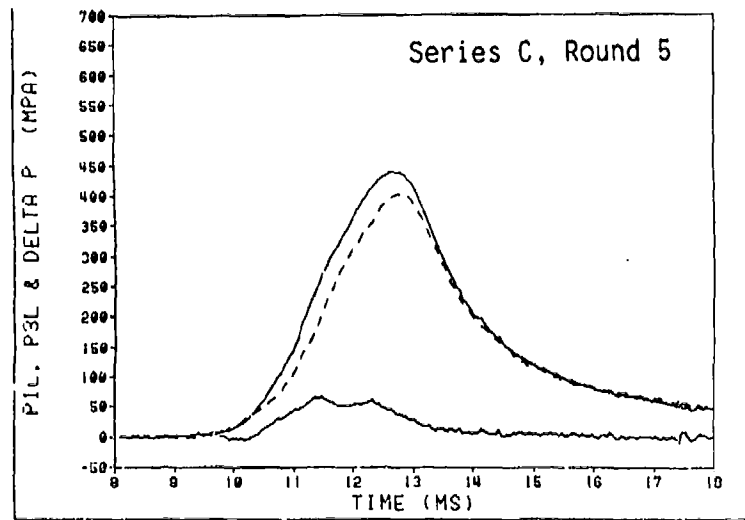
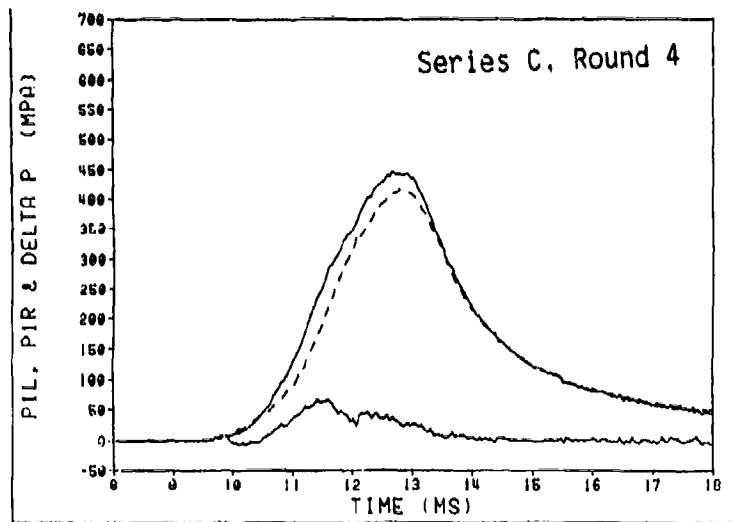












INTENTIONALLY LEFT BLANK.

<u>No. of</u> <u>Copies</u>	<u>Organization</u>	<u>No. of</u> <u>Copies</u>	<u>Organization</u>
2	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22304-6145	1	Commander U.S. Army Missile Command ATTN: AMSMI-RD-CS-R (DOC) Redstone Arsenal, AL 35898-5010
1	Commander U.S. Army Materiel Command ATTN: AMCDRA-ST 5001 Eisenhower Avenue Alexandria, VA 22333-0001	1	Commander U.S. Army Tank-Automotive Command ATTN: ASQNC-TAC-DIT (Technical Information Center) Warren, MI 48397-5000
1	Commander U.S. Army Laboratory Command ATTN: AMSLC-DL 2800 Powder Mill Road Adelphi, MD 20783-1145	1	Director U.S. Army TRADOC Analysis Command ATTN: ATRC-WSR White Sands Missile Range, NM 88002-5502
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-IMI-I Picatinny Arsenal, NJ 07806-5000	(Class. only) 1	Commandant U.S. Army Field Artillery School ATTN: ATSF-CSI Ft. Sill, OK 73503-5000
2	Commander U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-TDC Picatinny Arsenal, NJ 07806-5000	(Unclass. only) 1	Commandant U.S. Army Infantry School ATTN: ATSH-CD (Security Mgr.) Fort Benning, GA 31905-5660
1	Director Benet Weapons Laboratory U.S. Army Armament Research, Development, and Engineering Center ATTN: SMCAR-CCB-TL Watervliet, NY 12189-4050	1	Air Force Armament Laboratory ATTN: WL/MNOI Eglin AFB, FL 32542-5000 <u>Aberdeen Proving Ground</u>
(Unclass. only) 1	Commander U.S. Army Armament, Munitions and Chemical Command ATTN: AMSMC-IMF-L Rock Island, IL 61299-5000	2	Dir, USAMSAA ATTN: AMXSY-D AMXSY-MP, H. Cohen
1	Director U.S. Army Aviation Research and Technology Activity ATTN: SAVRT-R (Library) M/S 219-3 Ames Research Center Moffett Field, CA 94035-1000	1	Cdr, USATECOM ATTN: AMSTE-TD
		3	Cdr, CRDEC, AMCCOM ATTN: SMCCR-RSP-A SMCCR-MU SMCCR-MSI
		1	Dir, VLAMO ATTN: AMSLC-VL-D
		10	Dir, BRL ATTN: SLCBR-DD-T

