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TECHNICAL REPORT BRL-TR-3190

BRL

DETAILED CHARACTERIZATION OF
HYPERVELOCITY FIRINGS IN A
LONG 120-MM GUN

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ALBERT W. HORST

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13. ABSTRACT (Maximum 200 words) The applicability of lumped-parameter interior ballistic models to very high velocity guns is limited by the use of a superimposed pressure gradient to approximate the relationship between the space mean, breech, and projectile base pressures. Even modern two-phase flow interior ballistic models, specifically formulated to address the hydrodynamics of the problem, are largely untested in such regimes. Serious attempts to develop high-velocity solid propellant guns, however, require an accurate modeling capability for concept screening and charge optimization. Firings were conducted in a long 120-mm gun (Ballistic Tube) at a propellant charge to projectile mass (C/M) ratio of about 3 to provide muzzle velocities in the 2 - 2.5 km/s range. The tube was instrumented with pressure gages at 14 locations to determine the experimental pressure-displacement profile. Results were compared to predictions of a classical lumped-parameter code, a state-of-the-art two phase flow model, and a lumped-parameter code with a recently developed pressure gradient.				
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1. BACKGROUND TO THE PROBLEM

There has long existed substantial interest in high muzzle velocities for academic as well as indirect and direct military exploitation. The literature abounds with references on the subject¹⁻⁷. Many recent discussions focus on electric gun propulsion alternatives (e.g., rail gun, coil gun, electrothermal gun), most of which are purported to circumvent the upper velocity limitations of 2-3 km/s using chemical propulsion. While a complete discussion of this topic is outside the scope of this paper, the point may be made, from a military point of view, 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. The real concern will likely be high system weights associated with heavy-walled tubes to support the high pressures needed for conventional concepts versus currently excessive weights associated with power generation (and perhaps cooling) for electric gun concepts.

Muzzle velocities as high as 3950 m/s have been achieved by Baldini et al⁸ using solid propellant guns, though admittedly at C/M's and pressures too high for practical military use. The current study, however, addresses a somewhat lower but clearly interesting ballistic level with potentially acceptable system burdens. The goal was to measure experimentally the pressure gradient in a solid propellant gun firing at velocities in the 2 to 2.5 km/s range. A 120-mm, Ballistic Tube was available for use in this study. Unfortunately, existing projectile onboard instrumentation/telemetry packages would not withstand the high-acceleration environment (~100 kg's), so determination of the pressure gradient had to be made using pressure gages mounted at discrete locations in the tube sidewall. Preliminary calculations using a standard lumped-parameter interior ballistics code suggested that use of a 19-perforated JA2 propellant at a charge weight of about 9 kg would launch a 3 kg projectile to a velocity in the region of interest at an acceptable pressure (well under the 700 MPa pressure limit for the tube). Thus, results from this study would be 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. 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. A 120-mm, Ballistic Tube with 6276 mm of inbore travel (1524 mm more than the standard 120-mm, M256 Tube) was used for all firings. 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 cannon.

The gun tube was instrumented with five Kistler 6211 pressure gages in the chamber. As measured from the rear face of the tube, there were two each, 100 degrees apart at 95 mm, one at 286 mm (midchamber) and two each, 70 degrees apart at 489 mm. Gage redundancy at the breech and forward chamber positions was incorporated into the cannon because of the possibility of losing a gage and thereby data at the high pressures expected for these firings. To measure pressure at discrete down-tube locations, nine gages were located at 768 mm, 1048 mm, 1530 mm, 2292 mm, 3054 mm, 3816 mm, 4578 mm, 5340 mm and 6102 mm. A schematic of gage locations in the Ballistic Tube is shown in Figure 1.

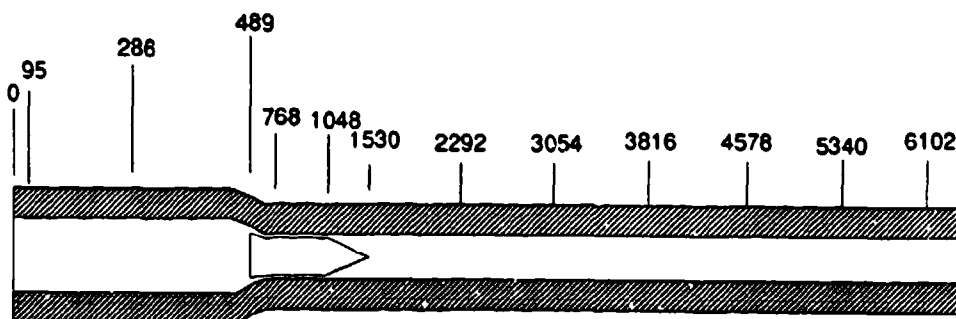


Figure 1. Location of Pressure Transducers in the 120-mm. Ballistic Tube.

Projectile displacement was determined by using a 15-GHz doppler radar to measure projectile motion both within and 10 meters beyond the gun muzzle. Projectile muzzle velocity was calculated using the doppler radar-time profile with a known time interval just after the projectile exited the gun tube. From the Weibel radar, both downrange velocity-time profiles and muzzle velocity, calculated from the profiles, were determined using system-resident Weibel software. Ignition delay was measured in reference to the application of the firing voltage to the 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.

Two Photec high-speed cameras and one smear camera were used to record both the inbore and initial free flight of the projectiles during and after the firing cycle. The schematic layout of the firing barricade, depicted in Figure 2, shows the positions of the three cameras, the inbore and downrange doppler units and the reflector medium for both the inbore doppler and inbore photography. Inbore camera coverage was compromised

somewhat since the mirror used to reflect the inbore position of the projectile to the camera lens was supported on the doppler Echosorb reflecting panel. Primary concern was in optimizing the doppler signal from the projectile to the doppler unit so that accurate muzzle velocities could be calculated. The downrange cameras were employed to determine if unburned propellant was expelled from the cannon and to confirm projectile survivability after launch through the high acceleration environment.

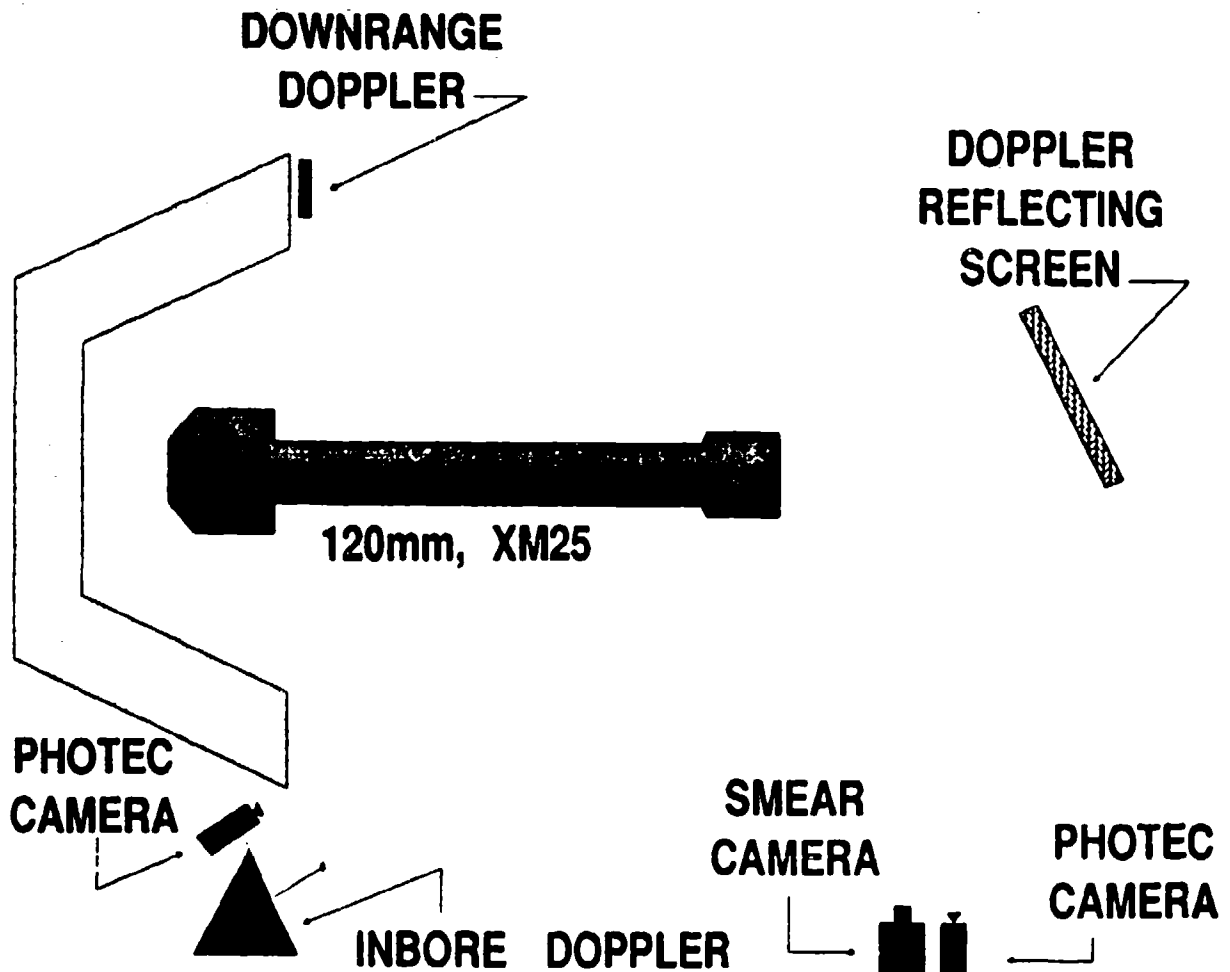


Figure 2. Schematic Layout of Firing Barricade.

Several projectile configurations were used during the course of this program; the initial design, shown in Figure 3, employed a Polypropolux plastic. This choice of material provided an inexpensive approach to meeting the projectile low weight requirement as well as incorporating a standard obturator configuration into the projectile design. A steel pusher plate was bolted to the base of the projectile to protect the plastic material from the propellant gases during inbore travel; an

aluminum front plate was bolted to the projectile to reflect the doppler radar signal during both inbore and free flight travel.

Cylindrical-shaped slug with steel base to limit plastic deformation and erosion from burning propellant

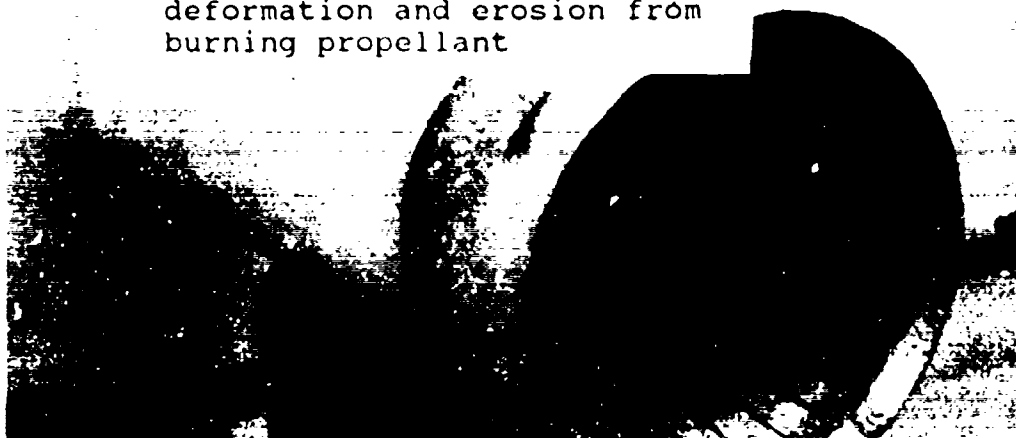


Figure 3. Polypropolux Projectile Configuration.

