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AFATL-TR-72-64

ENCAPSULATED LIQUID MONOPROPELLANT AMMUNITION DEMONSTRATION

THIOKOL CHEMICAL CORPORATION

TECHNICAL REPORT AFATL-TR-72-64

MARCH 1972

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Encapsulated Liquid Monopropellant Ammunition Demonstration

Stanley V. Peterson

FOREWORD

This report documents work performed during the period from August 1969 to June 1970 by Thiokol Chemical Corporation, Wasatch Division, Brigham City, Utah. Work was performed under the technical direction of John A. Peterson and Robert K. Lund with K. D. Holmgren and W. L. Corwin as program managers. Thiokol conducted this program under Contract F08635-70-C-0006 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. Mr. Otto K. Heiney and Mr. Ralph Blair (DLD) served as program monitors for the Armament Laboratory.

This technical report has been reviewed and is approved.

LEMUEL D. HORTON, Colonel, USAF
Chief, Guns and Rockets Division

ABSTRACT

Ammunition containing bulk loaded liquid monopropellant has the desirable characteristics of low flame temperature, high energy, reduced smoke and flash, and reduced fouling and longer barrel life. However, liquid monopropellants do not burn stably under the conditions existing in bulk loaded cartridges. High and erratic pressures are accompanied by high frequency, high amplitude pressure excursions. Extensive experimentation has not solved this problem. The results of this study showed that the problems of bulk loaded monopropellant can be overcome by encapsulation of the monopropellant into small spheres. Test firings in 7.62 mm NATO cartridges demonstrated good repeatability, and standard velocities were obtained while using polyethylene glycol gels of encapsulated alkyl nitrates plus ammonium nitrate. Standard velocities were difficult to achieve with the 7.62 mm cartridge when only using current encapsulated alkyl nitrates because of low packing fractions. The use of bimodal encapsulated propellants did not provide the expected performance gains. The small capsules, as currently fabricated, would not burn because of (1) high permeation losses during the drying cycle of the fabrication process and (2) comparatively thick, strong capsule walls which inhibit fracturing during firing.

Near standard velocities were achieved with 20 mm rounds using only encapsulated alkyl nitrate propellant. It is recommended that further research be completed to increase performance by using capsules containing gelled alkyl nitrates encapsulated with ammonium nitrate.

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SECTION I
INTRODUCTION

Rapid fire weapons currently in use have a relatively short barrel life. This short life results both from the high firing rates and the high solid propellant combustion temperatures. The use of propellant having a lower combustion temperature should significantly increase barrel life and reduce the weapon system cost.

Liquid monopropellants, because of their high energy and low flame temperature, have been considered and tried as possible replacements for conventional gun propellants. Various investigations have shown that the liquid monopropellants not only have low flame temperatures but also reduced smoke and flash with attendant advantages of reduced fouling and longer barrel life.

One unequivocal disadvantage preventing exploitation of liquid monopropellants is that they do not burn stably. High and erratic pressures damage the guns, cause erratic behavior of gas-operated weapons, and result in large muzzle velocity variations.

Extensive theoretical treatments of the hydrodynamics of bulk loaded liquid propellant guns have shown that gross instabilities characterize the normal behavior of liquids in a gun environment. Bulk loaded liquids are not predictable from the instant of ignition because, in contrast to solid propellant, the characteristic burning liquid dimensions corresponding to initial web size and grain form are variable and controlled by vagaries in the primer functioning and the system geometry.

Further, it has been shown theoretically and confirmed experimentally that a fluid accelerated by a less dense fluid will be characterized by an inherent instability between the surfaces of the two fluids. Also, theory predicts that the disturbances on the interface between the two fluids (propellant gas and unburned liquid) will grow exponentially with time. These so-called Taylor instabilities have been verified in laboratory experimentation wherein it was also shown that the initial disturbance grows until gas cavities penetrate the liquid and propagate through.

The so-called Helmholtz instability will inevitably occur whenever gas bubbles penetrate through the liquid. This instability promotes the growth of small disturbances on the interface between two fluids having a relative velocity.

Although the fluid dynamics of the system where a liquid monopropellant is accelerated and consumed by its own combustion gas has been treated theoretically, the instabilities characterizing the process and the many analytically untractable variables indicate that bulk loaded liquid propellants cannot be easily controlled.

Liquid encapsulation technology, however, has yielded substances which enable control of liquid propellants so that the other advantages can be realized. Encapsulated propellants give a very repeatable and uniform initial surface area and web thickness, corresponding closely to conventional ball propellants in form and handling ease. By their nature, these propellants exhibit a more stable behavior than the bulk liquids as the conditions for instabilities are absent.

The initial program[1] demonstrated the feasibility of using encapsulated liquid propellants in 7.62 mm NATO ammunition. In this study, control of pressure-time traces with liquid monopropellant was apparently much superior to that of all prior experimentation. Good progress was also achieved in encapsulation technology. The loading fraction of the liquid monopropellant was steadily increased.

Although the feasibility and advantages of encapsulated monopropellant in gun ammunition were demonstrated, it was apparent that to achieve standard or higher than standard projectile velocities, the amount of available energy of encapsulated monopropellant enclosed in the standard cartridge case would have to be increased. The method chosen to achieve this goal was to increase the packing fraction of the monopropellant by the use of bi- or trimodal capsule distributions with existing alkyl nitrate propellants. The use of a bimodal mixture of capsules in the cartridge case presented a promising method of increasing the packing fraction in the cartridge case. When using bimodal mixtures, the small diameter capsules fill the interstitial voids between the large diameter capsules.

[1] Lund, Robert K.: Encapsulated Liquid Monopropellant Ammunition Feasibility Study, AFATL-TR-69-27, Thiokol Chemical Corporation, May 1969.

SECTION II
PROGRAM OBJECTIVE

The program objective was to demonstrate that standard velocities could be achieved using liquid monopropellants while maintaining reproducibility and control. The objective was to be achieved by improving the monopropellant loading fraction of each capsule and by making small capsules for use as an interstitial fill. Bimodal mixtures of the large and small capsules were to be evaluated to determine if adequate capsule packing fractions could be obtained and to determine if the rounds continued to demonstrate repeatable velocities. Effort was to be continued to fabricate and evaluate capsules with more energetic walls.

SECTION III
TECHNICAL APPROACH

An increase in projectile velocity can be achieved by increasing the ratio between the propellant charge and the projectile weight. The following steps were taken to increase the total propellant weight packed in the cartridge case.

1. Increase the monopropellant loading fraction of each capsule.

2. Fabricate small (50μ to 100μ diameter) capsules for use as an interstitial fill.

3. Fvaluate the bimodal mixture of small and large capsules to determine if adequate capsule packing fractions were obtained.

4. Fabricate capsules with more energetic walls.

SECTION IV
PROPELLANT

A. ENCAPSULATED MONOPROPELLANT

The encapsulated monopropellant used during this program consisted of a mixture of 60 percent ethyl nitrate and 40 percent normal propyl nitrate. The basic constituent of the capsule wall was polyvinyl alcohol with carrageenan used as a gelling agent.

Capsules were fabricated in two general sizes: large ones ranging from 840 to 1,410 microns in diameter and small ones ranging from 50 to 354 microns in diameter. A summary of the propellant samples tested by Thiokol is presented in Table I.

B. EQUIPMENT

Two types of laboratory equipment were used in preparing the alkyl nitrate capsules. The centrifugal extrusion encapsulation device consisted of a rotating head with concentric orifice nozzles directed radially outward from the vertical axis of rotation. Monopropellant was pumped into the inner chamber and flowed through tubes which project into orifices located about the periphery of the head (Figure 1).

The shell material, in fluid form, was gear pumped into the head and flowed through the annuli formed by the orifices and filler tubes. In effect, this extruded the fluid "rods" of monopropellant encased in sheaths of fluid shell material. These "rods" broke into individual capsules while being projected to a collection area surrounding the base of the encapsulation device. The encapsulation head was about 7 ft above the collection area, and the capsules were firm enough when they reached the collection sheet that they did not rupture.

The encapsulation head, shell lines, and pump were heated (50° to 65°C) since the carrageenan, when warm, is of low viscosity but forms a firm gel on cooling. Without carrageenan in the solution, higher temperatures and higher polyvinyl alcohol content solutions would be necessary, and poor payloads would result.

Hardening of the fluid capsule shell was accomplished by using an aqueous shell formulation containing a gelling agent which hardened by a combination of cooling and drying. The capsule collection area for these runs was covered with a sheet of polyethylene film which was dusted with a thin layer of hydrophobic starch to minimize sticking and agglomeration. The partially dried capsules were then transferred to a fluidized bed dryer to complete the drying process.

TABLE I. TEST PROPELLANTS

Lot No.	Monopropellant (percent)	Capsule Diameter (microns)	Amount
4-887	88.9	840-1,410	300 gm
4-891	94.0	30-100	195 gm
4-925	87.7	840-1,410	5 lb
4-933	86.8	840-1,410	5 lb
4-935	53.4	105-250	100 gm
4-936	53.4	250-297	28 gm
4-942	41.1	<105	8 gm
4-943	42.3	105-250	33 gm
4-944	52.6	<105	25 gm
4-945	46.4	105-250	118 gm
4-954	46.9	105-250	13 gm
4-955	59.7	250-354	27 gm
4-956	46.3	105-250	58 gm
4-957	51.4	250-354	48 gm
4-958	34.4	<105	14 gm
4-959	41.4	105-250	76 gm
4-960	46.0	250-354	48 gm
4-968	30.2	<250	80 gm
4-969	30.2	250-354	108 gm
4-970	30.7	<250	134 gm
4-971	30.7	<250	40 gm

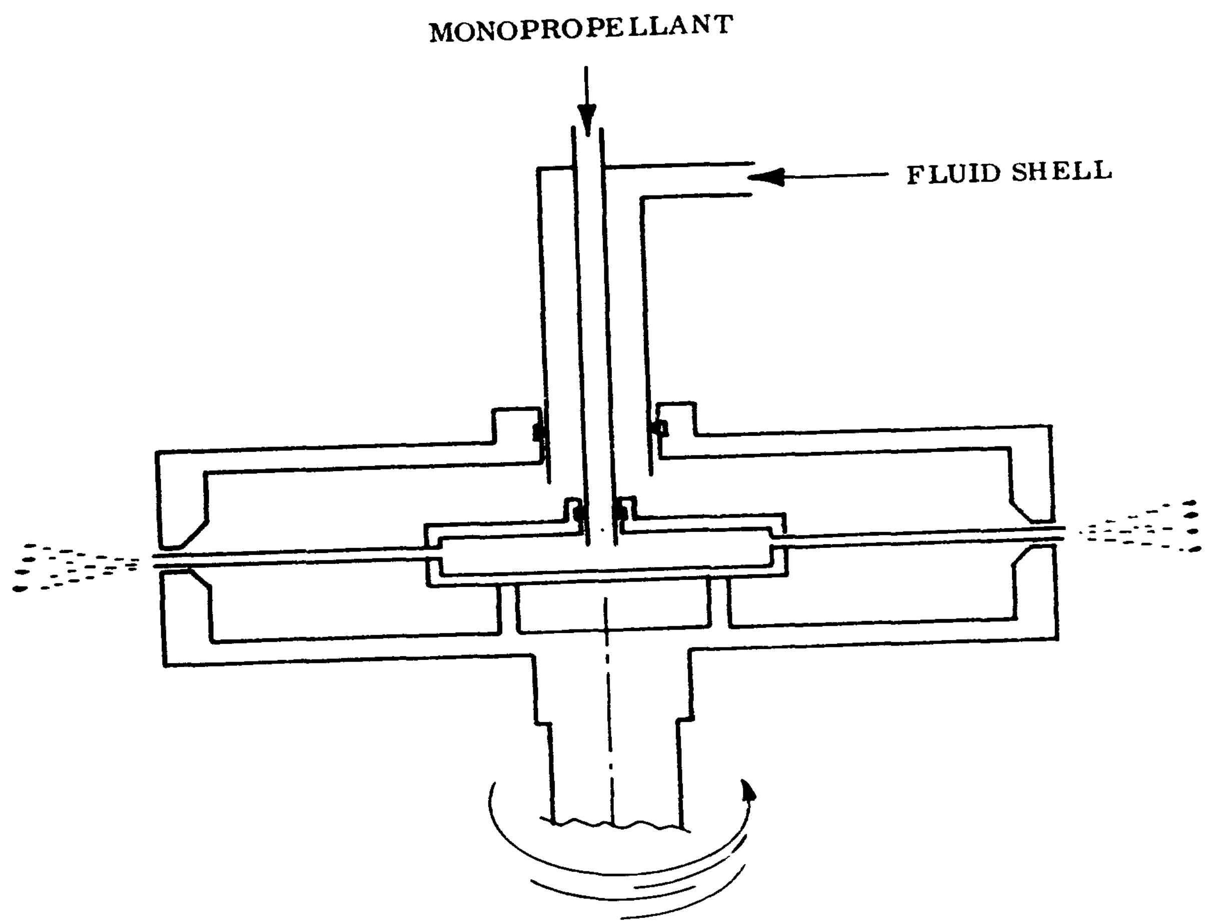


Figure 1. Centrifugal Extrusion Encapsulation Device

The other device for fabricating capsules was a 3-in.-diameter, high speed, air-driven disc (Figure 2). This device was used to prepare the smaller capsules and the 50-micron-diameter nitrocellulose particles. Capsules were prepared by gravity feeding an emulsion of alkyl nitrate in aqueous polymer solution onto the center of the rotating disc. Very small emulsion droplets were projected from the periphery of the disc and fell two feet to the collection area. The small capsules were gelled and almost dry when collected. As in the case of the centrifugal extrusion device, the capsules were collected on a polyethylene film. These capsules were usually multicore, although single core capsules could be formed under the right operating conditions. After collection, the capsules were transferred to a fluidized bed for final drying and removal of the starch.