No. of
Copies Organization

- 1 Commander
U.S. Army Concepts Analysis Agency
ATTN: D. Hardison
8120 Woodmont Ave.
Bethesda, MD 20014
- 1 C.I.A.
01R/DB/Standard
Washington, DC 20505
- 1 Director
U.S. Army Ballistic Missile
Defense Systems Command
Advanced Technology Center
P. O. Box 1500
Huntsville, AL 35807-3801
- 1 Chairman
DOD Explosives Safety Board
Room 856-C
Hoffman Bldg. 1
2461 Eisenhower Ave.
Alexandria, VA 22331-0600
- 1 Commander
U.S. Army Materiel Command
ATTN: AMCDE-DW
5001 Eisenhower Ave.
Alexandria, VA 22333-5001
- 2 Project Manager
Autonomous Precision-Guided Munition
(APGM)
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: AMCPM-CW
AMCPM-CWW
Picatinny Arsenal, NJ 07806-5000
- 1 Department of the Army
Office of the Product Manager
155mm Howitzer, M109A6, Paladin
ATTN: SFAE-AR-HIP-IP, Mr. R. De Kleine
Picatinny Arsenal, NJ 07806-5000

No. of
Copies Organization

- 2 Commander
Production Base Modernization Agency
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: AMSMC-PBM, A. Siklosi
AMSMC-PBM-E, L. Laibson
Picatinny Arsenal, NJ 07806-5000
- 3 PEO-Armaments
Project Manager
Tank Main Armament Systems
ATTN: AMCPM-TMA, K. Russell
AMCPM-TMA-105
AMCPM-TMA-120, C. Roller
Picatinny Arsenal, NJ 07806-5000
- 17 Commander
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: SMCAR-AEE
SMCAR-AEE-B,
A. Beardell
D. Downs
S. Einstein
S. Westley
S. Bernstein
N. Baron
A. Bracuti
J. Rutkowski
B. Brodman
P. Bostonian
R. Cirincione
A. Grabowsky
P. Hui
J. O'Reilly
N. Ross
SMCAR-AES, S. Kaplowitz
Picatinny Arsenal, NJ 07806-5000
- 2 Commander
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: SMCAR-CCD, D. Spring
SMCAR-CCH-V, C. Mandala
Picatinny Arsenal, NJ 07806-5000

No. of
Copies Organization

1 Commander
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: SMCAR-HFM, E. Barriores
Picatinny Arsenal, NJ 07806-5000

1 Commander
U.S. Army Armament Research,
Development, and Engineering Center
ATTN: SMCAR-FSA-T, M. Salsbury
Picatinny Arsenal, NJ 07806-5000