The propelling charge employed the conventional JA2 formulation used in the 120-mm tank gun; the propellant configuration, however, was a high progressivity/high density (HPD) concept known as partially cut (PC) stick propellant (Figure 4). Use of nearly any stick geometry results in a higher

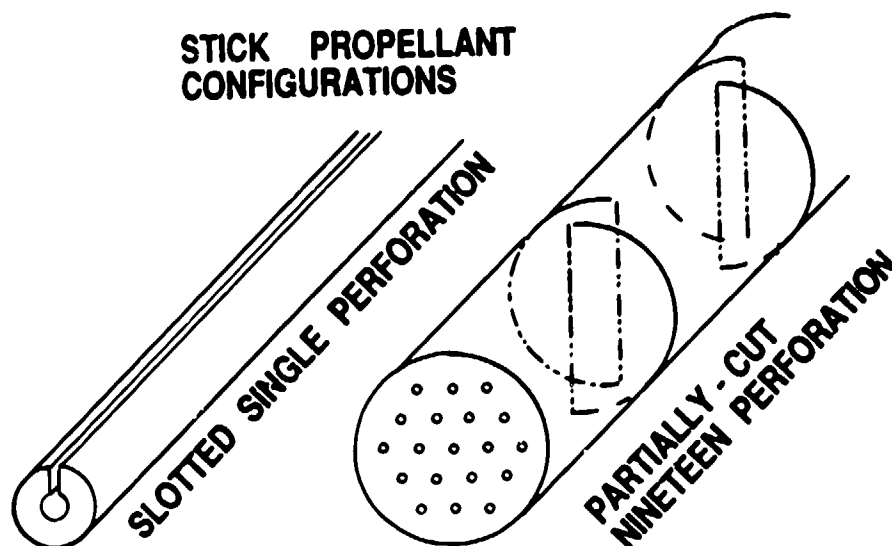


Figure 4. Venting Techniques for Different Stick Propellant Geometries.

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, stick fracture, and erratic performance⁸. The PC configuration circumvents this problem by providing lateral venting of the perforations at the required spacing to avoid pressure buildup (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.

The overall stick/sheet charge is shown in Figure 5 along with the standard 120-mm combustible cartridge case and ignition system consisting of the XM123 stub primer surrounded by a cloth donut containing 100 g of Class 1 black powder. Although not indicated on the schematic, the sheet propellant was placed around the cylindrical rear section of partially-cut stick propellant as noted by the two areas of small rectangles just in from of the black powder doughnut. Further details of the gun, projectile, and charge are tabulated in Table 1.

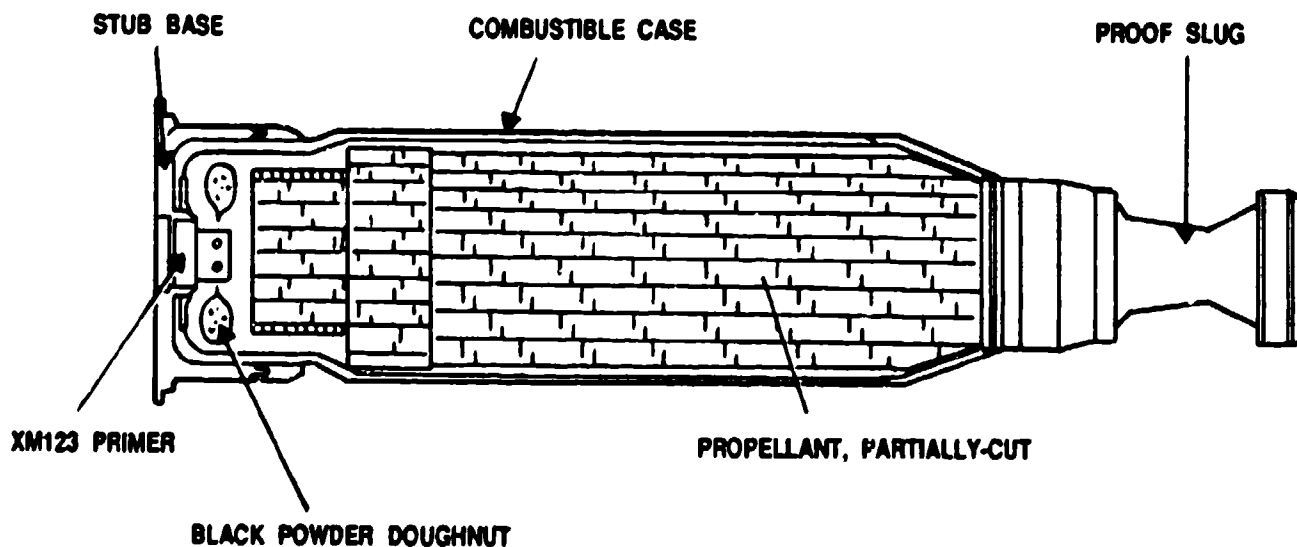


Figure 5. Overall Charge Configuration.

Table 1. Gun, Projectile and Charge Characteristics.

Testing Order	Characteristics	Charge Number				
		1	2	3	4	5*
	Gun Caliber	(-----120-mm-----)				
	Inbore Travel	(----- 6276 mm-----)				
A. First Phase Testing						
	Chamber Volume	(----- 9830 ml-----)				
	Projectile Weight (kg)	3.081	3.081	3.081	3.076	3.081
	Stick Weight (kg)	7.523	8.222	8.274	8.231	8.346
	Sheet Weight (kg)**	0.649	0.399	0.583	0.848	0.964
	Total Charge Weight (kg)	8.172	8.621	8.857	9.079	9.310
	C/M Ratio	2.65	2.80	2.87	2.95	3.02*
B. Second Phase Testing						
	Chamber Volume	(--10305 ml--)				
	Projectile Weight (kg)	3.073	3.072			
	Stick Weight (kg)	8.680	8.805			
	Sheet Weight (kg)	1.273**	1.177***			
	Total Charge Weight (kg)	9.953*	9.982*			
	C/M Ratio	3.24*	3.25*			

*Experimental rounds whose average pressure and velocity were compared with XNOVAKTC computer simulations. Stick propellant web was 1.82 mm (RAD-792-38)

**Sheet propellant thickness was 1.3 mm (RAD-792-29A)

***Sheet propellant thickness was 3 mm (RAD-792-29B)

2.2 First Phase Firing Results and Comparison with Simulations.

The first test series was intended to be a charge assessment and confirmation of projectile integrity. Results for all the firings are listed in Table 2.

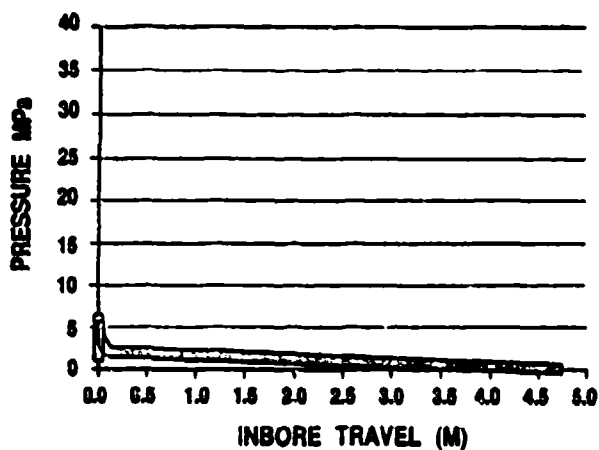
Table 2. Experimental Firing Results for Polypropolux Cartridges, First Phase Firing Series.

Round No.	Charge Wt (kg)	Projectile Wt (kg)	C/M	Pressure (MPa)	Velocity (m/s)
1	8.172	3.081	2.65	405	2057
2	8.621	3.081	2.80	491	2190
3	8.857	3.081	2.87	530	2237
4	9.079	3.078	2.95	569	2279
5	9.310	3.081	3.02	610	2311

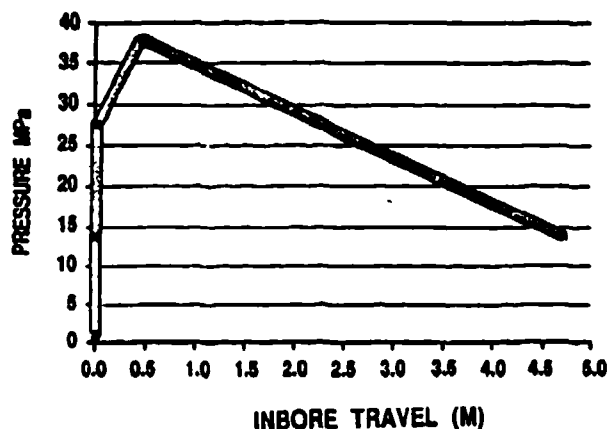
A summary of firing results for the C/M of 3.02, along with simulations provided by the standard IBHVG2 lumped-parameter code⁹, the XNOVAKTC two-phase flow code¹⁰, and IBRGA, a modified lumped-parameter code¹¹ including a new pressure gradient to account for the effects of chambrage and the existence of both two-phase and single-phase regions of flow, is provided in Table 3. For these initial simulations, input data were based on parameters shown above in Table 1; in addition, for all but the last line of simulated performance data, values for bore resistance were based on earlier measurements provided by onboard pressure and acceleration measurements using a special 120-mm slug projectile (Figure 6)¹².

Table 3. Experimental and Simulated Data for a Polypropolux Cartridge with a C/M of 3.02.

Type of Data	Breech Pressure (MPa)	Muzzle Velocity (m/s)	Proj Travel at Peak Pressure (mm)
Ballistic Cannon, Experimental	610	2311	~1000
IBHVG2 Simulation	692	2431	404
IBRGA	543	2280	457
XNOVAKTC	549	2378	1295
XNOVAKTC + air shock	550	2345	1295
XNOVAKTC + air shock + high resistance	615	2307	1143



Experimentally Measured



Hypothetically Assumed

Figure 6. Bore Resistance Versus Displacement Profile.

Experimental results disclosed that the maximum loadable charge mass of 9.31 kg yielded acceptable maximum chamber pressures, the value of about 610 MPa falling closer to the prediction of IBHVG2 than that of XNOVAKTC; however, the measured velocity was considerably lower than that predicted by either code. The modified lumped-parameter code (IBRGA) yielded pressure results closer to those of XNOVAKTC.

Several after-the-fact simulations with XNOVAKTC were performed to probe the influence of particular inputs which might have been in error. An arbitrary increase in burning rate coefficient to match the observed peak pressure for the 9.31 kg charge overpredicted the observed muzzle velocity by 115 m/s. The resistance to projectile motion resulting from the air ahead of the projectile (air shock) is not accounted for in the basic XNOVAKTC code; however, the traveling charge option does allow for this effect. After the data base was modified to run as a traveling charge with no traveling charge (booster charge only), computer runs were made with the air shock option both turned on and off. The effect was negligible on peak pressure (projectile velocity still relatively low at that point), while the velocity loss from the added resistance was predicted to be about 33 m/s (see Table 3). All subsequent calculations employed this option of the code.