Due to the technical problems anticipated in manufacturing small diameter capsules, a sample of small diameter (30-to 100-micron) nitrocellulose was prepared to provide a propellant for filling the cartridge interstices. The nitrocellulose particles were formed by feeding a solution of the material onto the rotating disc. The droplets projected from the disc were collected on a sheet of polyethylene film, and the residual solvent was allowed to evaporate.

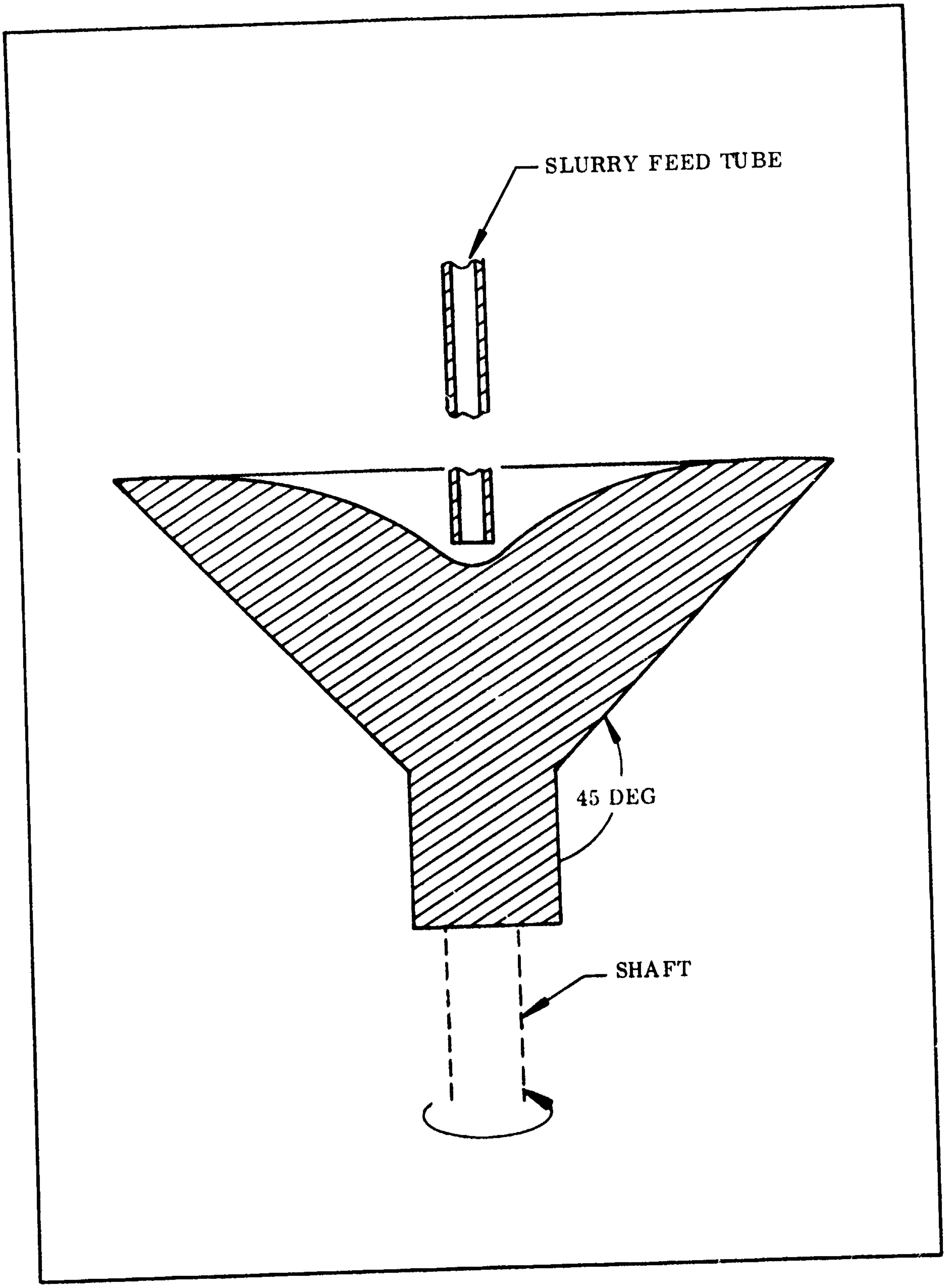


Figure 2. Modified Disc Device

SECTION V
TEST EQUIPMENT

A. TEST RIFLE

The test rifle and equipment for measuring projectile velocity and breech pressure were mounted inside the main building of the Thiokol gun range. The test rifle consisted of a Mauser bolt action with a 26-in. barrel, chambered for the 7.62 mm NATO cartridge. The twist of the rifling was one turn in 10 inches.

A pneumatic cylinder actuated the trigger (Figure 3). Pneumatic pressure was provided by a nitrogen bottle and electrical solenoid.

B. VELOCITY MEASUREMENTS

Two ballistic photovoltaic transducer screens measured bullet velocities by timing the bullet flight. The first screen was located 10 ft from the muzzle and the second screen 10 ft farther downrange. Each screen detected the shadow of the projectile as it passed between a columnated light source and the photovoltaic cells. The electronic circuitry generated a 15-volt square wave pulse with a very sharp leading edge. This pulse was sent to a timer which measured the interval of bullet passage between the screens. A brief listing of all test equipment is given in Table II.

C. PRESSURE MEASUREMENTS

A piezoelectric transducer, charge amplifier, and oscilloscope (Figure 4) were used to measure the breech pressure. The oscilloscope trace was recorded on Polaroid® film.

The voltage rise from the transducer and charge amplifier initiated the oscilloscope sweep. The triggering level control was generally set so that a sweep occurred when the breech pressure was approximately 2,000 psi.

Pressure was also measured by using a deformation type "crusher" gage. The installation of the pressure instrumentation is shown in Figure 5. It should be noted that the centerline of the pressure taps for both measuring systems was 0.130 in. forward of the cartridge case mouth, thus requiring bullet movement before any pressure was measured (Figure 6). This technique eliminated the need for drilled cartridge cases with the associated loading and alignment problems.

Figure 3. Test Rifle

TABLE II. TEST EQUIPMENT

Rifle

Caliber: 7.62 mm NATO
Action: Mauser Bolt Action
Barrel: 26 in. long, rifling twisting 1 turn in 10 in.

Velocity Measuring Equipment

Ballistic Screens: All solid state photovoltaic transducers, Model 6100
- Sensitive area: 336 sq in. (24 by 14 in.)
- Signal output rise time: less than 50 nanosec
- Output pulse width: 1 millisec
- Output pulse: to +18 v
- Screen spacing: 10 ft
- Distance from muzzle to first screen: 10 ft
- Manufacturer: Electronic Counters, Inc., Englewood, New Jersey

Timer: Universal EPUT and Timer, Model 7361
- Input frequency: dc to 1 mc
- Resolution: 1 microsec
- Trigger voltage level: adjustable from -1 to +1 v at the attenuated signal
- Trigger slope: plus or minus
- Manufacturer: Beckman Instruments, Inc., Berkeley Division, Richmond, California

Pressure Measuring Equipment

Pressure Transducer: Piezoelectric quartz pressure transducer, Model 607A
- Full scale pressure range: to 70,000 psi
- Rise time: 1.5 microsec
- Linearity: 2 percent
- Manufacturer: Kistler Instrument Corp., Clarence, New York

Charge Amplifier: Model 568
- Manufacturer: Kistler Instrument Corp., Clarence, New York

Oscilloscope: Dual beam Tektronix, type 535 cathode-ray oscilloscope
- Manufacturer: Tektronix, Inc., Beaverton, Oregon

Camera: Model F296 for Polaroid 3000 speed type 47 film
- Manufacturer: Fairchild Camera and Instrument Corp., Fairchild Avenue, Plainview, New York

Deformation Gage: Copper crusher cylinder, 0.225 in. diameter x 0.500 in. long
- Manufacturer: Olin Mathieson Chemical Corp., Winchester Western Division, East Alton, Illinois