1 Commander, USACECOM
R&D Technical Library
ATTN: ASQNC-ELC-IS-L-R, Myer Center
Fort Monmouth, NJ 07703-5301

1 Commander
U.S. Army Harry Diamond Laboratories
ATTN: SLCHD-TA-L
2800 Powder Mill Rd.
Adelphi, MD 20783-1145

1 Commandant
U.S. Army Aviation School
ATTN: Aviation Agency
Fort Rucker, AL 36360

2 Program Manager
U.S. Tank-Automotive Command
ATTN: AMCPM-ABMS, T. Dean (2 cy)
Warren, MI 48092-2498

1 Program Manager
U.S. Tank-Automotive Command
Fighting Vehicles Systems
ATTN: AMCPM-BFVS
Warren, MI 48092-2498

1 President
U.S. Army Armor & Engineer Board
ATTN: ATZK-AD-S
Fort Knox, KY 40121

1 Project Manager
U.S. Army Tank-Automotive Command
M-60 Tank Development
ATTN: AMCPM-ABMS
Warren, MI 48092-2498

No. of
Copies Organization

1 Director
HQ, TRAC RPD
ATTN: ATCD-MA
Fort Monroe, VA 23651-5143

2 Director
U.S. Army Materials Technology
Laboratory
ATTN: SLCMT-ATL (2 cy)
Watertown, MA 02172-0001

1 Commander
U.S. Army Research Office
ATTN: Technical Library
P.O. Box 12211
Research Triangle Park, NC 27709-2211

1 Commander
U.S. Army Belvoir Research and
Development Center
ATTN: STRBE-WC
Fort Belvoir, VA 22060-5006

1 Director
U.S. Army TRAC-Ft. Lee
ATTN: ATRC-L, Mr. Cameron
Fort Lee, VA 23801-6140

1 Commandant
U.S. Army Command and General
Staff College
Fort Leavenworth, KS 66027

1 Commandant
U.S. Army Special Warfare School
ATTN: Rev and Trng Lit Div
Fort Bragg, NC 28307

3 Commander
Radford Army Ammunition Plant
ATTN: SMCAR-QA/HI LIB (3 cys)
Radford, VA 24141-0298

1 Commander
U.S. Army Foreign Science and
Technology Center
ATTN: AMXST-MC-3
220 Seventh Street, NE
Charlottesville, VA 22901-5396

<u>No. of</u> <u>Copies</u>	<u>Organization</u>
2	Commander Naval Sea Systems Command ATTN: SEA 62R SEA 64 Washington, DC 20362-5101
1	Commander Naval Air Systems Command ATTN: AIR-954-Technical Library Washington, DC 20360
1	Assistant Secretary of the Navy (R, E, and S) ATTN: R. Reichenbach Room 5E787 Pentagon Bldg Washington, DC 20375
1	Naval Research Laboratory Technical Library Washington, DC 20375
1	Commandant U.S. Army Command and General Staff College Fort Leavenworth, KS 66027
2	Commandant U.S. Army Field Artillery Center and School ATTN: ATSF-CO-MW, E. Dublisky (2 cys) Fort Sill, OK 73503-5600
1	Office of Naval Research ATTN: Code 473, R. S. Miller 800 N. Quincy Street Arlington, VA 22217-9999
3	Commandant U.S. Army Armor School ATTN: ATZK-CD-MS, M. Falkovitch (3 cys) Armor Agency Fort Knox, KY 40121-5215
2	Commander U.S. Naval Surface Warfare Center ATTN: J. P. Consaga C. Gotzmer Indian Head, MD 20640-5000

<u>No. of</u> <u>Copies</u>	<u>Organization</u>
4	Commander Naval Surface Warfare Center ATTN: Code 240, S. Jacobs Code 730 Code R-13, K. Kim R. Bernecker Silver Spring, MD 20903-5000
2	Commanding Officer Naval Underwater Systems Center ATTN: Code 5B331, R. S. Lazar Technical Library Newport, RI 02840
5	Commander Naval Surface Warfare Center ATTN: Code G33, J. L. East W. Burrell J. Johndrow Code G23, D. McClure Code DX-21 Technical Library Dahlgren, VA 22448-5000
3	Commander Naval Weapons Center ATTN: Code 388, C. F. Price Code 3895, T. Parr Information Science Division China Lake, CA 93555-6001
1	OSD/SDIO/IST ATTN: Dr. Len Caveny Pentagon Washington, DC 20301-7100
3	Commander Naval Ordnance Station ATTN: T. C. Smith D. Brooks Technical Library Indian Head, MD 20640-5000
1	AL/TSTL (Technical Library) ATTN: J. Lamb Edwards AFB, CA 93523-5000