One of the major concerns from the first firing series had been projectile integrity. Smear photographs (Figure 7) revealed no sign of breakup though the hydrostatic behavior of the material, possibly indicated by the flaring at the front end of the slug to relieve the stress as the projectile exited the tube, could have significantly influenced bore resistance and thus further reduced muzzle velocity from the predicted level. An alternate bore resistance profile, also shown in Figure 6, was arbitrarily defined to approximate both the observed peak

pressure and muzzle velocity for the 9.31 kg charge. While it is unclear whether such a profile is possible for this material, the potential effect was clearly defined (Table 3).

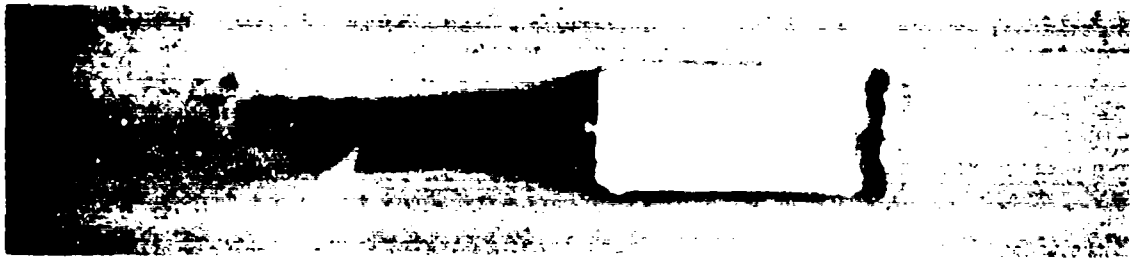


Figure 7. Smear Photograph of Projectile.

2.3 Reconfiguration of Projectile.

Since, in the first phase of testing, there was some question concerning the influence of the Polypropolux material on the bore resistance and thus on muzzle velocity, an aluminum slug, similar in shape to proof slugs used in firings in the standard 120-mm, M256 Cannon at the BRL, was redesigned for use in the second phase of testing. A schematic of the projectile is shown in Figure 8. The resistance profile for a rigid metal

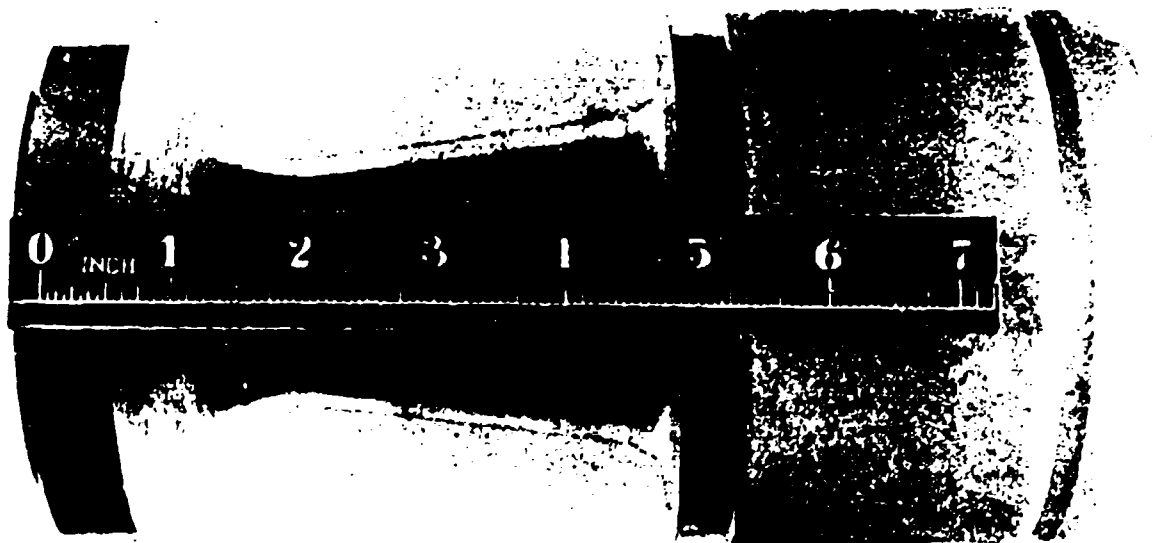


Figure 8. Aluminum Proof Slug Configuration.

projectile using a nylon obturator has been well defined from firings in the standard 120-mm gun. Assuming the much higher C/M of the current cartridge (Table 1) does not alter this profile (Figure 6), results for the second phase of tests were expected to show better agreement between the experimental and simulated data. Unfortunately, in order to duplicate the weight of the plastic projectiles, two cylindrical sections of aluminum had to be removed from the projectile base, increasing the initial chamber volume of the cartridge by 0.475 liters.

2.4 Second Phase Firing Results and Comparison with Simulations.

A summary of the firing results for the two cartridges using the aluminum proof slugs along with the simulations done with the various codes are shown in Table 4.

Table 4. Experimental and Simulated Data for Aluminum Cartridges with a C of 3.24.

Type of Data	Breech Pressure (MPa)	Muzzle Velocity (m/s)	Proj Travel at Peak Pressure (mm)
Ballistic Cannon, Experimental			
Round 1	734	2455	~1000
Round 2	809	2499	~1000
Average	776	2477	~1000
IBHVG2 Simulation	945	2607	371
IBRGA	720	2435	439
XNOVAKTC	---	----	----
XNOVAKTC + air shock	709	2518	1219
XNOVAKTC + air shock + high resistance	776	2467	1118

3. DISCUSSION

3.1 Analysis of Data.

Since only the final XNOVAKTC simulation, using the increased bore resistance profile and including the effect of air compression ahead of the projectile, showed any success in simulating actual firing data, attention to date has focused on a detailed comparison of theory to experiment using this model. Figure 9 presents available experimental pressure-time curves for Round 5 of the initial firing series, while Figure 10 presents simulated pressure-time data for the firing.

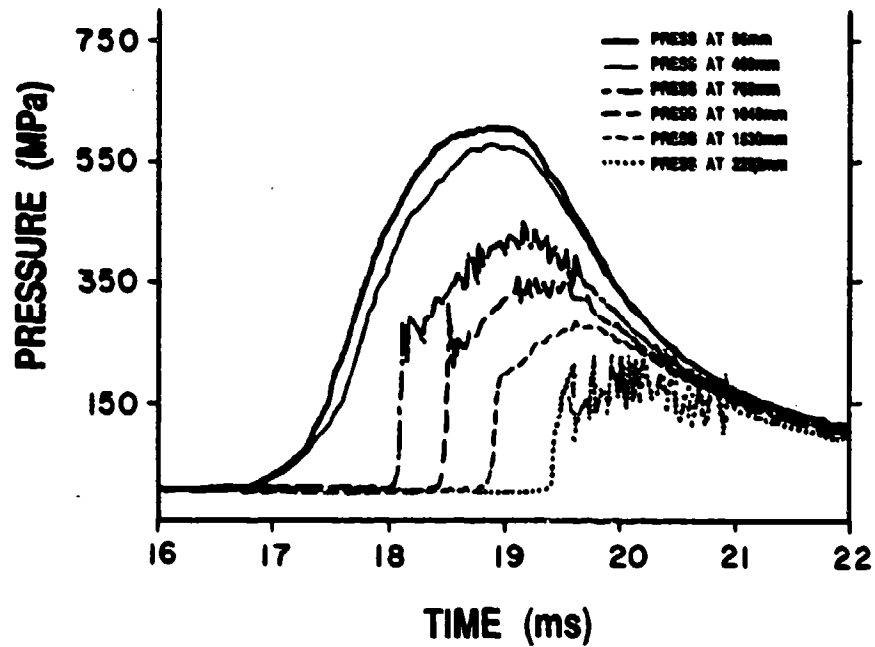


Figure 9. Experimental Pressure-Time Curves for Round 5 of First Phase Firing Series.

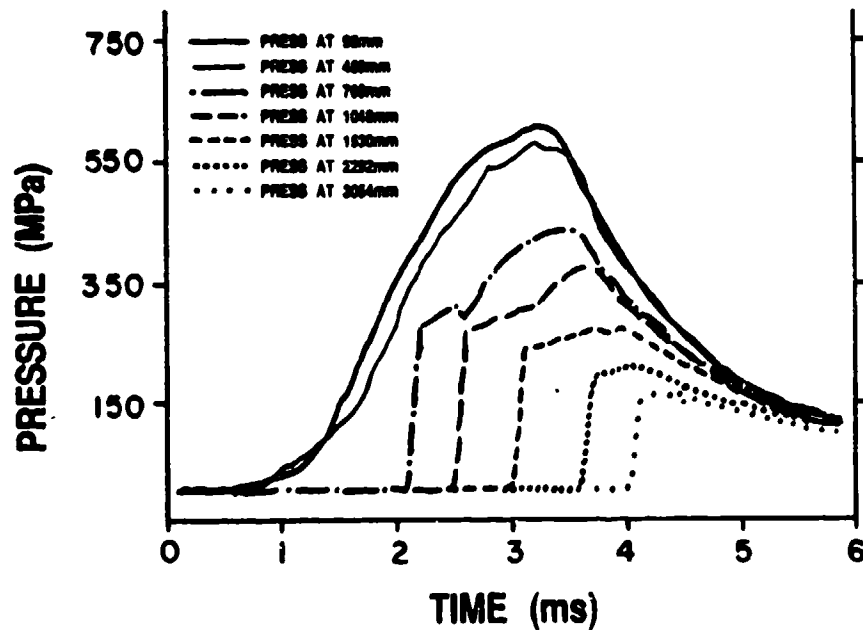


Figure 10. XNOVAKTC Simulation of Pressure-Time Curves for Round 5 of First Phase Firing Series.

We remind the reader that overall agreement in peak breech pressure was forced by manipulation of the bore resistance profile; however, all other features of the simulation follow from the hydrodynamics of the simulation without adjustment. We note first that the simulation of the relationship between breech and forward chamber pressures is quite good, capturing both the small reverse pressure gradient associated with the flamespreading event and the approximate magnitude of the more classical pressure gradient at the time of peak pressure. Moreover, the comparison of projectile travel, as inferred from passage of the various downbore pressure gages, appears to be excellent prior to peak pressure. However, the simulated event proceeds at a slower rate, and, while the difference in shape of corresponding breech curves somewhat clouds this issue of timing, it is quite clear from projectile arrival times that reality is ahead of the simulation by approximately 0.2 ms when the projectile reaches the gage at 2292 mm.