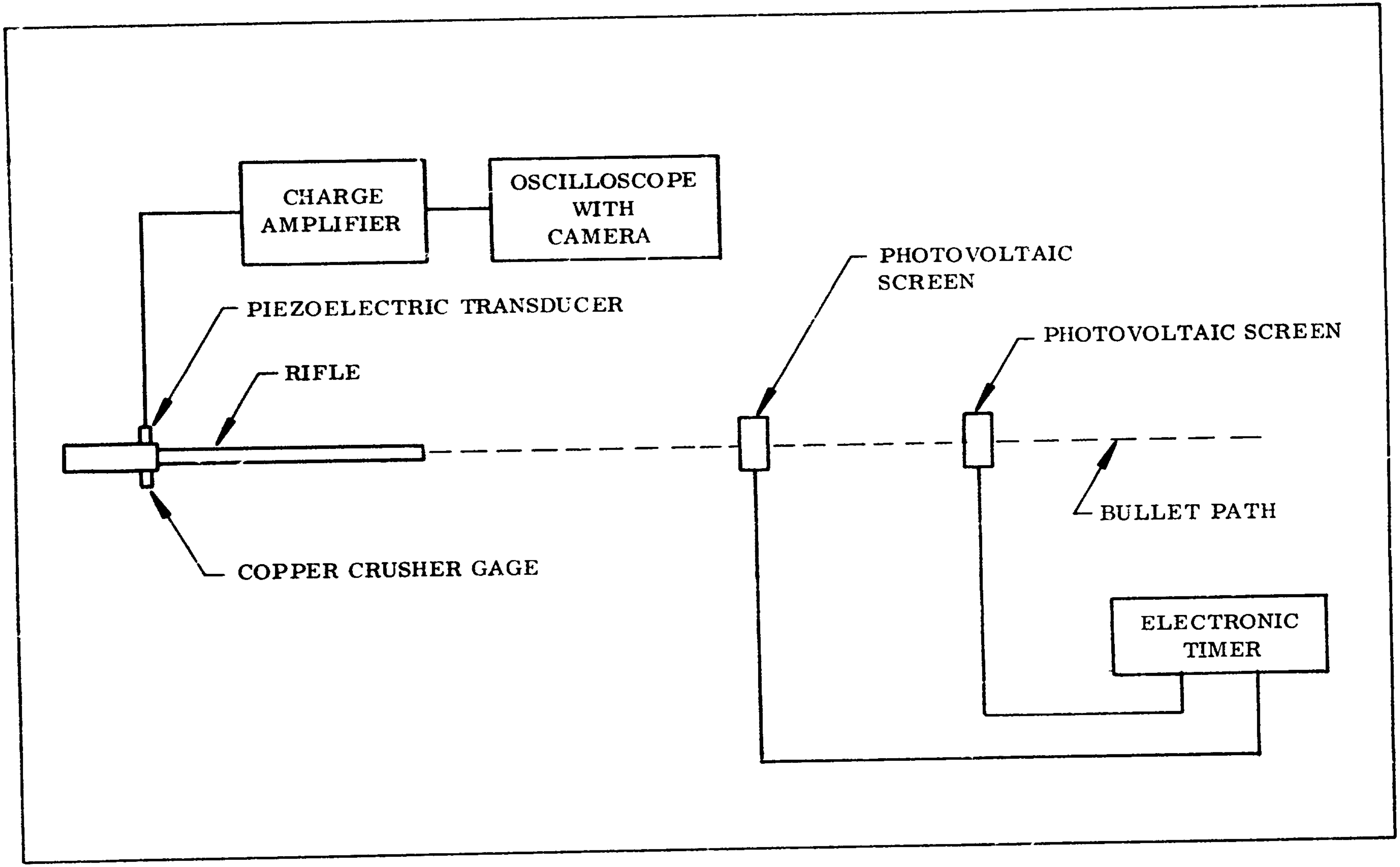


Figure 4. Block Diagram of Instrumentation

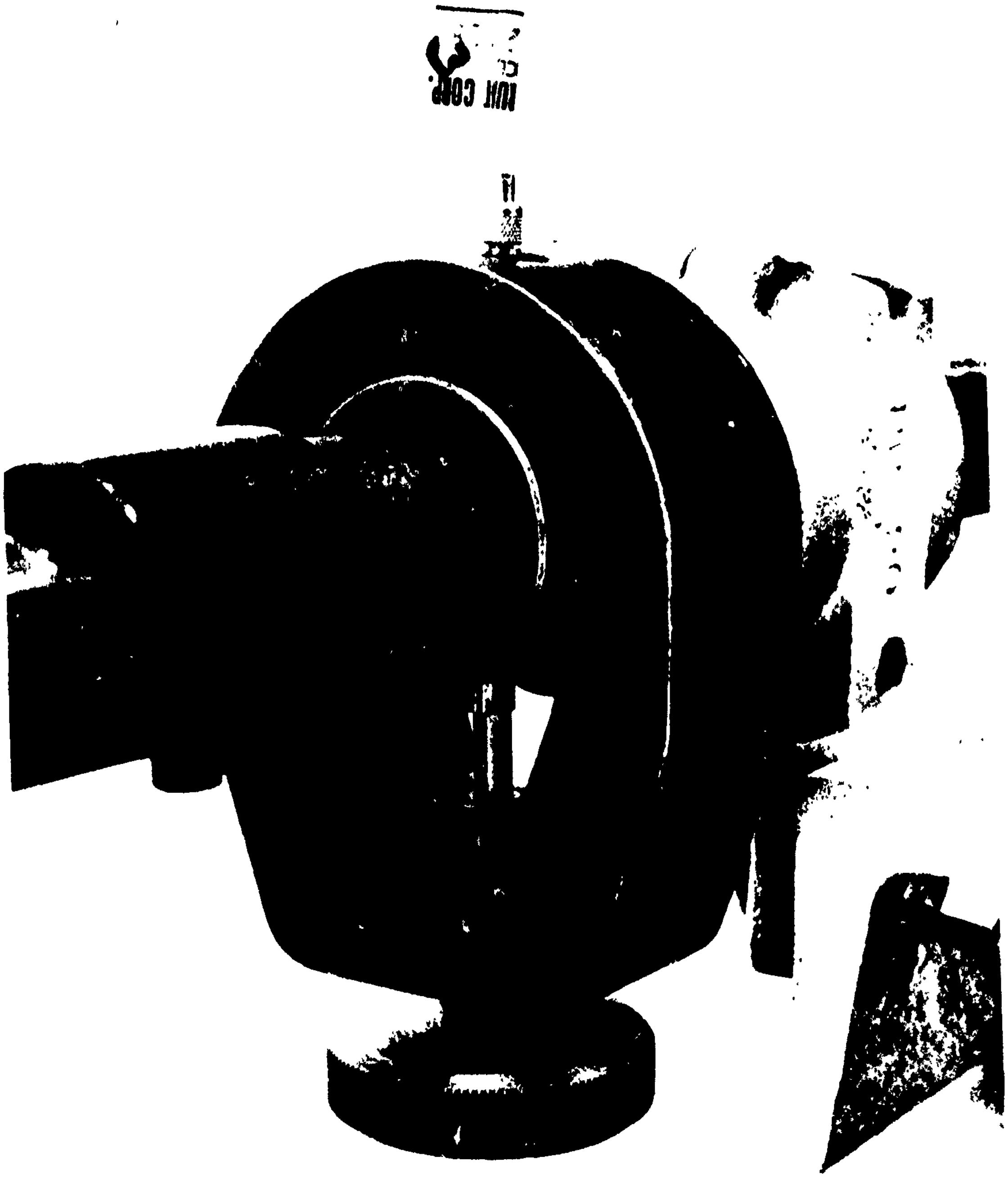


Figure 5. Closeup View of Pressure Instrumentation

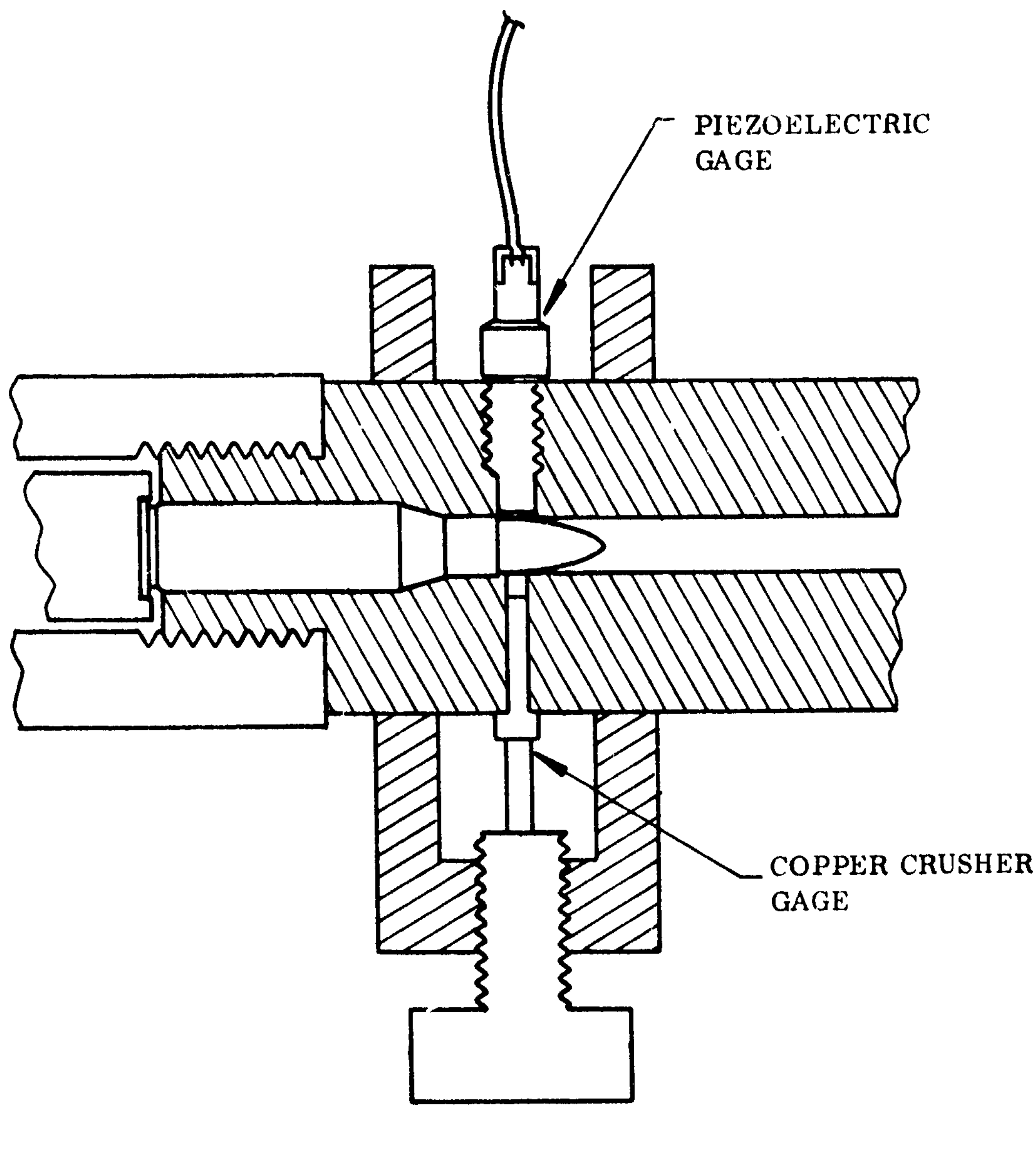


Figure 6. Cross-Section of Pressure Instrumentation

SECTION VI
TEST PROCEDURES

Thiokol conducted all firings at a small canyon gun range in a remote corner of the Research and Development facility.

A. AMMUNITION LOADING

Ammunition components scheduled for testing were removed from a 70° F conditioning cabinet. Ammunition loading was conducted in the following manner.

1. During the early part of the program, the primer pocket flash hole was sealed by placing a small piece of Mylar® in the bottom of the primer pocket over the flash hole to prevent any possible poisoning of the primer by any propellant constituent. During the latter part of the program, the flash hole was sealed by a drop of ethyl acetate cement. After sealing the flash hole, the primer was seated full depth in the primer pocket.

2. Encapsulated monopropellant and any supplemental propellants were next weighed separately to ± 0.05 grain and placed into the case. Care was taken to assure that the monopropellant did not stand open to the atmosphere for long periods after weighing, thus avoiding any propellant loss by permeation through the capsule wall.

3. In those rounds which required free liquids a calibrated hypodermic syringe was used to inject the liquid into the cartridge case. Bullets were immediately seated in the case neck to prevent propellant loss.

B. FIRING PROCEDURE

The timer was reset and the oscilloscope adjustment was verified before loading a round in the gun. Before each test sequence, a calibration round was fired to check both velocity and pressure instrumentation. After cartridge loading, the camera shutter for oscilloscope trace recording was opened and the fire signal given. Closing a keyed electrical interlock and pressing the firing button discharged the round.

SECTION VII
TEST RESULTS

A. 7.62 MM RIFLE

Initial attempts to fabricate large capsules with high mass fractions of encapsulated monopropellant were successful. The amount of monopropellant was increased to a maximum of 89.3 percent of the total capsule weight as compared to the previous maximum loading of 83.1 percent monopropellant.

Initial testing on the first shipment of encapsulated monopropellant verified the ignition effect of Remington 9-1/2 primers and Winchester 120 primers. During testing under a previous contract, both of these primers had provided good propellant ignition with the Remington 9-1/2 primer being slightly better. Figures 7 and 8 are Polaroid® photographs of oscilloscope traces of these fired rounds. The rounds using Remington 9-1/2 primers (Figure 7) appear to have fewer ignition transients at lower pressures and more stable high pressure combustion than the rounds using Winchester 120 primers (Figure 8). The average velocity difference between the rounds using Remington 9-1/2 primers and Winchester 120 primers is only 2.5 feet per second (fps).

Propellant sample 4-887 (88.9 percent monopropellant by weight) was screened to determine the particle size distribution. Table III indicates that 96.4 percent of the sample was between 840 and 1,410 microns diameter. These graded sizes were individually tested to determine the effect, if any, upon measured velocity and breech pressure.

The effect of increasing the propellant charge is shown in Figure 9. The data for the 1,095- and 1,300-micron-diameter samples are the average of five rounds. This indicates that projectile velocity is essentially unaffected by capsule size. Sufficient propellant was not available in the smaller sizes for extensive testing.

The capsules in propellant lot 4-925 contained 87.7 percent monopropellant by weight. The data obtained by firing this propellant in the 7.62 mm gun are shown in Figure 10. The average velocity of the five rounds was 2,266 fps. Propellant lot 4-925 weighed 5 lb, and most of the testing done in this program used propellant from this lot.

Near the end of the previous program, capsules with walls containing "Tris Nitro" (Trishydroxmethyl nitromethane) were fabricated and tested. The performance of these reactive walled capsules was superior to all other propellants tested. Therefore, a sample was prepared with walls containing 10.63 percent "Tris Nitro" in an attempt to again improve the performance. The test results in Figure 11 show an average velocity of 2,102 fps, somewhat slower than the average velocity of capsules not containing "Tris Nitro." The "Tris Nitro" capsules were 86.8 percent monopropellant. It was concluded that the performance gain in the previous program was attributable to improved fabrication techniques at the end of the program.