<u>No. of Copies</u>	<u>Organization</u>
1	AFATL/DLYV Eglin AFB, FL 32542-5000
1	AFATL/DLXP Eglin AFB, FL 32542-5000
1	AFATL/DLJE Eglin AFB, FL 32542-5000
1	NASA/Lyndon B. Johnson Space Center ATTN: NHS-22 Library Section Houston, TX 77054
1	AFELM, The Rand Corporation ATTN: Library D 1700 Main Street Santa Monica, CA 90401-3297
3	AAI Corporation ATTN: J. Herbert J. Frankle D. Cleveland P.O. Box 126 Hunt Valley, MD 21030-0126
2	Aerojet Solid Propulsion Company ATTN: P. Michell L. Torreyson Sacramento, CA 96813
1	Atlantic Research Corporation ATTN: M. King 5390 Cherokee Ave. Alexandria, VA 22312-2302
3	AL/LSCF ATTN: J. Levine L. Quinn T. Edwards Edwards AFB, CA 93523-5000
1	AVCO Everett Research Laboratory ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149-5936

<u>No. of Copies</u>	<u>Organization</u>
2	Calspan Corporation ATTN: C. Murphy (2 cys) P.O. Box 400 Buffalo, NY 14225-0400
1	General Electric Company Tactical Systems Department ATTN: J. Mandzy 100 Plastics Ave. Pittsfield, MA 01201-3698
1	IITRI ATTN: M. J. Klein 10 W. 35th Street Chicago, IL 60616-3799
1	Hercules, Inc. Allegheny Ballistics Laboratory ATTN: William B. Walkup P.O. Box 210 Rocket Center, WV 26726
1	Hercules, Inc. Radford Army Ammunition Plant ATTN: E. Hibshman Radford, VA 24141-0299
3	Lawrence Livermore National Laboratory ATTN: L-355, A. Buckingham M. Finger L-324, M. Constantino P.O. Box 808 Livermore, CA 94550-0622
1	Olin Corporation Badger Army Ammunition Plant ATTN: F. E. Wolf Baraboo, WI 53913
2	Olin Ordnance ATTN: E. J. Kirschke A. F. Gonzalez P.O. Box 222 St. Marks, FL 32355-0222

<u>No. of Copies</u>	<u>Organization</u>
1	Paul Gough Associates, Inc. ATTN: Dr. Paul S. Gough 1048 South Street Portsmouth, NH 03801-5423
1	Physics International Company ATTN: Library, H. Wayne Wampler 2700 Merced Street San Leandro, CA 98457-5602
1	Princeton Combustion Research Laboratory, Inc. ATTN: M. Summerfield 475 U.S. Highway One Monmouth Junction, NJ 08852-9650
2	Rockwell International Rocketdyne Division ATTN: BA08, J.E. Flanagan J. Gray 6633 Canoga Ave. Canoga Park, CA 91363-2703
1	Thiokol Corporation Huntsville Division ATTN: Technical Library Huntsville, AL 35807
1	Sverdrup Technology, Inc. ATTN: Dr. John Deur 2001 Aerospace Parkway Brook Park, OH 44142
2	Thiokol Corporation Elkton Division ATTN: R. Biddle Technical Library P.O. Box 241 Elkton, MD 21921-0241
1	Veritay Technology, Inc. ATTN: E. Fisher 4845 Millersport Highway East Amherst, NY 14501-0305

<u>No. of Copies</u>	<u>Organization</u>
1	Universal Propulsion Company ATTN: H. J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 84029
1	Battelle ATTN: TACTEC Library, J.N. Huggins 505 King Ave. Columbus, OH 43201-2693
1	Brigham Young University Department of Chemical Engineering ATTN: M. Beckstead Provo, UT 84601
1	California Institute of Technology 204 Karman Laboratory Main Stop 301-46 ATTN: F.E.C. Culick 1201 E. California Street Pasadena, CA 91109
1	California Institute of Technology Jet Propulsion Laboratory ATTN: L. D. Strand, MS 512/102 4800 Oak Grove Drive Pasadena, CA 91109-8099
1	University of Illinois Department of Mechanical/Industrial Engineering ATTN: H. Krier 144 MEB; 1206 N. Green Street Urbana, IL 61801-2978
1	University of Massachusetts Department of Mechanical Engineering ATTN: K. Jakus Amherst, MA 01002-0014
1	University of Minnesota Department of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55414-3368