This disparity between the observed and simulated projectile travel versus time, although not discernible because of the scaling, is shown plotted in Figure 11. It is interesting to note, however, that this same data suggest that projectile travel

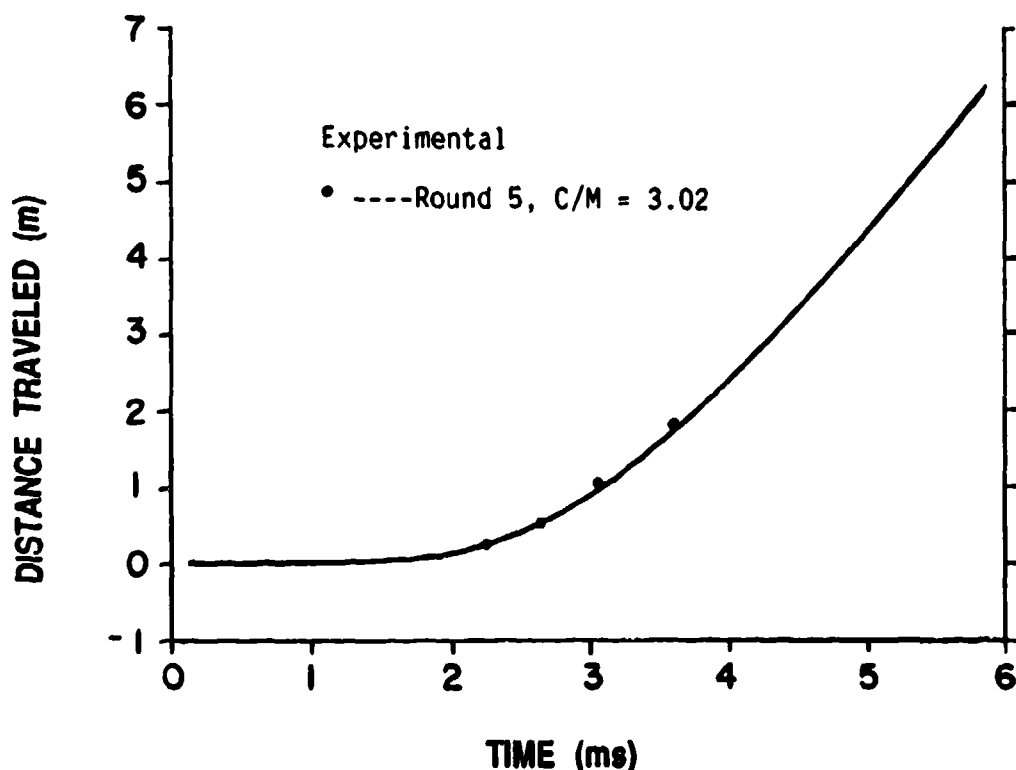


Figure 11. Experimental and Simulated Travel-Time Curves for Round 5 of First Phase Firing Series.

at peak pressure is about 1000 mm, somewhat behind that of the simulation but far greater than values predicted by the lumped-parameter codes. Actual acceleration after peak pressure, however, appears to exceed that simulated, leading to the acceptable match in muzzle velocity.

Plots of ratios of breech pressure to base pressure as a function of travel for IBHVG2 code/Piddick-Kent gradient, IBRGA code/chambrage gradient, XNOVAKTC code with two different options and for experimental data are shown plotted in Figure 12. Since IBHVG2 has a gradient that assumes a constant ratio between breech and base pressure, the straight line generated from this code is neither unexpected nor does it model the experimental data. Both the IBRGA code with its chambrage gradient and XNOVAKTC code, which includes the effects of chambrage as well as flamespreading and intergranular stress, show much closer agreement to the experimental data. The fact that the simulated curves have assumed the general shape of the experimental data is indicative that the major interior ballistic parameters have been modeled even though absolute agreement has not been achieved.

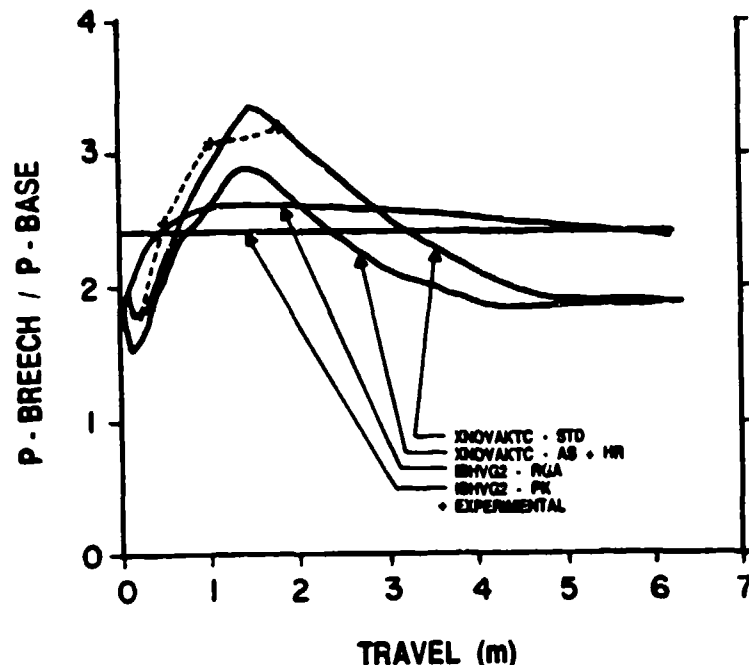


Figure 12. Code-Calculated and Experimental Breech/Base Pressure Ratio Versus Travel Curves.

Figures 13 and 14 display experimental pressure-time curves for the two firings conducted using aluminum slugs. While propellant loading was not identical for the two rounds (a difference in the quantity and dimensions of the small amount of sheet stock used to supplement the stick propellant to achieve maximum loading density), it is unclear whether this was enough to account for the observed difference in performance. No attempt was made to model the difference (the total charge was assumed to be stick propellant); however, use of the resistance profile arbitrarily determined to match Round 5 of the initial

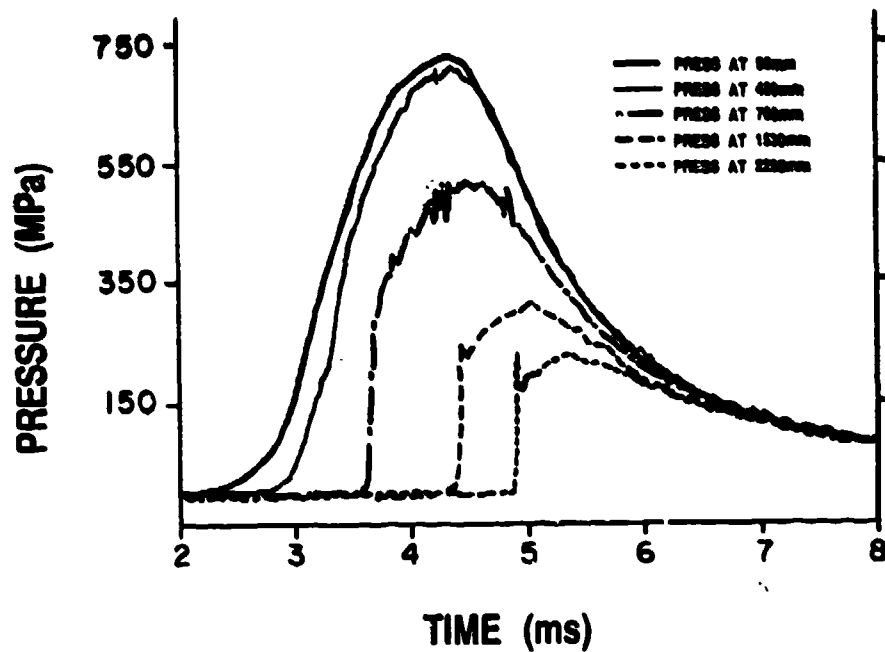


Figure 13. Experimental Pressure-Time Curves for Round 1 of Second Phase Firing Series.

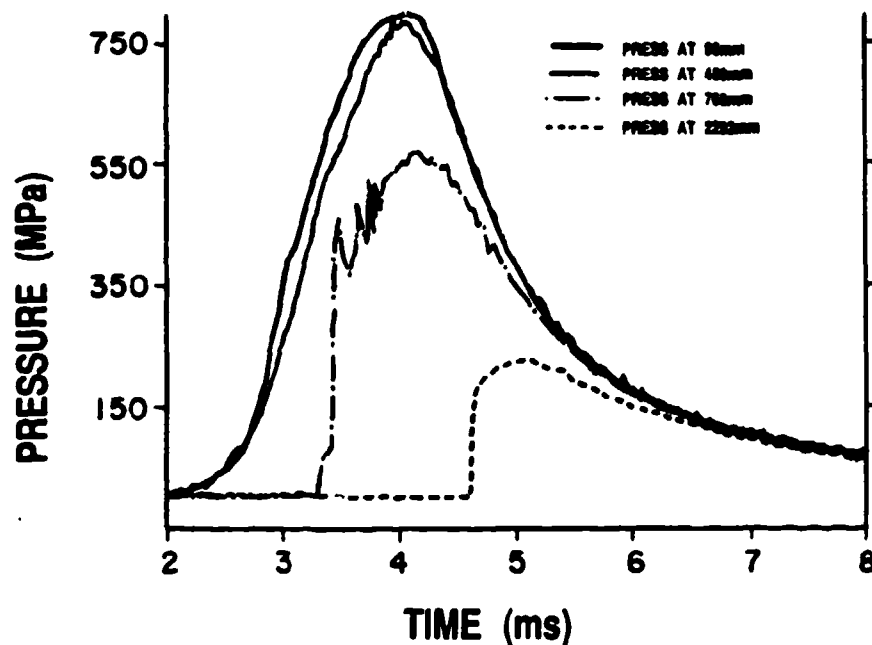


Figure 14. Experimental Pressure-Time Curves for Round 2 of Second Phase Firing Series.

series led to similarly good agreement in modeling the second phase firings, as evidenced by the simulated pressure-time curves shown in Figure 15. Corresponding projectile travel versus time data for theory and experiment are plotted in Figure 16.

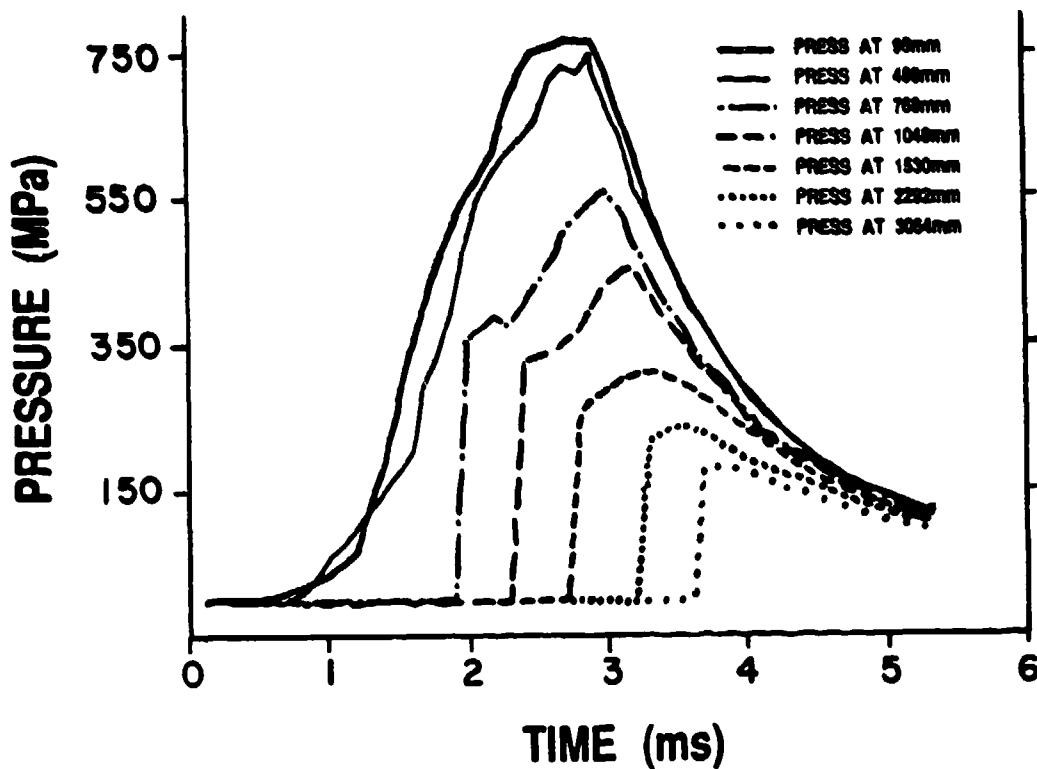


Figure 15. XNOVAKTC Simulation of Pressure-Time Curves for Rounds 1 and 2 of Second Phase Firing Series.