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
35-GRAIN LOAD
LOADING DENSITY: 88.9%
PVA WALL
LOT 4-887

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM GOVT
150-GRAIN BULLET

PRESSURE SCALE (VERTICAL)

10,000 PSI/CM

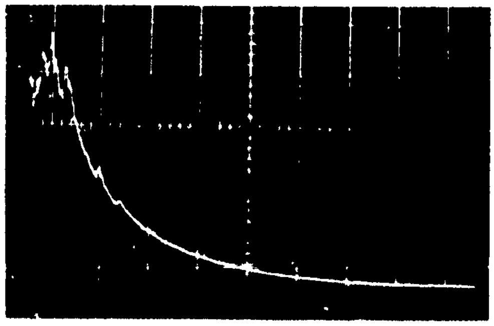
TIME SCALE (HORIZONTAL)

0.2 MSEC/CM

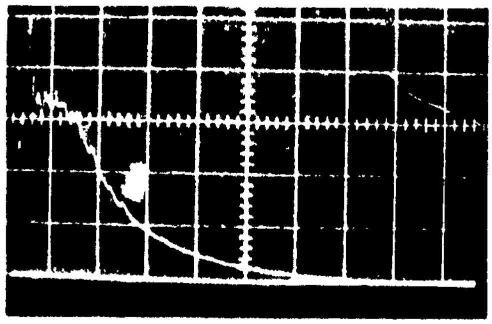
AVG VELOCITY

2,318.5 FPS

PROJECTILE VELOCITY (FPS)



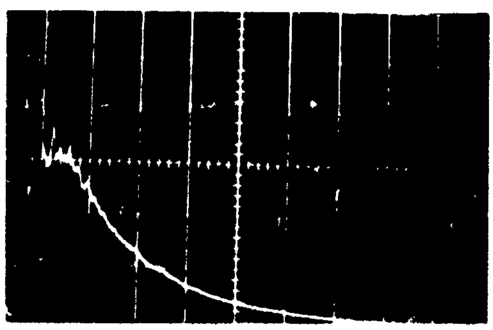
2,348
ROUND 1



2,295
ROUND 2

NO TRACE

2,344
ROUND 3



2,287
ROUND 4

Figure 7. Breech Pressure, 35 Grains Encapsulated Monopropellant, Remington 9-1/2 Primer

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
35-GRAIN LOAD
LOADING DENSITY: 88.9%
PVA WALL
LOT 4-887

PRIMER

WINCHESTER 120

CARTRIDGE

7.62 MM GOVT
150-GRAIN BULLET

PRESSURE SCALE (VERTICAL)

10,000 PSI/CM

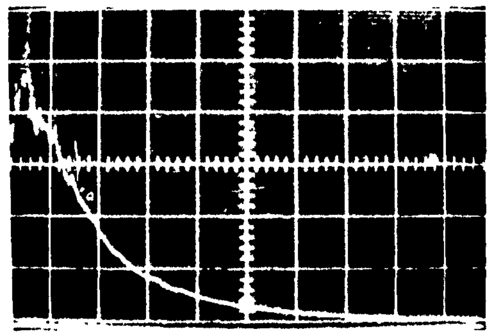
TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,321 FPS

PROJECTILE VELOCITY (FPS)



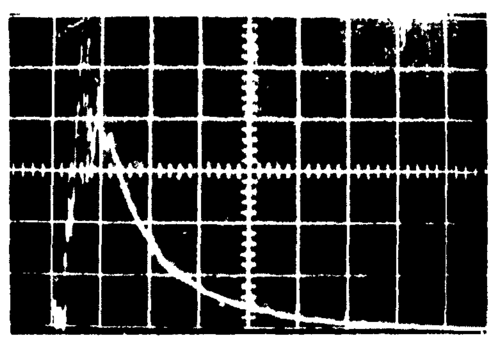
2,337
ROUND 5

NO TRACE

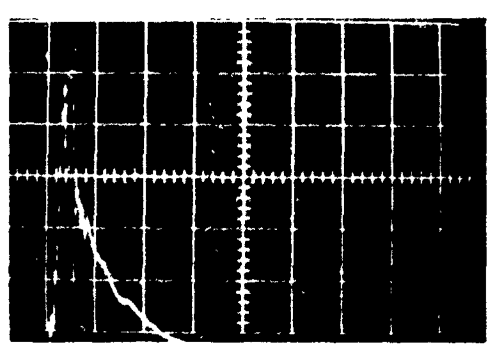
2,300
ROUND 6

NO TRACE

2,284
ROUND 7



2,328
ROUND 8



2,356
ROUND 9

Figure 8. Breech Pressure, 35 Grains Encapsulated Monopropellant, Winchester 120 Primer

TABLE III. CAPSULE SIZE DISTRIBUTION
(Propellant Sample 4-887)

Size Range (microns)	Average Diameter (microns)	Percent
Smaller than 500	--	0.1
500 to 710	605	0.2
710 to 840	775	1.1
840 to 1,000	920	10.9
1,000 to 1,190	1,095	45.4
1,190 to 1,410	1,300	40.1
Larger than 1,410	--	2.2

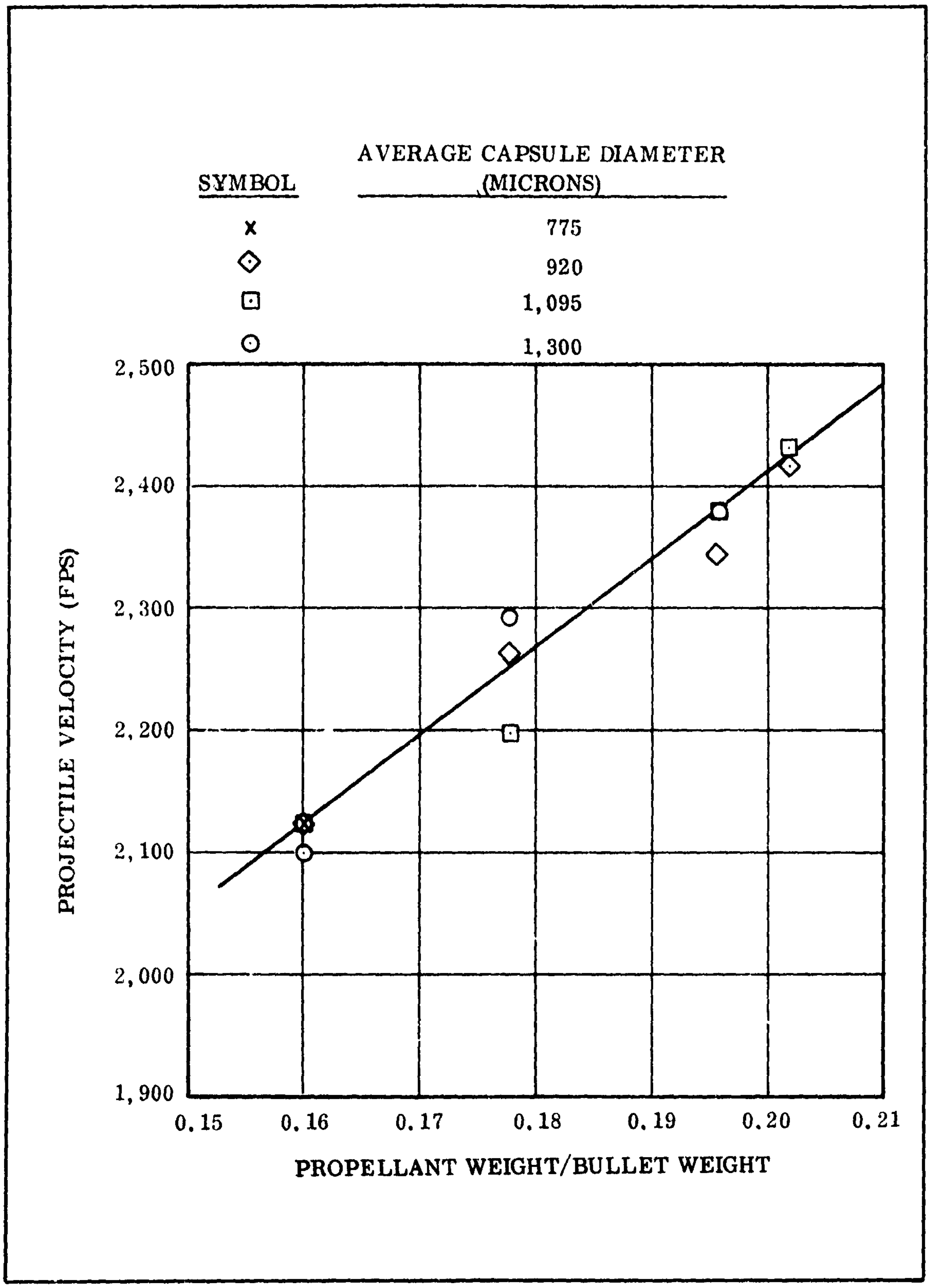


Figure 9. Projectile Velocity, Propellant Sample 4-887

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

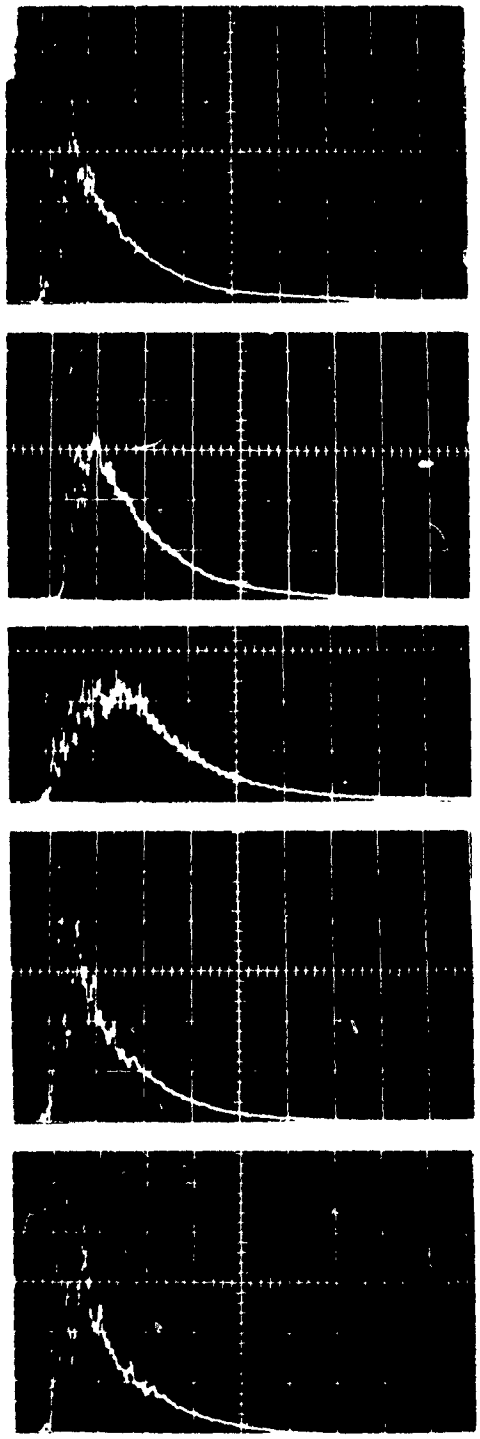
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,274 FPS



PROJECTILE VELOCITY (FPS)

2,294
ROUND 134

2,268
ROUND 136

2,188
ROUND 137

2,299
ROUND 138

2,283
ROUND 139

Figure 10. Breech Pressure 87.7% Capsule Loading Density

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 86.6%
WALL: PVA WITH TRIS NITRO
LOT 4-933

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

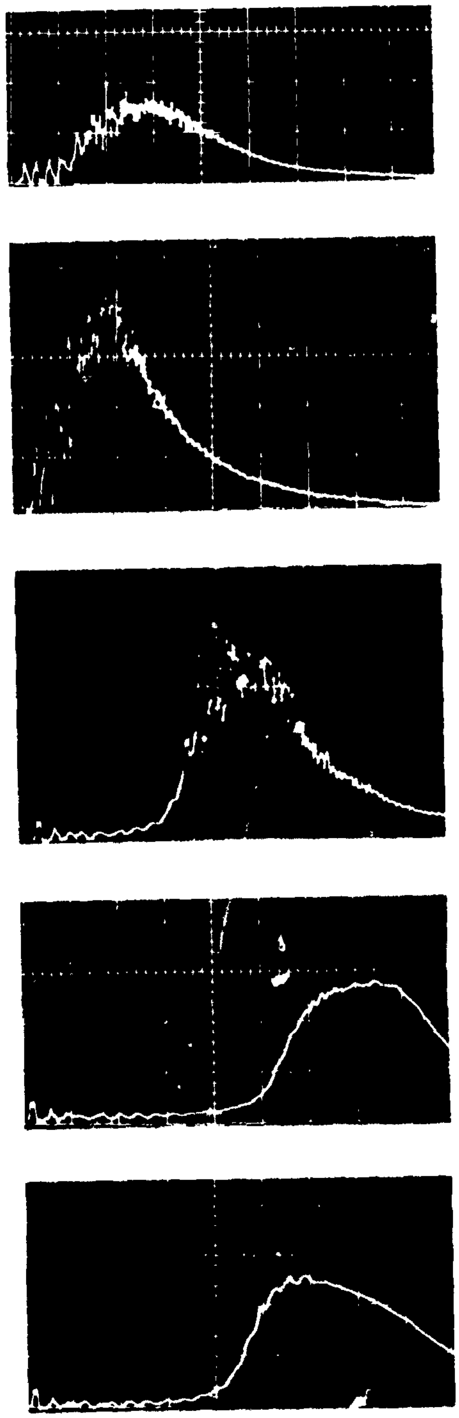
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,102 FPS



PROJECTILE VELOCITY (FPS)	
2,092	ROUND 179
2,169	ROUND 180
2,148	ROUND 181
2,032	ROUND 182
2,070	ROUND 183

Figure 11. Bre[illegible] Pressure, Tris Nitro Capsules

Because small diameter encapsulated propellant capsules were not yet available, experimentation was performed to determine the effect of small particles in the cartridge interstices.