<u>No. of Copies</u>	<u>Organization</u>
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: B.T. Zim E. Price W.C. Strahle Atlanta, GA 30332
1	Institute of Gas Technology ATTN: D. Gidaspow 3424 S. State Street Chicago, IL 60616-3896
1	Johns Hopkins University Applied Physics Laboratory Chemical Propulsion Information Agency ATTN: T. Christian Johns Hopkins Road Laurel, MD 20707-0690
1	Massachusetts Institute of Technology Department of Mechanical Engineering ATTN: T. Toong 77 Massachusetts Ave. Cambridge, MA 02139-4307
1	Pennsylvania State University Applied Research Laboratory ATTN: G. M. Faeth University Park, PA 16802-7501
1	Pennsylvania State University Department of Mechanical Engineering ATTN: K. Kuo University Park, PA 16802-7501
1	Purdue University School of Mechanical Engineering ATTN: J. R. Osborn TSPC Chaffee Hall West Lafayette, IN 47907-1199
1	SRI International Propulsion Sciences Division ATTN: Technical Library 333 Ravenwood Ave. Menlo Park, CA 94025-3493

<u>No. of Copies</u>	<u>Organization</u>
1	Rensselaer Polytechnic Institute Department of Mathematics Troy, NY 12181
2	Director Los Alamos Scientific Laboratory ATTN: T3, D. Butler M. Division, B. Craig P.O. Box 1663 Los Alamos, NM 87544
1	General Applied Sciences Laboratory ATTN: J. Erdos 77 Raynor Ave. Ronkonkama, NY 11779-6649
1	Battelle PNL ATTN: Mr. Mark Garnich P.O. Box 999 Richland, WA 99352
1	Stevens Institute of Technology Davidson Laboratory ATTN: R. McAlevy, III Castle Point Station Hoboken, NJ 07030-5907
1	Rutgers University Department of Mechanical and Aerospace Engineering ATTN: S. Temkin University Heights Campus New Brunswick, NJ 08903
1	University of Southern California Mechanical Engineering Department ATTN: OHE200, M. Gerstein Los Angeles, CA 90089-5199
2	University of Utah Department of Chemical Engineering ATTN: A. Baer G. Flandro Salt Lake City, UT 84112-1194

**No. of
Copies Organization**

- 1 Washington State University
Department of Mechanical Engineering
ATTN: C. T. Crowe
Pullman, WA 99163-5201

- 1 Alliant Techsystems, Inc.
ATTN: R. E. Tompkins
MN38-3300
5700 Smetana Drive
Minnetonka, MN 55343

- 1 Science Applications, Inc.
ATTN: R. B. Edelman
23146 Cumorah Crest Drive
Woodland Hills, CA 91364-3710

- 1 Battelle Columbus Laboratories
ATTN: Mr. Victor Levin
505 King Ave.
Columbus, OH 43201-2693

- 1 Allegheny Ballistics Laboratory
Propulsion Technology Department
Hercules Aerospace Company
ATTN: Mr. Thomas F. Farabaugh
P.O. Box 210
Rocket Center, WV 26726

- 1 MBR Research Inc.
ATTN: Dr. Moshe Ben-Reuven
601 Ewing St., Suite C-22
Princeton, NJ 08540

Aberdeen Proving Ground

Cdr, CSTA
ATTN: STECS-LI, R. Hendricksen

USER EVALUATION SHEET/CHANGE OF ADDRESS

This laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers below will aid us in our efforts.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) _____

2. How, specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) _____

3. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. _____

4. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) _____

BRL Report Number BRL-MR-3921 Division Symbol _____

Check here if desire to be removed from distribution list. _____

Check here for address change. _____

Current address: Organization _____
Address _____

DEPARTMENT OF THE ARMY
Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066



NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

OFFICIAL BUSINESS

BUSINESS REPLY MAIL
FIRST CLASS PERMIT No 0001, APG, MD

Postage will be paid by addressee.

Director
U.S. Army Ballistic Research Laboratory
ATTN: SLCBR-DD-T
Aberdeen Proving Ground, MD 21005-5066