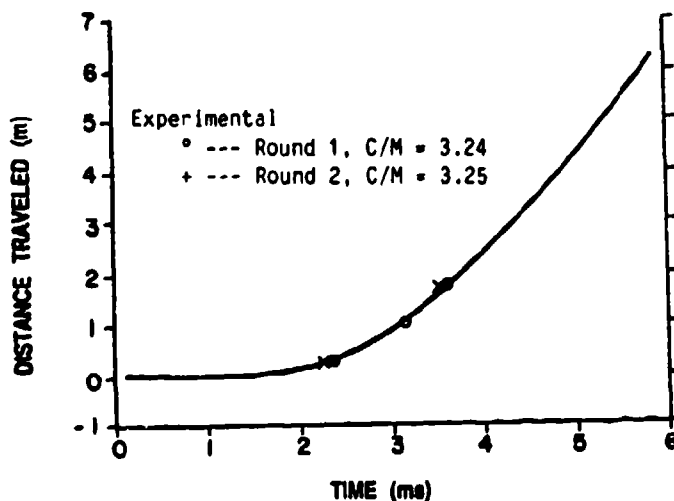


Figure 16. Experimental and Simulated Travel-Time Curves for Rounds 1 and 2 of Second Phase Firing Series.

All of the earlier comments pertaining to Round 5 apply equally well to these rounds. No significant change appears to have resulted from use of the aluminum round, for which use of the high resistance profile has little motivation. Certainly, some continued juggling of inputs (e.g., higher low-pressure burning rates to speed up the early part of the cycle and reduced downbore resistance pressures to allow for an increase in downbore acceleration) might well lead to a more acceptable simulation, but little satisfaction is gained from such an approach.

3.2 Future Plans.

Efforts are continuing on techniques to evaluate inbore radar data to provide a more detailed comparison of predicted and observed inbore trajectories. From this analysis, we hope to determine whether the current disparity between theory and experiment is caused primarily by the use of incorrect input data or whether there exists a more fundamental problem associated with the hydrodynamic description on which the code is based, which manifests itself particularly in the high velocity regime. Simplifications of the propulsion system, such as elimination of the combustible case, will be pursued in future firings. Some improvements in instrumentation will also be sought, as all pressure gages at the two locations nearest the muzzle were destroyed apparently by transverse motion of the tube on nearly every firing. Finally, it is intended to complete an experimental data base in the 120-mm tube for C/M's up to 5, probably a practical limit for conventional solid propellant guns, even in hypervelocity applications.

4. CONCLUSIONS

The current study clearly demonstrates that launch masses as high as 3 kg were propelled to velocities of about 2.3 km/s from a 120-mm gun tube operating at conventional pressures. Indeed, velocities as high as 2.5 km/s could be obtained via conventional solid propellant gun techniques, albeit with a large increase in peak chamber pressure.

Simulation of this performance with existing lumped-parameter and two-phase flow interior ballistic codes using input data bases reflecting best available values for propellant thermochemistry, burning rates, and projectile bore resistance data was not satisfactory. The lumped-parameter code overpredicted peak pressure and muzzle velocity by 13% and 10% respectively, while the two-phase flow code underpredicted peak pressure by 10% and overpredicted muzzle velocity by 3%.

A modified data base with an increase in bore resistance, the magnitude of which roughly mimicked the pressure-travel curve, led to a significant improvement, with simulations of peak pressure and muzzle velocity both falling within 1% of measured values. Calculations of peak downbore pressures were in

of pressurization and the motion of the projectile, however, lagged reality by a little over a tenth of a millisecond at the time of peak pressure, with the disparity approaching half a millisecond at muzzle exit.

Resolution of the above discrepancies between theory and experiment should be pursued to determine whether a fundamental limitation exists in the hydrodynamic treatment in current two-phase flow codes.

5. ACKNOWLEDGMENTS

The authors wish to acknowledge Dr. Thomas Minor and Mr. Frederick Robbins of the Applied Ballistics Branch, Ballistic Research Laboratory, for their significant contributions to initial planning of this effort and for their expert advice throughout its execution. Dr. George Keller, also of the Applied Ballistics Branch, is to be commended for his much appreciated efforts to provide graphical output for the XKTC code. Mr. William Donavon of the Mechanics and Structures Branch is gratefully acknowledged for his efforts in the design of the polypropolux projectiles used in the first phase of testing and his consultative advice on the gage/gun interactions during both phases of testing. Personnel responsible for all phases of the test setup, instrumentation and firing of the weapon and recording the data which included Messrs. J. Bowen, J. Colburn, J. Hewitt, and J. Tuerk of the Applied Ballistics Branch, and Messrs. R. May, D. Meier, and S. Little of Applied Concepts Corporation are acknowledged for their usual high level of cooperation and support at the branch's Sandy Point Firing Facility. Finally, the authors are grateful to Messrs. E. Rapacki and R. Mudd of the Terminal ballistics Division for their helpful and useful suggestions for improving the report.

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APPENDIX A - Propellant Description Sheets

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PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-2a
AR 335-15

COMPOSITION

PROPELLANT, JA-2, 19 PERFORATION STICK

DA LOT NUMBER

RAD-PE-792-38

SPECIFICATION

DDO-P-64035 AND SMCR-EN DTD 8-6-87

PACKED AMOUNT

1400 LB

MFG AT

RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.

CONTRACT NUMBER

DAAA09-86-Z-0003

PRELIMINARY

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

B95191, B95192, B95193, B95194, B95195, B95197

NITROGEN CONTENT

MAX %

MIN %

AVG 13.08 %

KI STARCH

(65.5°C)

MIN

MIN

45+ MIN

STABILITY (134.5°C)

MIN

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

CONSTITUENT	PERCENT	PERCENT	PERCENT	TESTS	FORMULA	ACTUAL
	FORMULA	TOLERANCE	MEASURED			
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	NF 1 H
DIETHYLENE GLYCOL DINITRATE	24.80	+/- 1.50	24.33			
ACAROT II	0.70	+/- 0.20	0.68	TALIANI:		
MAGNESIUM OXIDE	0.05	- 0.02	0.05	SLOPE AT 100 mmHg	<1 mmHg/min	0.297
GRAPHITE	0.05	- 0.02	0.04	HOE, cal/g	1120 NOM.	1115
TOTAL	100.00		100.00			
MOISTURE CONTENT	0.5	+/- 0.3	0.3	ABSOLUTE DENSITY, g/cc	1.56 MIN	1.59
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	RELATIVE					UNIFORMITY BY	
			QUICKNESS	FORCE					MEAN VARIATION, %	
					SPECIFICATION	DIE	FINISHED		SPEC	ACTUAL
		+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	0.567	N/A	1.49
		-40	101.65	97.46	PERF (d)	0.039 NOM	0.037	0.036		
STD	PE-472-138	+90	100.00%	100.00%	WEB				DATES	
REMARKS FIRED IN NOMINAL SIZE 700cc CLOSED BOMB AT 0.2 g/cc LOADING DENSITY					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	
TYPE OF PACKING CONTAINER BOX, FIBERBOARD, PPP-B-636J; BAG, BARRIER, MIL-B-117E; BOX, WOOD, MIL-B-242/G					D:d	N/A	N/A	15.58	FORWARDED	

REMARKS

SIGNATURE OF CONTRACTOR'S REPRESENTATIVE

SIGNATURE OF GOVERNMENT ASSURANCE REPRESENTATIVE

D. M. KINPAIRICK

D. M. Kinpaerrick

PROPELLANT DESCRIPTION SHEET

REPORT CONTROL SYMBOL
EXEMPT-PARA 7-28
AR 335-15

COMPOSITION JA-2 Sheet Stock LOT NUMBER RAD-PE-792-29A
SPECIFICATION TWA R 2114307 Jul 86 PACKED AMOUNT 100 lbs
SMCRA-EN dtd. 7-30-86 : DOD-P-63493 CONTRACT NUMBER
MFG AT RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. DAAA09-86-Z-0003

NITROCELLULOSE

ACCEPTED BLEND NUMBERS
Y 95100, 95101, 95102, 95103

NITROGEN CONTENT		RI STARCH (65.5°C)	STABILITY (134.5°C)
MAX 13.14 %	MIN	MIN	MIN
MIN 12.79 %	MIN	MIN	MIN
AVG 13.11 %	45+ MIN	30+	MIN

EXPLOSION NR

MANUFACTURE OF SOLVENTLESS PROPELLANT

PERCENTAGE REMIX TO WHOLE None

TEMPERATURES °		PROCESS- DRYING	TIME	
FROM	TO		DAYS	HOURS
		N/A		

PROPELLANT COMPOSITION				TESTS OF FINISHED PROPELLANT		STABILITY AND PHYSICAL TESTS	
CONSTITUENT	PERCENT FORMULA	PERCENT TOLERANCE	PERCENT MEASURED	TESTS	FORMULA	ACTUAL	
NITROCELLULOSE	55.50	±2.00	59.01	HEAT	NoCC 40'	NoCC60+'	
NITROGLYCERIN	14.90	±1.00	15.49	NO FUMES	NF 1 hr.	NF 1 hr.	
DIETHYLENE GLYCOL DINITRATE	24.80	±1.50	24.72	FORM OF PROPELLANT	Sheet Stock	Sheet Stock	
AKARDIT II	0.70	±0.2	0.71	*ITALIANI	11.0 Hg/mm		
MAGNESIUM OXIDE	0.05	MAX.	0.04		Siore at 100mm		
GRAPHITE	0.05	MAX.	0.03	NOE	1120.0cal		
MOISTURE	0.5	±0.3	0.27				
TOTAL	100	100	100.00	ABS DENSITY	1.562 g/cc.		
				COMPRESSIBILITY			

CROSSED BOMS

PROPELLANT DIMENSIONS (INCHES)

TEST	LOT NUMBER	TEMP °F	RELATIVE HUMIDITY	PARAMETER	SPECIFICATION	DIE	FINISHED	SPEC	ACTUAL
				LENGTH (L)					
				DIAMETER (D)					
				PERF. DIA. (D)					
STANDARD			100.00%	Sheet Stock					
REMARKS				Thickness	0.050nom		0.0530	PACKED	10-2-86
								SAMPLED	10-2-86
								TEST FINISHED	10-10-86
				LD				OFFERED	
				D-4				DESCRIPTION SHEETS FORWARDED	13 Nov 86

TYPE OF PACKING CONTAINER FIBER DRUMS: 5 @ 20 lbs net.

REMARKS
Chemical specifications were taken from DOD-P-63493. Physical dimensions were given in the SMCRA-EN letter dated 7-30-86.