A series of test firings were conducted using, as interstitial materials, 50-micron-diameter nitrocellulose, ammonium nitrate, and a ball powder.

The results of firing 30 grains of encapsulated propellant with 5 grains of 50-micron-diameter nitrocellulose (lot 4-891) are shown in Figure 12. The pressure traces are generally characterized by a high pressure spike of short duration immediately after ignition, followed by rough combustion. The measured velocities are quite consistent, the average velocity being 2, 428 fps. The fastest velocity is 33 fps higher than the average while the slowest velocity is 32 fps below the average (Table IV).

Adding 10 grains of nitrocellulose to 25 grains of encapsulated propellant gives the results shown in Figure 13. Peak and average breech pressures are about 10, 000 psi lower while the average velocity is 2, 402 fps. The round repeatability is excellent, the highest velocity being 28 fps faster than average and the slowest being 34 fps slower than the average velocity. Although nitrocellulose contains less energy, it apparently burns more efficiently than the encapsulated monopropellant. This causes the rounds containing 10 grains of nitrocellulose and 25 grains of encapsulated propellant to achieve higher velocities than rounds containing more encapsulated propellant and less nitrocellulose.

Figures 14 and 15 present the results of firing encapsulated propellant with interstitial ammonium nitrate. The ammonium nitrate used had been coated with silane to prevent water absorption and caking. The average velocities are higher than the rounds using corresponding amounts of nitrocellulose. However, the breech pressures are also significantly higher.

A ball powder was used as a propellant additive (Figures 16 and 17). This powder was obtained from the operational military 7.62 mm cartridge. Both the average velocity (Table IV) and the breech pressure decrease with the increasing amount of ball powder, which indicates that the available energy of 5 grains of ball powder is somewhat less than that of 5 grains of encapsulated propellant.

Up to this point, small (50- to 250-micron-diameter) monopropellant capsules had not been available because of the difficulties encountered in the fabrication process. We found that under the best conditions small capsules did not hold the alkyl nitrates well, and many of the capsules agglomerated during the recovery process. The agglomeration can be avoided by using an enclosed system which, because of the explosive hazard and time limitations, was not practical during this program.

No real effort was made to reduce the size of the small capsules to less than 100 microns using the centrifugal extrusion device because of poor capsule formation and very low propellant content. Results with the disc device were similar to those obtained with the extrusion device. The dried capsules contained slightly over 50 percent encapsulated monopropellant, and the loss rate for the capsules exposed to the atmosphere was high.

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

BOOSTER

5 GRAINS 50 μ DIA NITROCELLULOSE (LOT 4-891)

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

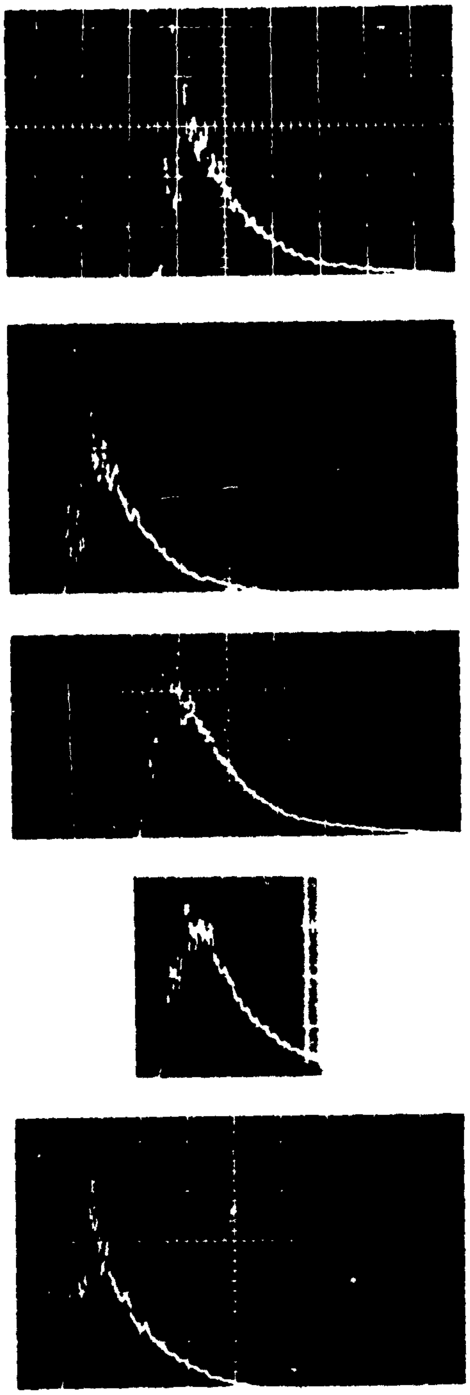
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,428 FPS



PROJECTILE VELOCITY (FPS)

2,410
ROUND 204

2,396
ROUND 206

2,434
ROUND 207

2,438
ROUND 208

2,461
ROUND 209

Figure 12. Breech Pressure, 30 Grains Monopropellant, 5 Grains Nitrocellulose

TABLE IV. VELOCITY REPEATABILITY

Parameter	Figure Reference 10	12	13	14	15	16	17	11	**
Wall	PVA	PVA	PVA	PVA	PVA	PVA	PVA	PVA*	--
Load (Grains)	30	30	25	30	25	30	25	30	--
Monopropellant (Percent)	87.7	87.7	87.7	87.7	87.7	87.7	87.7	86.8	--
Additive	None	NC	NC	AN	AN	Ball	Ball	None	--
Additive Weight (Grains)	0	5	10	5	10	5	10	0	--
Sample Size	5	6	5	5	5	7	5	5	40
Projectile Velocity (fps)									
Average	2,266	2,428	2,402	2,466	2,568	2,418	2,357	2,102	2,811
Max Above Average	33	33	28	47	120	37	21	67	30
Max Below Average	78	32	34	44	51	20	29	70	49
Peak Breech Pressure (psi x 10,000)	74	79	60	84	--	76	67	61	--
Peak Ignition Pressure (psi x 10,000)	91	91	69	92	--	102	86	65	--

*With Tris Nitro

**Government reference rounds, Lot LC 7.62-904

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
25-GRAIN LOAD
LOADING DENSITY: 86.8%
PVA WALL
LOT 4-933

PRIMER

REMINGTON 9-1/2

BOOSTER

10 GRAINS 50 μ NITRO-CELLULOSE (LOT 4-891)

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

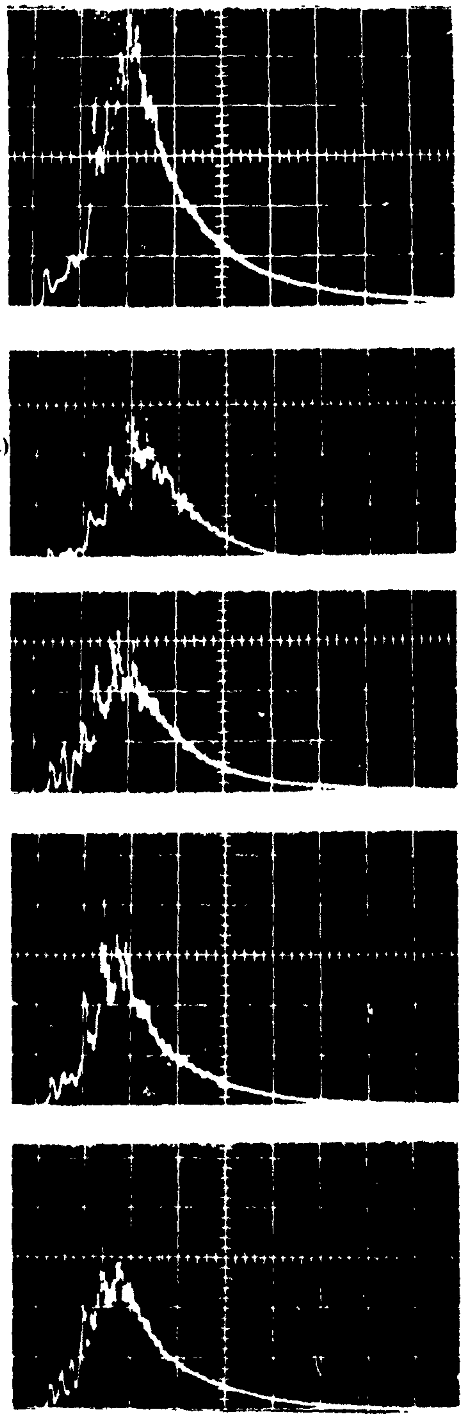
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,402 FPS



PROJECTILE VELOCITY (FPS)

2,430
ROUND 184
(PRESSURE SCALE = 10,000 PSI/CM)

2,396
ROUND 185

2,393
ROUND 186

2,421
ROUND 187

2,368
ROUND 188

Figure 13. Breech Pressure, 25 Grains Monopropellant, 10 Grains Nitrocellulose

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

BOOSTER

5 GRAINS AMMONIUM NITRATE

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

20,000 PSI/CM

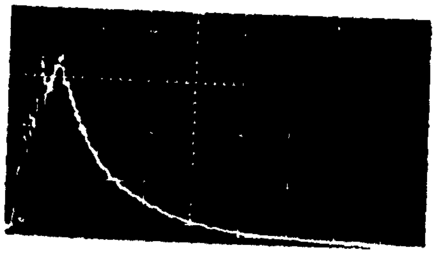
TIME SCALE

0.2 MSEC/CM

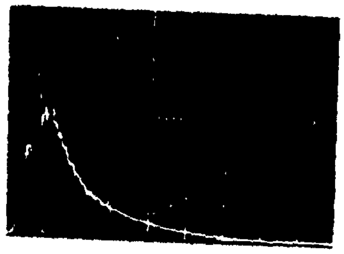
AVG VELOCITY

2,466 FPS

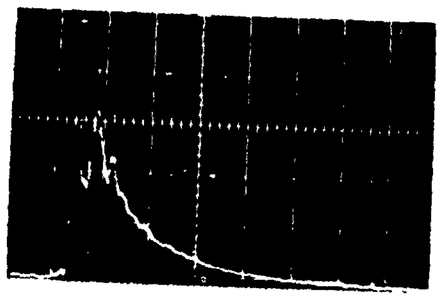
PROJECTILE VELOCITY (FPS)



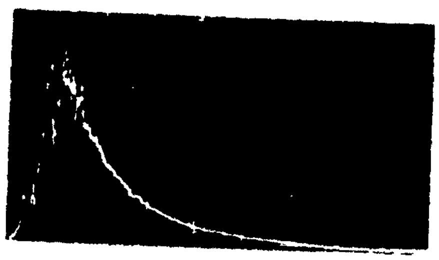
2,513
ROUND 210



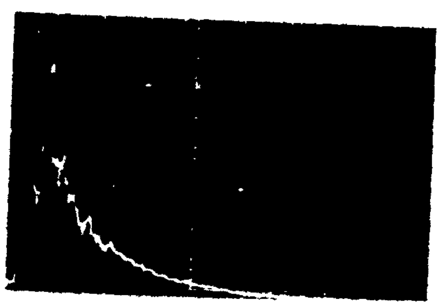
2,511
ROUND 211



2,432
ROUND 212



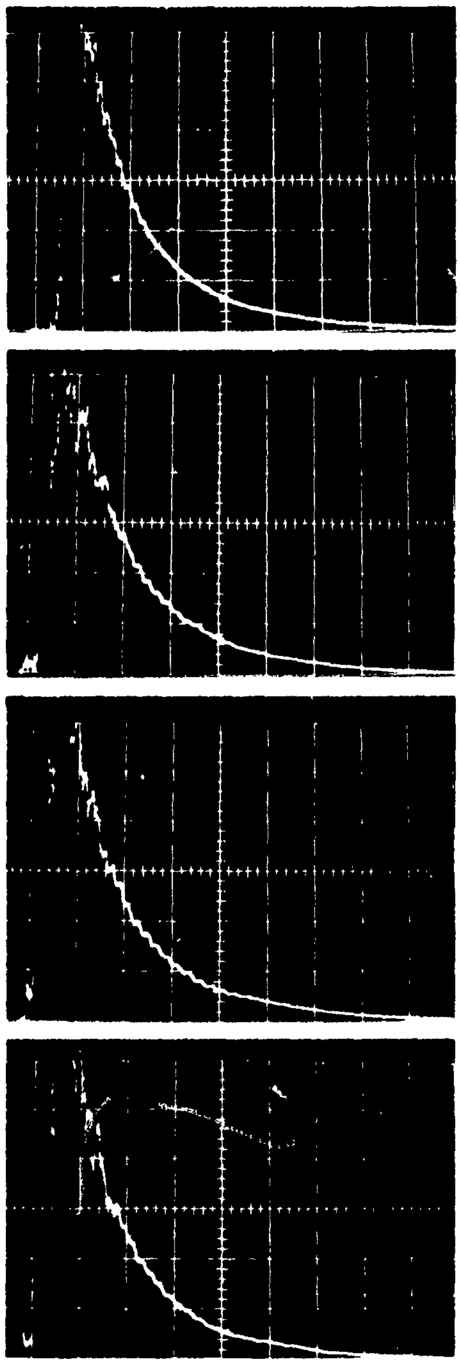
2,422
ROUND 213



2,453
ROUND 214

Figure 14. Breech Pressure, 30 Grains Monopropellant, 5 Grains Ammonium Nitrate

PROJECTILE VELOCITY (FPS)	
NO TRACE	2,538 ROUND 124
	2,688 ROUND 125
	2,519 ROUND 126
	2,517 ROUND 127
	2,577 ROUND 128



CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
25-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

BOOSTER

10 GRAINS AMMONIUM NITRATE

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

10,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,568 FPS

Figure 15. Breech Pressure, 25 Grains Monopropellant, 10 Grains Ammonium Nitrate

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

BOOSTER

5 GRAINS BALL POWDER

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

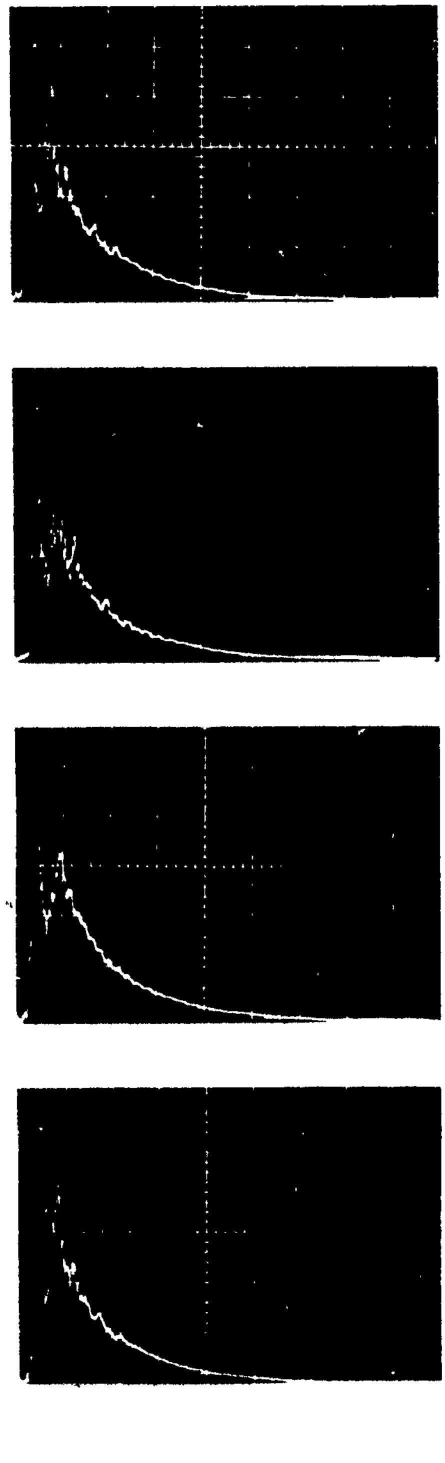
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,418 FPS



PROJECTILE VELOCITY (FPS)

2,422
ROUND 227

2,399
ROUND 228

2,455
ROUND 229

2,398
ROUND 230

Figure 16. Breech Pressure, 30 Grains Monopropellant, 5 Grains Ball Powder

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
25-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925

PRIMER

REMINGTON 9-1/2

BOOSTER

10 GRAINS BALL POWDER

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

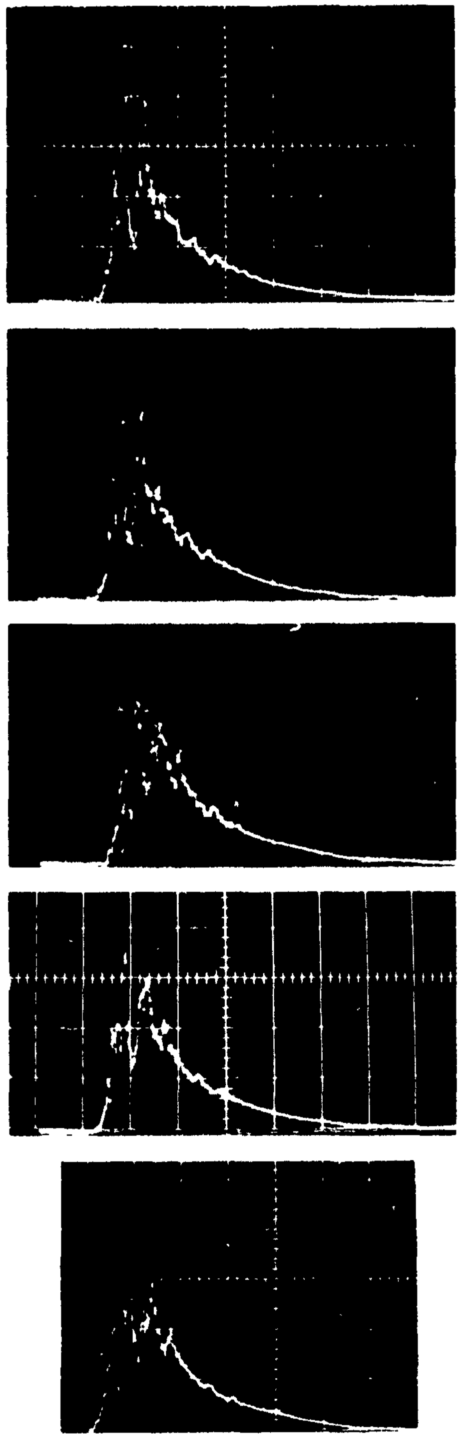
20,000 PSI/CM

TIME SCALE

0.1 MSEC/CM

AVG VELOCITY

2,357 FPS



PROJECTILE VELOCITY (FPS)
2,328 ROUND 231
2,369 ROUND 232
2,366 ROUND 233
2,378 ROUND 234
2,344 ROUND 235

Figure 17. Breech Pressure, 25 Grains Monopropellant, 10 Grains Ball Powder

Several samples were finally made available for firing in the 7.62 mm gun. Small diameter (<250 microns) propellant capsules were mixed with the larger (840-1,410 microns) capsules from lot 4-925 and fired to verify any performance gain attributable to the small capsules. Thirty grains of the large capsules (sample 4-925-4) were poured into the cartridge case simultaneously with 10 grains of the small diameter propellant capsules. The cartridge case was continuously vibrated to assure good distribution of the smaller propellant capsules in the interstitial spaces.

Because each small diameter capsule propellant sample was somewhat different in regard to diameter, percent fill, and capsule wall material content, each sample was individually tested. The data obtained from these bimodal firings are shown in Figures 18 through 22.

A bimodal mixture containing 30 grains of large capsules (lot 4-925-4) and 10 grains of 60-micron-diameter propellant from sample 4-944 was tested, and the data are shown in Figure 18. The average velocity increased 254 fps, from 2,184 fps without small capsules to 2,438 fps (+62, -57 fps). The average breech pressure increased from 53,000 psi without small capsules to 59,500 psi for the bimodal mixture. The performance of these rounds was superior to rounds using any of the other small diameter propellant samples. Attempts to fabricate additional propellant which would duplicate lot 4-944 were unsuccessful.

Figure 19 shows the data from firing a bimodal mixture using sample lot 4-942 as the interstitial filler propellant. Only a slight increase in velocity (59 fps) was achieved over the performance of the single mode tests. Figures 20 and 21 present the data obtained by firing sample lots 4-943 and 4-945 as the interstitial propellants. The average velocities of these five-round samples (2,225 and 2,253 fps) represent a negligible increase over the reference performance of 2,184 fps. When sample 4-935 was tested (Figure 22), the average velocity was 2,055 fps, a slight decrease from the reference performance.

The absence of any significant bimodal performance increase, when using small diameter propellant capsules from samples 4-942, 4-943, 4-945 and 4-935 can be attributed to any one of a number of factors. Traces of unburned small capsules were frequently found in the head end and on the cartridge walls of a fired cartridge case, indicating poor combustion. The propellant evaporation loss from the capsule samples certainly reduces the available energy content within the capsules. In addition, the percent fill of the capsules varies with a subsequent variation in the available energy content.

By mixing 10 grains of small capsules from lot 4-956 throughout the cartridge case, the average velocity was 2,254 fps (Figure 23). However, a further velocity increase to 2,424 fps was obtained by mixing the 10 grains of small capsules with only the last two-thirds of large capsule charge. This was accomplished by pouring one-third of the measured 30 grains of large capsules into the cartridge case, and then simultaneously pouring into the case the remaining 20 grains of large capsules and the 10 grains of small capsules. The pressure-time traces recorded during testing using lot 4-925 are shown in Figures 23 and 24. Figure 23 illustrates the

LARGE CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
PVA WALL
LOT 4-925 #4

SMALL CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
LESS THAN 105 μ DIA
(CA 60 μ DIA
10 GRAIN LOAD
LOADING DENSITY: 52.6%
PVA WALL
LOT 4-944

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

10,000 PSI/CM

TIME SCALE

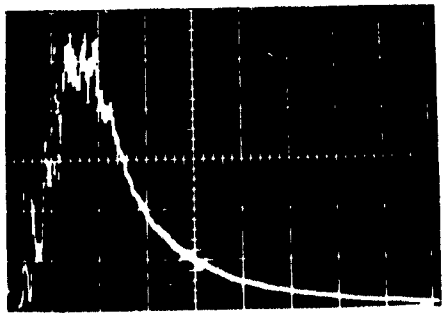
0.2 MSEC/CM

AVG VELOCITY

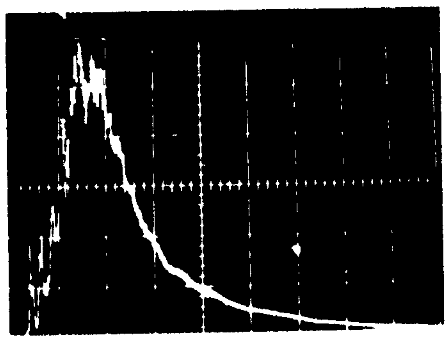
2,438 FPS

PROJECTILE VELOCITY (FPS)