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SIGNATURE OF CONTRACTOR'S REPRESENTATIVE

E.A. Rivenbark
E.A. Rivenbark

SIGNATURE OF GOVERNMENT QUALITY ASSURANCE REPRESENTATIVE

Ronald H. Brown

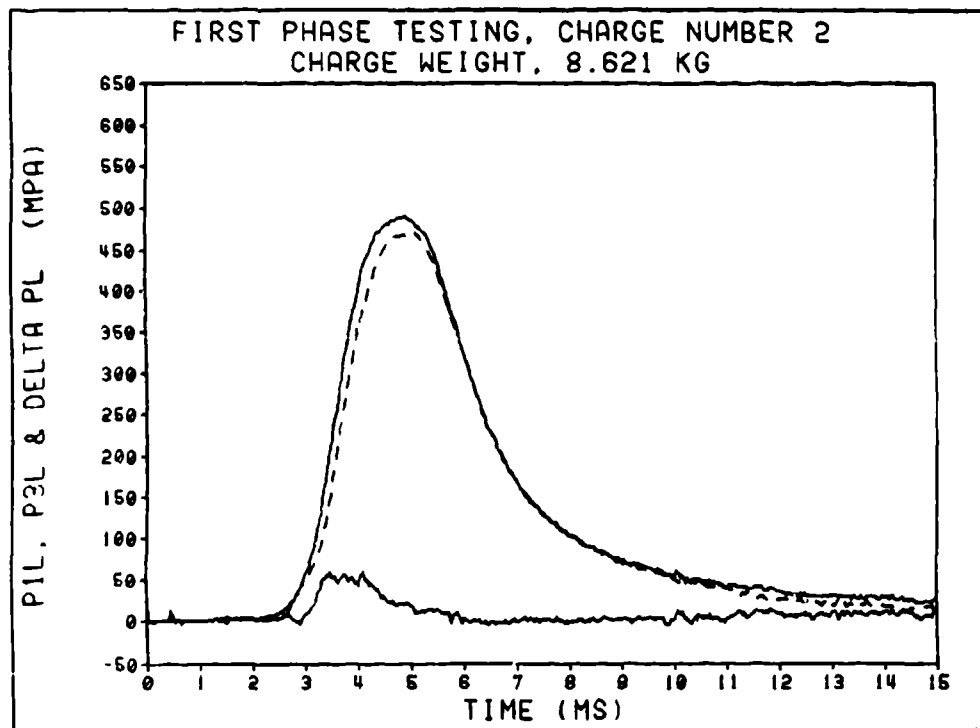
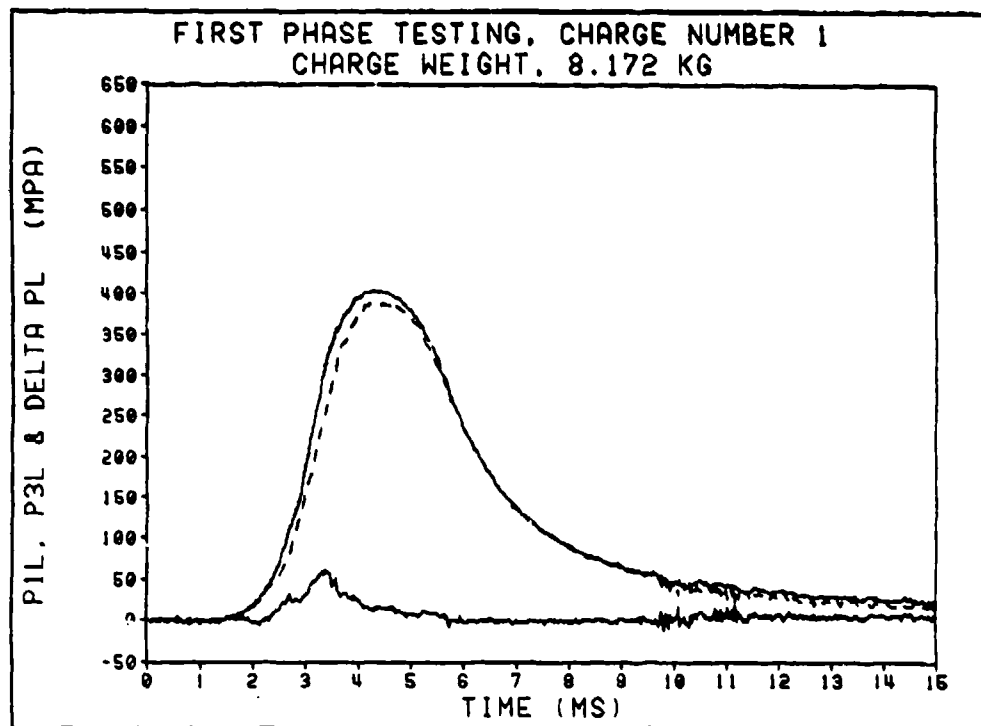
REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-28
AR 335-15

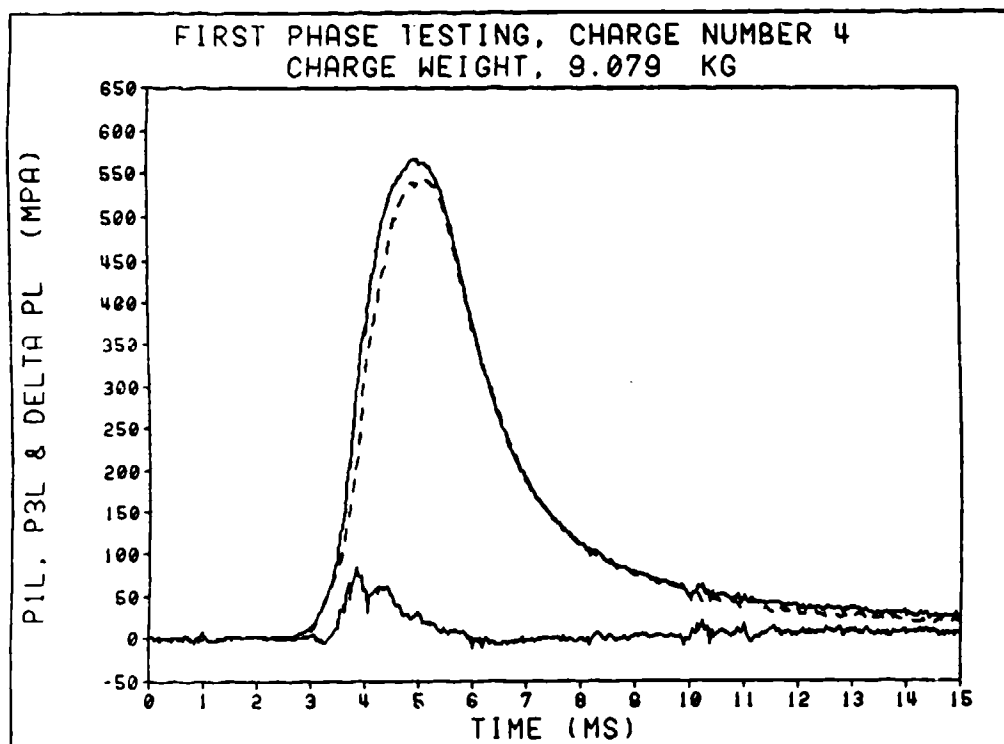
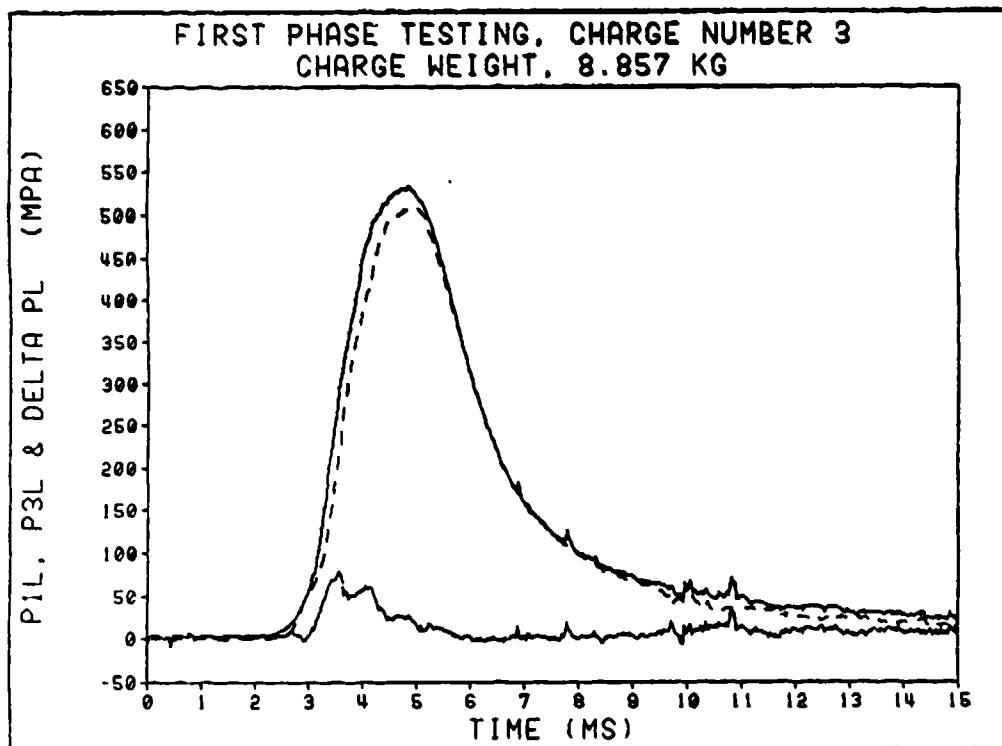
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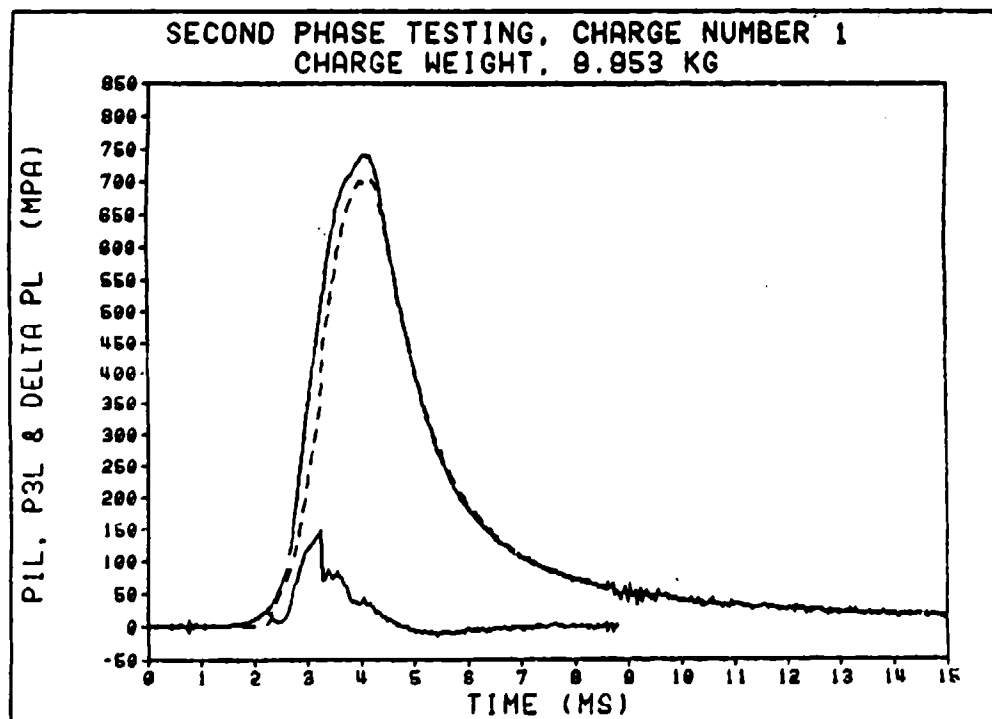
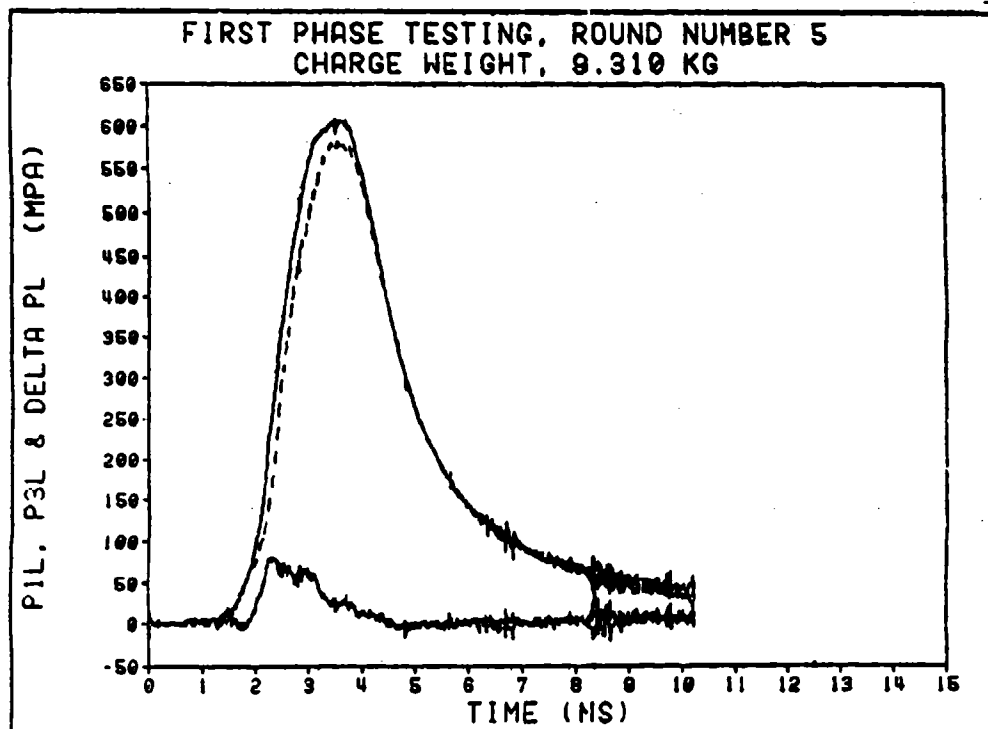
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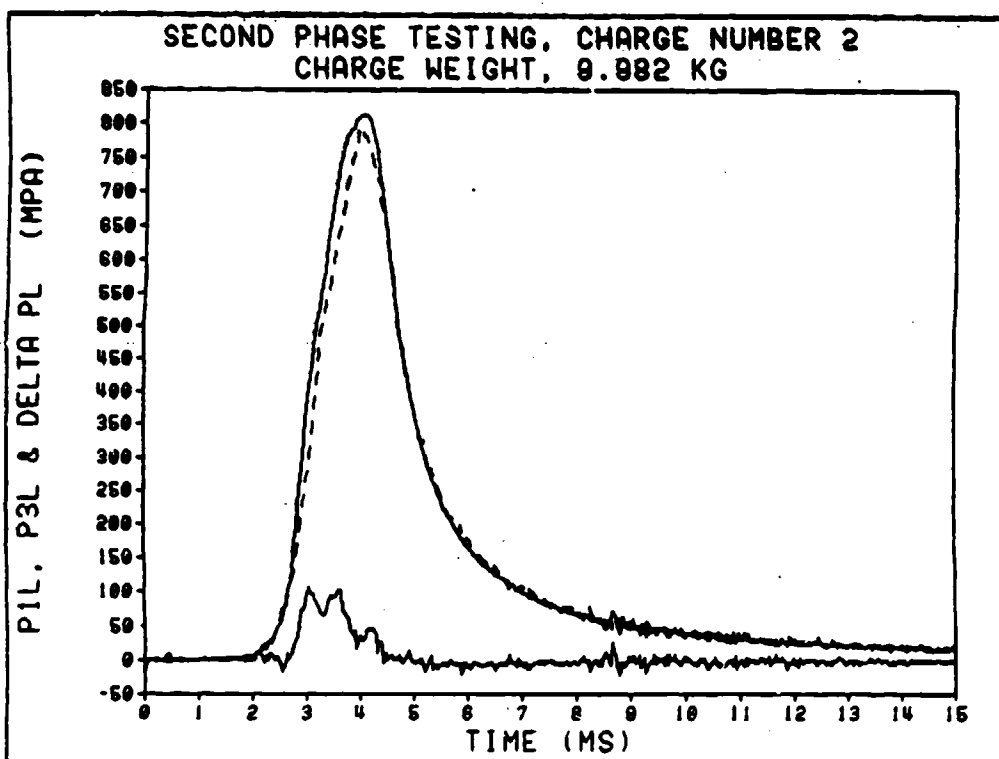
APPENDIX B - Plots of Breech Pressure (Solid Line),
Forward Chamber Pressure (Dashed Line), and
Pressure Difference Versus Time