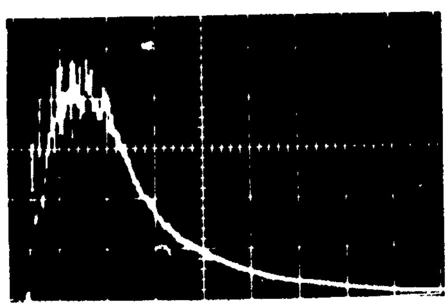
NO TRACE — 2,445 ROUND 314



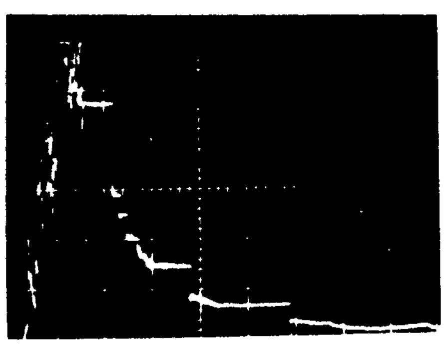
2,421 ROUND 315



2,445 ROUND 316



2,381 ROUND 317



2,500 ROUND 318

Figure 18. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-944

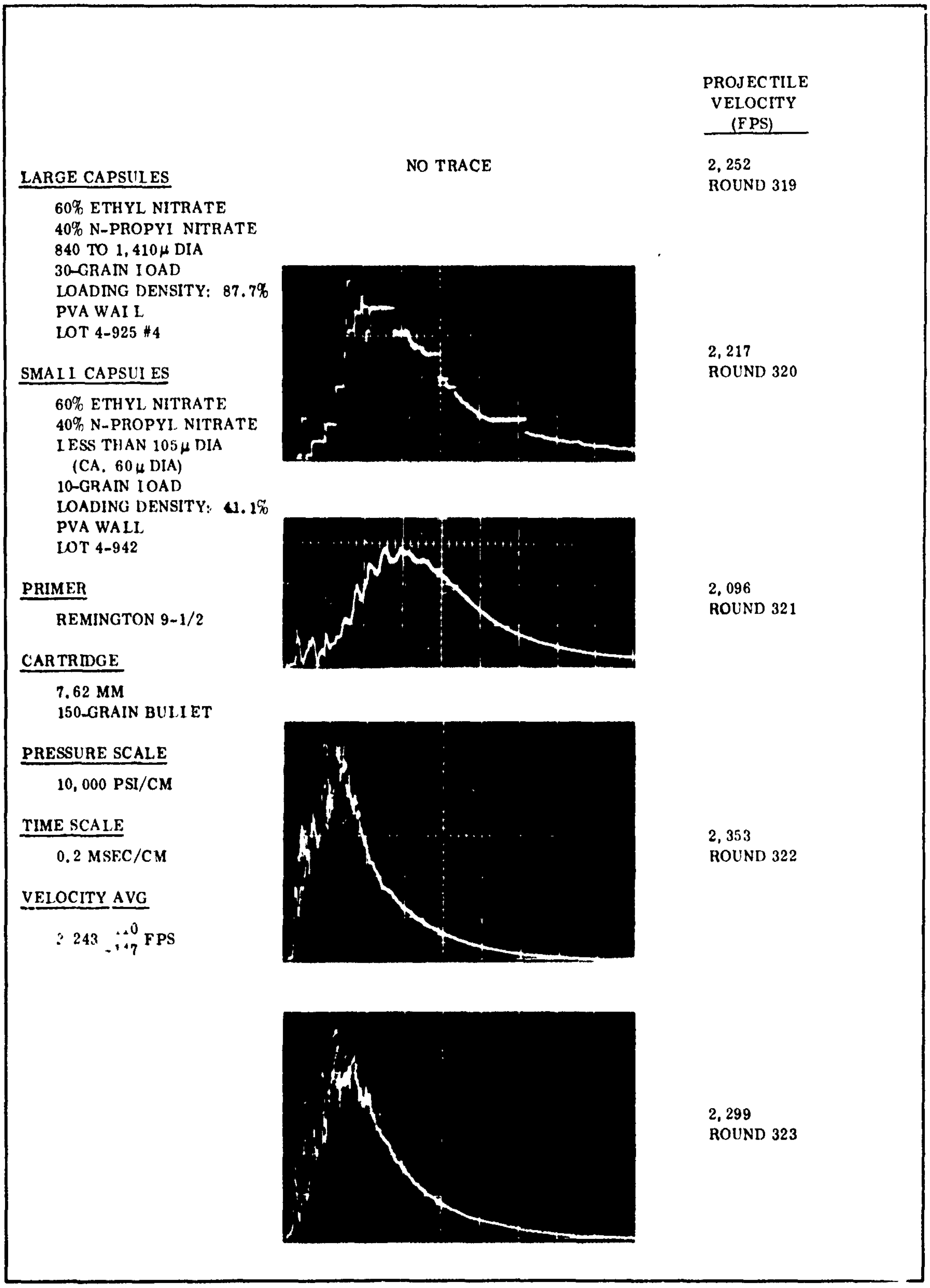


Figure 19. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-942

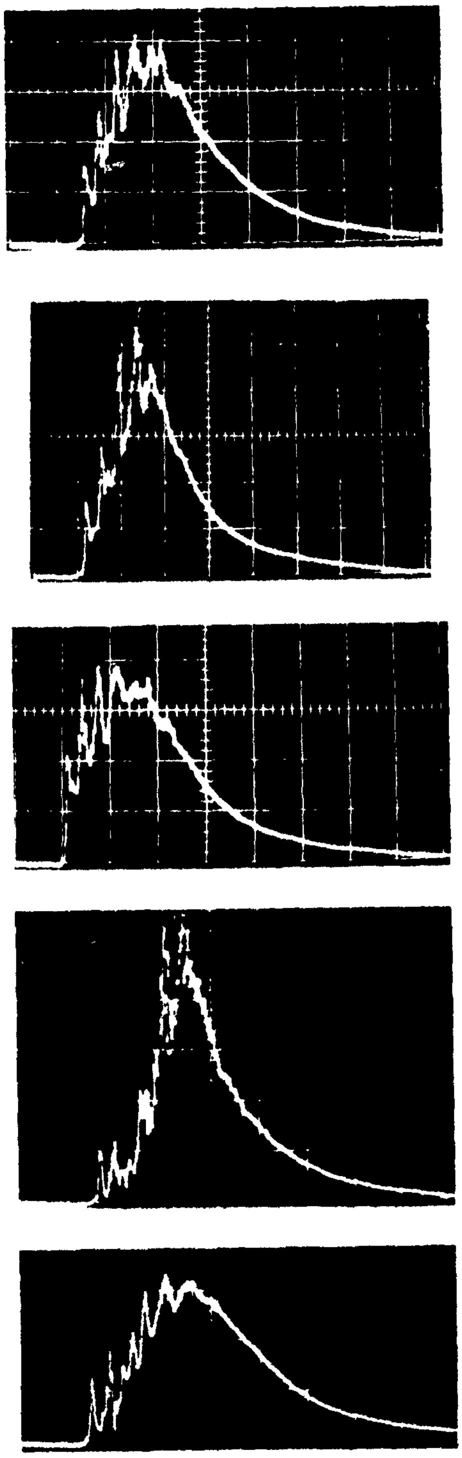


Figure 20. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-943

LARGE CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925 #4

SMALL CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
105 TO 250 μ DIA
10-GRAIN LOAD
LOADING DENSITY: 46.4%
PVA WALL
LOT 4-945

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

10,000 PSI/CM

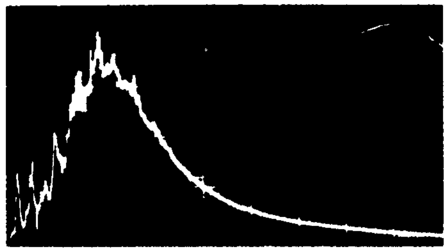
TIME SCALE

0.2 MSEC/CM

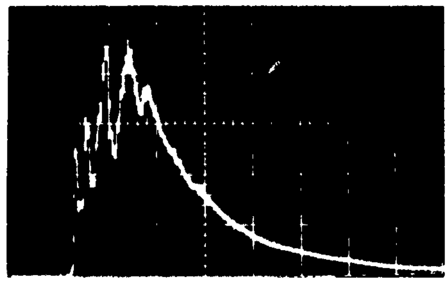
AVG VELOCITY

$2,253^{+83}_{-84}$ FPS

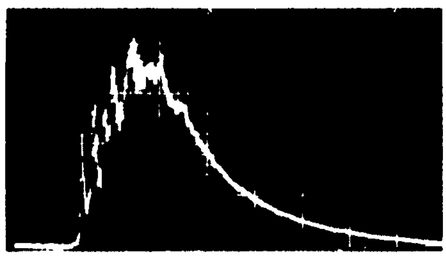
PROJECTILE VELOCITY (FPS)



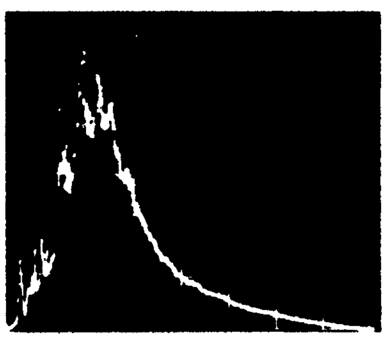
2,169
ROUND 329



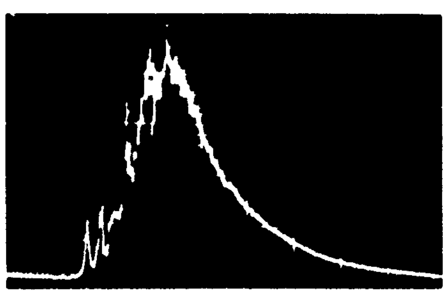
2,262
ROUND 330



2,218
ROUND 331



2,336
ROUND 332



2,278
ROUND 333

Figure 21. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-945

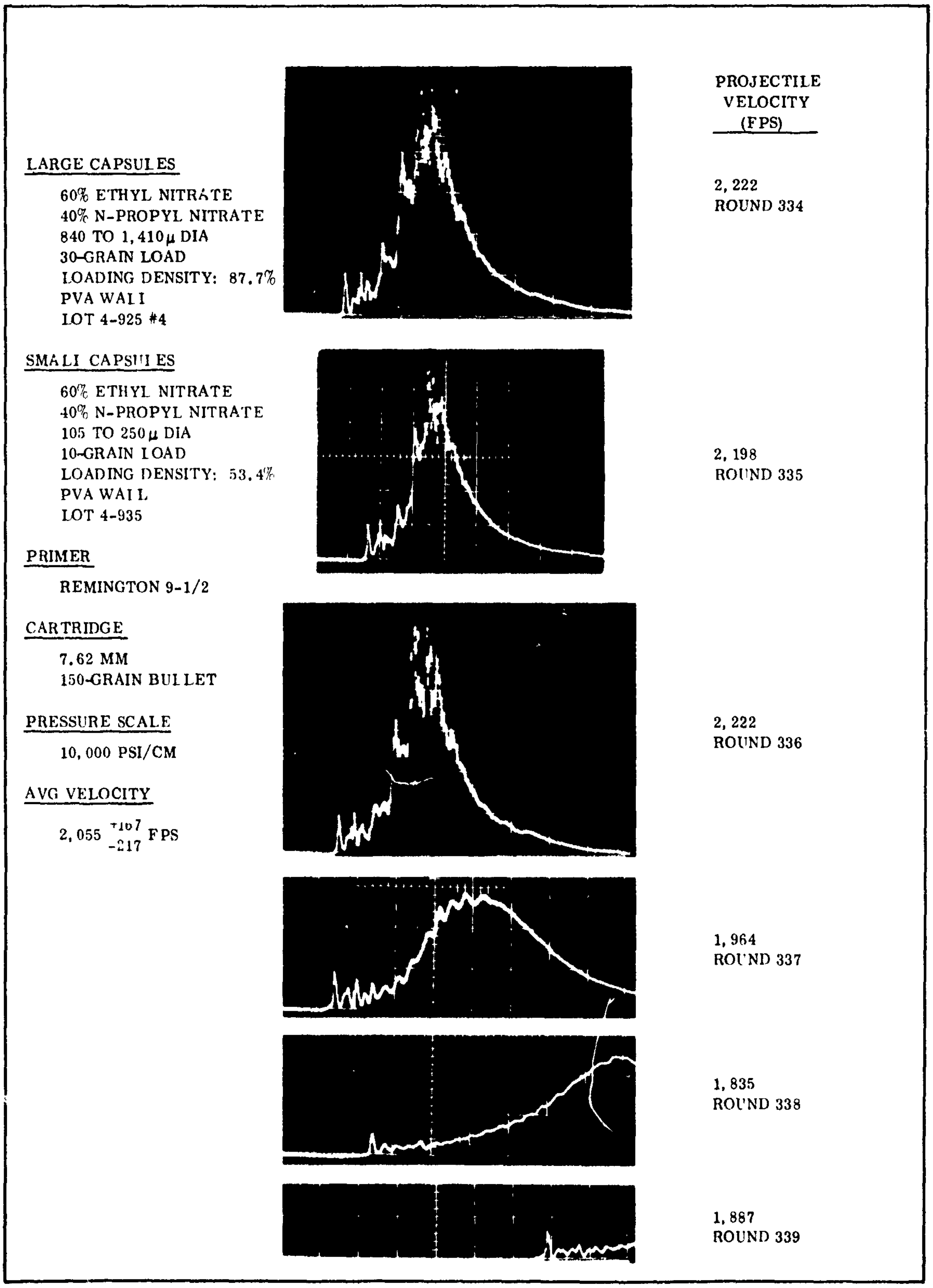


Figure 22. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-935

LARGE CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925 #4

SMALL CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
105 TO 250μ DIA
10-GRAIN LOAD
LOADING DENSITY: 46.3%
PVA WALL
LOT 4-956