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APPENDIX C - XNOVAKTC Inputs for Simulations

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CONTROL DATA

LOGICAL VARIABLES:

PRINT T DISK WRITE F DISK READ F
 I.B. TABLE T FLAME TABLE T PRESSURE TABLE(S) T
 ERODIVE EFFECT 0 WALL TEMPERATURE CALCULATION 0
 BED PRECOMPRESSED 0
 HEAT LOSS CALCULATION 1

BORE RESISTANCE FUNCTION 1

SOLID TRAVELING CHARGE OPTION (0=NO,1=YES) 1
 EXPLICIT COMPACTION WAVE(0=NO;1=YES) 0
 CONSERVATIVE SCHEME TO INTEGRATE SOLID-PHASE CONTINUITY EQUATION (0=NO,OLD; 1=YES,NEW) 0
 KINETICS MODE (0=NONE;1=GAS-PHASE ONLY;2=BOTH PHASES) 0
 TANK GUN OPTION (0=NO,1=YES) 1
 INPUT ECHO OPTION 0
 FORWARD BOUNDARY CONDITION (0=CLOSED;1=OPEN;2=ROCKET) 0
 LIQUID TRAVELING CHARGE OPTION(0=NO,1=YES) 0
 GRAIN FRACTURE OPTION(0=NO;1=YES) 0
 GRAIN FRACTURE DATA BASED ON INTRINSIC AVERAGE STRESS
 (0=NO;1=YES) 0

INTEGRATION PARAMETERS

NUMBER OF STATIONS AT WHICH DATA ARE STORED	25
NUMBER OF STEPS BEFORE LOGOUT	3500
TIME STEP FOR DISK START	0
NUMBER OF STEPS FOR TERMINATION	3500
TIME INTERVAL BEFORE LOGOUT(SEC)	0.1000E-02
TIME FOR TERMINATION (SEC)	10.00
PROJECTILE TRAVEL FOR TERMINATION (INS)	246.90
MAXIMUM TIME STEP (SEC)	0.1000E-03
STABILITY SAFETY FACTOR	2.00
SOURCE STABILITY FACTOR	0.0500
SPATIAL RESOLUTION FACTOR	0.0100
TIME INTERVAL FOR I.B. TABLE STORAGE(SEC)	0.1000E-03
TIME INTERVAL FOR PRESSURE TABLE STORAGE (SEC)	0.1000E-03

FILE COUNTERS

NUMBER OF STATIONS TO SPECIFY TUBE RADIUS	6
NUMBER OF TIMES TO SPECIFY PRIMER DISCHARGE	9
NUMBER OF POSITIONS TO SPECIFY PRIMER DISCHARGE	6
NUMBER OF ENTRIES IN BORE RESISTANCE TABLE	6
NUMBER OF ENTRIES IN WALL TEMPERATURE TABLE	0
NUMBER OF ENTRIES IN FORWARD FILLER ELEMENT TABLE	0
NUMBER OF TYPES OF PROPELLANTS	1
NUMBER OF BURN RATE DATA SETS	2
NUMBER OF ENTRIES IN VOID FRACTION TABLE(S)	0 0 0
NUMBER OF ENTRIES IN PRESSURE HISTORY TABLES	8
NUMBER OF ENTRIES IN REAR FILLER ELEMENT TABLE	0

GENERAL PROPERTIES OF INITIAL AMBIENT GAS

INITIAL TEMPERATURE (DEG.R)	529.0
-----------------------------	-------

INITIAL PRESSURE (PSI)	14.7
MOLECULAR WEIGHT (LBM/LBMOL)	28.896
RATIO OF SPECIFIC HEATS	1.4000

GENERAL PROPERTIES OF PROPELLANT BED

INITIAL TEMPERATURE (DEG.R)	529.0
MINIMUM IMPACT VELOCITY FOR EXPLICIT COMPACTION WAVE (IN/SEC)	100000000.

PROPERTIES OF PROPELLANT 1

PROPELLANT TYPE	JA2 19P LOT 792-38
MASS OF PROPELLANT (LBM)	22.0000
DENSITY OF PROPELLANT (LBM/IN**3)	0.0576
FORM FUNCTION INDICATOR	9
OUTSIDE DIAMETER (INS)	0.5610
INSIDE DIAMETER (INS)	0.0360
LENGTH (INS)	1.5000
NUMBER OF PERFORATIONS	19.
SLOT WIDTH (NFORM=11) OR SCROLL DIA. (NFORM=13) (INS)	0.0000
PROPELLANT STACKED (0=NO,1=YES)	1
ATTACHMENT CONDITION (0=FREE,1=ATTACHED TO TUBE, 2=ATTACHED TO PROJECTILE)	0
BOND STRENGTH (LBF) (N.B. ZERO DEFAULTS TO INFINITY)	0.000000
GRAIN INHIBITED ON OUTER SURFACE (0=NO,1=YES)	0

RHEOLOGICAL PROPERTIES

SPEED OF COMPRESSION WAVE IN SETTLED BED (IN/SEC)	41754.
SETTLING POROSITY	1.0000
SPEED OF EXPANSION WAVE (IN/SEC)	41754.
POISSON RATIO (-)	0.5000

SOLID PHASE THERMOCHEMISTRY

MAXIMUM PRESSURE FOR BURN RATE DATA (LBF/IN**2)	6000.
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC/PSI**BN)	0.1500E-01
BURNING RATE EXPONENT	0.5750
MAXIMUM PRESSURE FOR BURN RATE DATA (LBF/IN**2)	100000.
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC/PSI**BN)	0.1531E-02
BURNING RATE EXPONENT	0.8380
BURNING RATE CONSTANT (IN/SEC)	0.0000
IGNITION TEMPERATURE (DEG.R)	800.0
THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	0.2770E-01
THERMAL DIFFUSIVITY (IN**2/SEC)	0.1345E-03
EMISSION FACTOR	0.600

GAS PHASE THERMOCHEMISTRY

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM) .20372E+08
 MOLECULAR WEIGHT (LBM/LBMOL) 24.8226
 RATIO OF SPECIFIC HEATS 1.2268
 COVOLUME 26.9800

LOCATION OF PACKAGE(S)

PACKAGE	LEFT BODY(INS)	RIGHT BODY(INS)	MASS(LBM)	INNER RADIUS(IN)	OUTER RADIUS(IN)
1	0.750	21.800	22.000	0.000	0.000

PROPERTIES OF PRIMER

CHEMICAL ENERGY RELEASED IN BURNING(LBF-IN/LBM) 0.9968E+07
 MOLECULAR WEIGHT (LBM/LBMOL) 30.9300
 RATIO OF SPECIFIC HEATS 1.2210
 SPECIFIC VOLUME OF SOLID(IN**3/LBM) 23.0000

PRIMER DISCHARGE FUNCTION (LBM/IN/SEC)

POS.(INS)	0.00	0.74	0.75	12.00	12.10	21.30
TIME(SEC)						
0.000	0.00	0.00	0.00	0.00	0.00	0.00
0.250E-03	50.00	50.00	0.00	0.00	0.00	0.00
0.525E-02	50.00	50.00	0.00	0.00	0.00	0.00
0.550E-02	0.00	0.00	0.00	0.00	0.00	0.00
0.560E-02	0.00	0.00	0.00	0.00	0.00	0.00
0.575E-02	0.00	0.00	0.00	0.00	0.00	0.00
0.600E-02	0.00	0.00	0.00	0.00	0.00	0.00
0.625E-02	0.00	0.00	0.00	0.00	0.00	0.00
0.725E-02	0.00	0.00	0.00	0.00	0.00	0.00

PARAMETERS TO SPECIFY TUBE GEOMETRY

DISTANCE(IN)	RADIUS(IN)
0.000	3.000
18.800	3.000
21.800	2.360
22.960	2.360
23.370	2.360
208.350	2.360

BORE RESISTANCE TABLE

POSITION(INS)	RESISTANCE(PSI)
21.800	100.
22.000	100.
22.500	1000.

23.100	100.
40.000	100.
208.350	100.

THERMAL PROPERTIES OF TUBE

THERMAL CONDUCTIVITY (LBF/SEC/DEG.R)	7.770
THERMAL DIFFUSIVITY (IN**2/SEC)	0.2280E-01
EMISSION FACTOR	0.700
INITIAL TEMPERATURE (DEG.R)	529.00

PROJECTILE AND RIFLING DATA

INITIAL POSITION OF BASE OF PROJECTILE (INS)	0.000
MASS OF PROJECTILE (LBM)	0.000
POLAR MOMENT OF INERTIA (LBM-IN**2)	0.000
ANGLE OF RIFLING (DEG)	0.000

POSITIONS FOR PRESSURE TABLE STORAGE

3.7500	19.0000	30.0000	41.0000	60.0000	90.0000	120.0000	19.0000
LOCATION RELATIVE TO TUBE (0) OR REAR OF AFTERBODY (1)							

0	0	0	0	0	0	0	0
---	---	---	---	---	---	---	---

TANK GUN OPTION DATA

NUMBER OF DATA TO DESCRIBE AFTERBODY	0
TUBE SURFACE SOURCE (0=NONE,1=TABULAR,2=MODELED)	2
CENTERLINE SOURCE (0=NONE,1=TABULAR,2=MODELED)	0
AFTERBODY SURFACE SOURCE (0=NONE,1=TABULAR,2=MODELED)	0
NUMBER OF ENDWALL DATA SETS	0
NUMBER OF PERMEABILITY DATA SETS	0
NUMBER OF REACTIVITY DATA SETS	0
NUMBER OF SEGMENTS ON TUBE SURFACE SOURCE	1
NUMBER OF SEGMENTS ON CENTERLINE SURFACE SOURCE	0
NUMBER OF SEGMENTS ON AFTERBODY SURFACE SOURCE	0
CONTROL CHARGE PRESENT (0=NO;1=YES)	0
NUMBER OF DATA TO DEFINE EXTERNAL GEOMETRY OF	
CONTROL CHARGE CHAMBER	0
CONTROL CHARGE DETERRED (0=NO;1=YES)	0

DESCRIPTION OF TUBE SURFACE SOURCE

NUMBER OF DATA TO DESCRIBE THICKNESS OF LAYER	2
NUMBER OF DATA TO DESCRIBE DENSITY OF SEGMENT 1	4
NUMBER OF DATA TO DESCRIBE DENSITY OF SEGMENT 2	0
NUMBER OF DATA TO DESCRIBE DENSITY OF SEGMENT 3	0

THICKNESS OF REACTIVE LAYER

AXIAL POS.(IN)	THICKNESS(IN)	SEGMENT
0.000	0.145	1
18.000	0.145	1

DENSITY OF REACTIVE LAYER

DENSITY(LBM/IN**3)	PRESSURE(PST)
0.0295	15.
0.0455	11000.
0.0497	25000.
0.0548	100000.

NUMBER OF DATA TO DESCRIBE BURN RATE 2

BURN RATE DATA

MAX.PRESS(PST)	COEFF(IN/SEC/PST**BN)	EXPONENT
10000.	0.13100E-03	1.3010
100000.	3.9500	0.1761

BURN RATE ADDITIVE CONSTANT (IN/SEC)	0.0000
IGNITION TEMPERATURE (R)	800.0
THERMAL CONDUCTIVITY (LBF/SEC/R)	0.2770E-01
THERMAL DIFFUSIVITY (IN**2/SEC)	0.1345E-03
EMISSION FACTOR(-)	0.000

CHEMICAL ENERGY (LBF-IN/LBM)	.93000E+07
MOLECULAR WEIGHT (LBM/LBMOL)	22.3900
RATIO OF SPECIFIC HEATS (-)	1.2500

T.C. CONTROL DATA

IDEAL BURN RATE LAW	0
CONTINUUM MODEL OF UNREACTED PROPELLANT	0
NUMBER OF PROPELLANTS	1
PROPELLANT WALL FRICTION PARAMETER	0
NUMBER OF ENTRIES IN PROJECTILE BORE	
RESISTANCE TABLE	6
INDICATOR FOR AIR RESISTANCE	1
NUMBER OF ENTRIES IN ORBITATOR FRICTION	
TABLE	0

INTEGRATION PARAMETERS

MAXIMUM NUMBER OF MESH POINTS	25
MINIMUM MESH SIZE (IN)	0.001

PROJ. AND TRAV. CHARGE PROPERTIES

T.C. DIAMETER (IN)	4.720
INITIAL POSITION OF REAR FACE OF PROPELLANT (IN)	21.800
PROJECTILE MASS (LBM)	6.80000
CHARGE MASS (LBM)	0.000
MAXIMUM PRESSURE IN UNREACTED PROPELLANT (PSI), IF IDEAL=2	0.
MAXIMUM MACH NUMBER OF REACTION PRODUCTS	0.999
MAXIMUM ACCELERATION OF PROJECTILE (GRAV)	0.

RATIO OF SPECIFIC HEATS OF AIR (-)	1.4000
PRESSURE OF AIR IN BARREL (PSI)	14.700
TEMPERATURE OF AIR IN BARREL (DEG.R)	529.0
MOLECULAR WEIGHT OF AIR IN BARREL (LBM/LBMOL)	28.8960

RESISTIVE PRESSURE DUE TO OBSTURATOR

TRAVEL (IN)	RESISTIVE PRESSURE (PSI)
0.000	100.
0.200	100.
0.700	2000.
1.300	4000.
18.200	5500.
186.550	2000.

PROPERTIES OF PROPELLANT NUMBER 1

RATIO OF SPECIFIC HEATS (-)	1.200
COVOLUME (IN**3/LBM)	30.000
MOLECULAR WEIGHT (LBM/LBMOL)	25.000
CHEMICAL ENERGY OF PROPELLANT (LBF-IN/LBM)	10000000.
DENSITY OF PROPELLANT (LBM/IN**3)	0.0572
INITIAL MASS (LBM)	0.0000
IGNITION DELAY (MSEC)	100.000
DELAY FOR TRANS. TO FULL BURN RATE (MSEC)	100.000
BURNING RATE ADDITIVE CONSTANT (IN/SEC)	0.0000
BURNING RATE PRE-EXPONENTIAL FACTOR (IN/SEC-PSI**BN)	1.000000
BURNING RATE EXPONENT (-)	1.0000
TC GRAIN LENGTH (IN)	0.000

LENGTH BRECH TO PROJECTILE BASE (IN) 21.800

BURN RATE FORMAT (0=EXP;1=TABULAR) 0
BURN RATE DEPENDENCE (0=PRE;1=STRESS) 0

VARIABLE BURN RATE DATA

STEP	INTERCEPT	COEFFICIENT	EXPONENT	Z
1	0.000	1.00000	1.0000	0.0000

SETTLING POROSITY AT REFERENCE COMPOSITION HAS BEEN DEFAULTED TO 0.28187
TO AVOID INITIAL BED COMPACTION OF PROPELLANT TYPE 1

EQUIVALENT INTBAL DATA

PROJECTILE TRAVEL(IN)	246.900
CHAMBER VOLUME(IN**3)	599.572
GUN MASS(LBM)	0.100E+21
GUN RES. FAC.	0.000
ELEV. ANGLE(DEG)	0.000
PROJECTILE MASS(LBM)	0.000

PROJECTILE TRAV. (IN)	RESISTANCE(PSI)
-----------------------	-----------------

0.000	100.000
0.200	100.000
0.700	1000.000
1.300	100.000
18.200	100.000
186.550	100.000

VEL. THRESHOLD FOR DYN. RES.(F/S)	27.000
VEL. DEPENDENCE ON CHARGE WEIGHT(F/S/LBM)	0.000
ESTIMATED MUZZLE VELOCITY(F/S)	0.000
N.B. USE VALUE FROM SUMMARY TABLE. INTBAL WILL NOT ACCEPT ZERO	
BORE AREA(IN**2)	17.497
AIR DENSITY(LBM/FT**3)	0.000
IGNITER MASS(LBM)	0.1477
FLAME TEMPERATURE(K)	2040.535
RATIO OF SPECIFIC HEATS(-)	1.2210
IMPETUS(LBF-IN/LBM)	2202827.9

INITIAL CHARGE WEIGHT(LBM)	22.000
FINAL CHARGE WEIGHT(LBM)	22.000
CHARGE WEIGHT INCREMENT(LBM)	1.000
FLAME TEMPERATURE(K)	3434.921

RATIO OF SPECIFIC HEATS(-)	1.2268
IMPETUS(LBF-IN/LBM)	4620467.8
INITIAL TEMPERATURE(K)	293.9
DENSITY(LBM/IN**3)	0.05763
COVOLUME(IN**3/LBM)	26.980

COEFF(IN/S/PSI**N)	EXPONENT(-)	UPPER PRES. LIM. (PSI)
0.1500E-01	0.5750	6000.
0.1531E-02	0.8380	0.1000E+06

LENGTH OF GRAIN(IN)	1.5000
EXTERNAL DIAMETER(IN)	0.5610
CENTER PERF. DIAMETER(IN)	0.0360
OUTER PERF. DIAMETER(IN)	0.0360
DIST. BETWEEN PERF. CENTERS(IN)	0.1492
OFFSET(IN)	0.0000
ANGLE(DEG)	0.0000

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