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

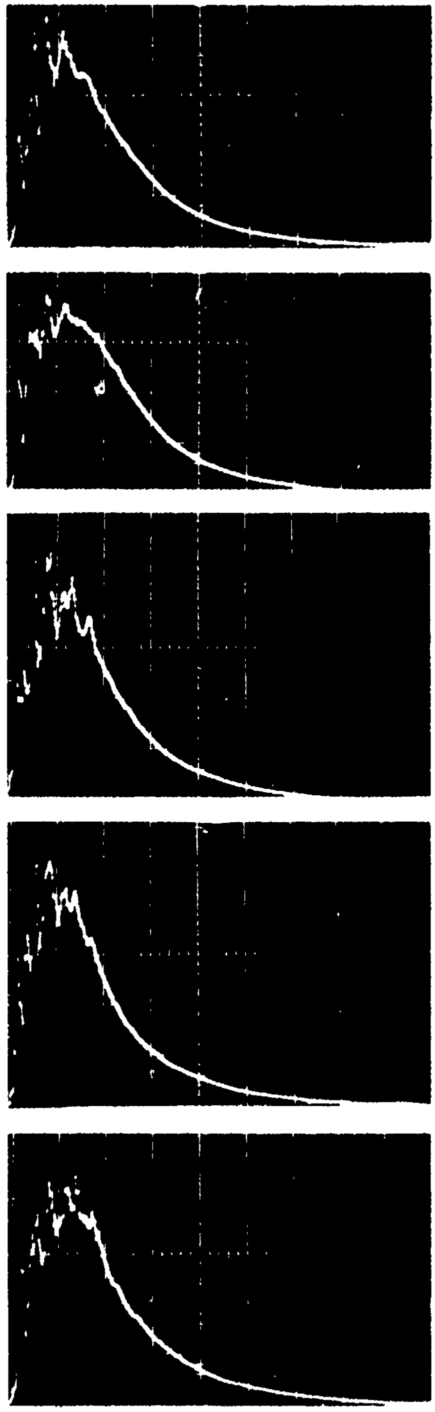
10,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,254 FPS



PROJECTILE VELOCITY (FPS)

2,443
ROUND 360

2,235
ROUND 361

2,262
ROUND 362

2,290
ROUND 363

2,238
ROUND 364

Figure 23. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-956, Small Capsules Mixed Throughout Cartridge Case

LARGE CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410μ DIA
30-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925 #4

SMALL CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
105 TO 250μ DIA
10-GRAIN LOAD
LOADING DENSITY: 46.3%
PVA WALL
LOT 4-956

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

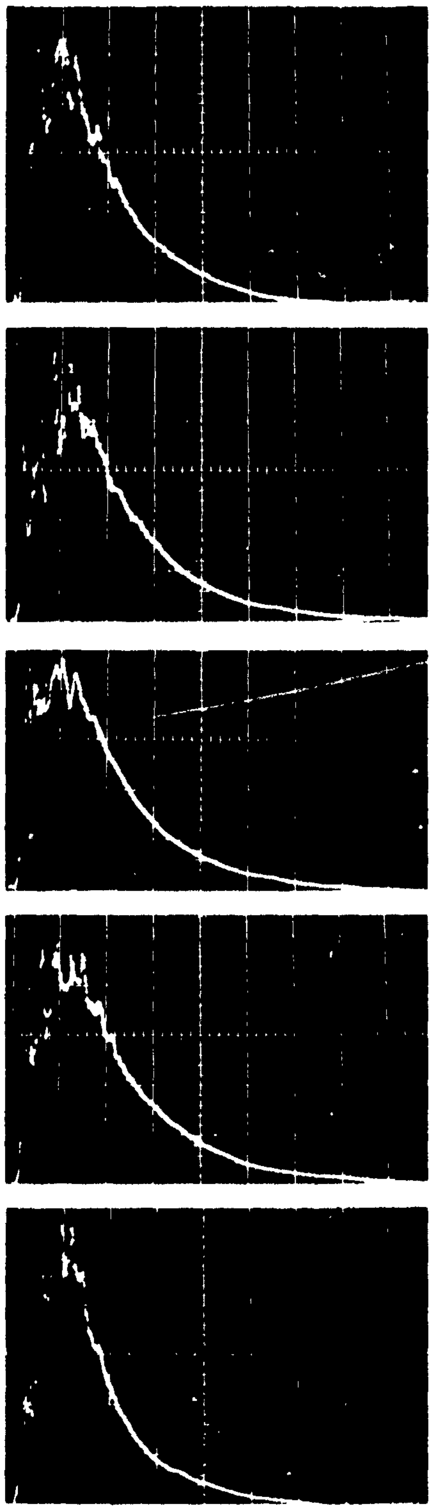
10,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVG VELOCITY

2,424 FPS



PROJECTILE VELOCITY (FPS)

2,436
ROUND 368

2,432
ROUND 369

2,404
ROUND 370

2,365
ROUND 371

2,485
ROUND 372

Figure 24. Breech Pressure, 30 Grains Monopropellant, 10 Grains Lot 4-956, Small Capsules in Upper Two-Thirds of Cartridge Case

performance when using a bimodal mixture with the small capsules mixed equally throughout the cartridge case. Figure 24 shows the result of mixing the smaller capsules only in the upper two-thirds of the cartridge case. The average velocity increased 120 fps while the peak breech pressure increased from 44,800 psi to 51,200 psi.

This performance increase probably results from an absence of small capsules in the area of combustion initiation. A well established combustion zone apparently can more fully utilize the small capsules which seem relatively difficult to ignite. The above described method of loading propellant into a cartridge case was used in all further propellant loading operations.

We tried to increase the reactivity of the small diameter capsule walls under the assumption that the small capsules were not sufficiently fractured to insure good burning, and that the residence time was insufficient to burn through the comparatively inert capsule wall. Ammonium nitrate, sodium nitrate, or potassium nitrate was dissolved in the aqueous capsule wall solution to provide a capsule shell containing 16.7 percent nitrate. The capsules containing ammonium nitrate in the wall seemed to burn quite readily in the open air. The addition of sodium nitrate as a capsule wall constituent seemed to be of little help and leaves much more residue. Potassium nitrate was also tried, but drying was too slow and a sample was not obtained. Drying was slow with all runs having very high evaporation losses.

Increasing the effective propellant percent fill was attempted by eliminating the empty or partially filled capsules. Good separation occurred by pouring the capsules into a bath of ethyl-propyl nitrate Empty and partially filled capsules were skimmed from the surface and near the surface. Firing the flotation-separated capsules produced an average velocity (Figure 25) of 2,330 fps (+97, -103 fps) which was 146 fps faster than velocities produced by the unseparated capsules.

A review of the test program thus far pointed out two facts.

1. The small capsules generally were not contributing to the combustion process.
2. The packing fraction of the large capsules alone was inadequate to achieve standard velocities.

Based on the above facts, we studied several propellants offering greater impetus. Figure 26 shows the volumetric impetus of several of these improved propellants as a function of the mixture ratio. It is evident from Figure 26 that several propellants will produce volumetric impetus values from 30 to 50 percent greater than that of the currently used alkyl nitrates.

Figure 27 shows the combustion temperature of these same propellant mixtures. Although the combustion temperature always increases as the impetus is increased, use of these improved propellants results in impetus increases with little increase in combustion temperature above that of the alkyl nitrate mixture.

Several mixture ratios of each improved propellant provide high impetus levels. This variety allows some freedom in selecting mixture ratios for handling, encapsulation ease, and burning rate control.

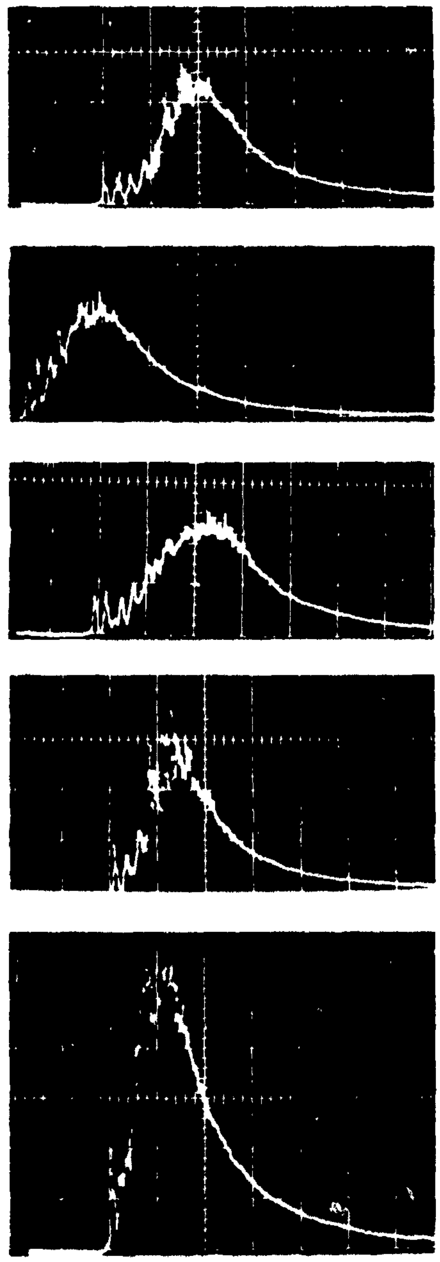


Figure 25. Breech Pressure, 30 Grains Monpropellant, Flotation Separation

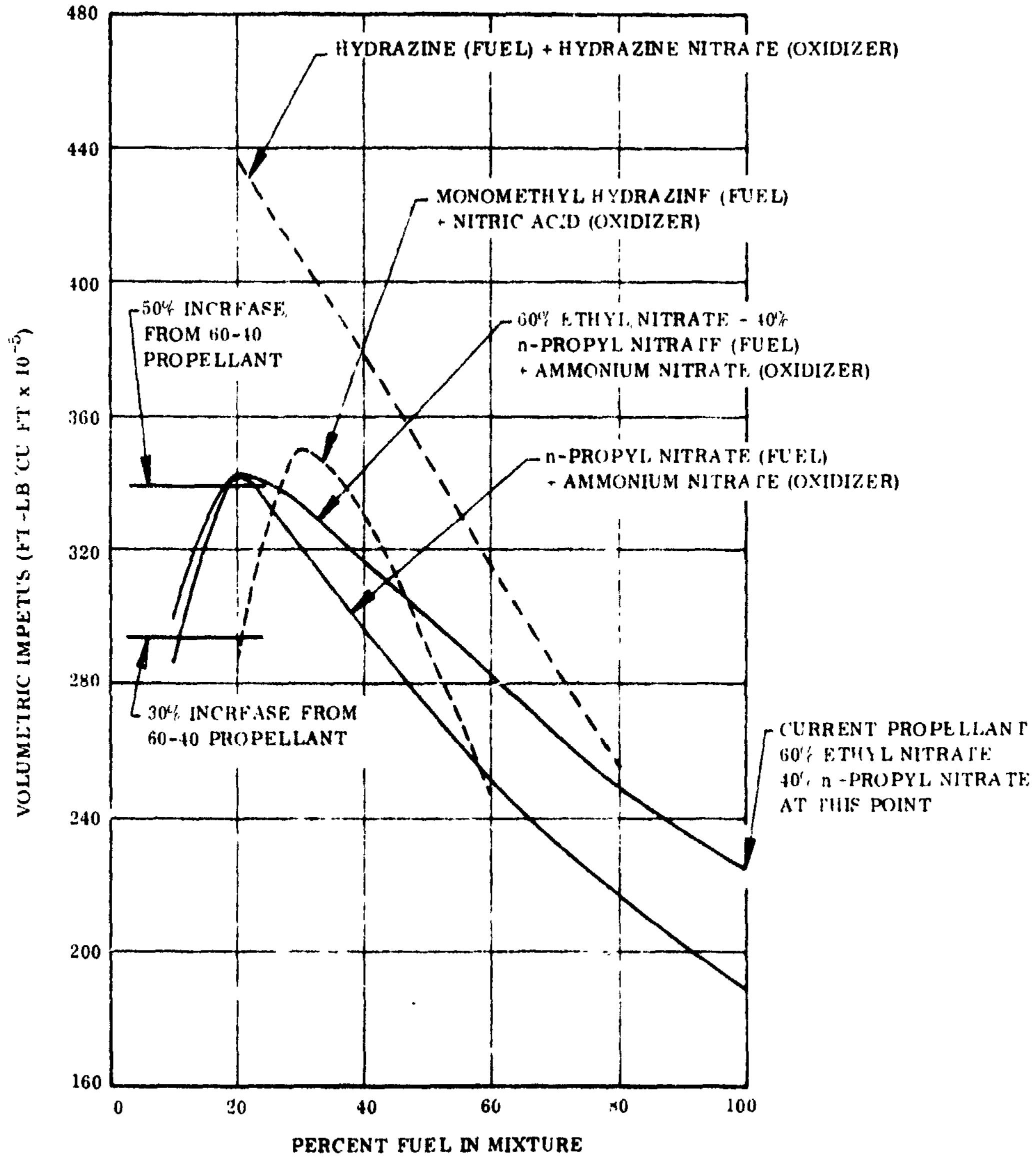


Figure 26. Volumetric Impetus for Several Propellants

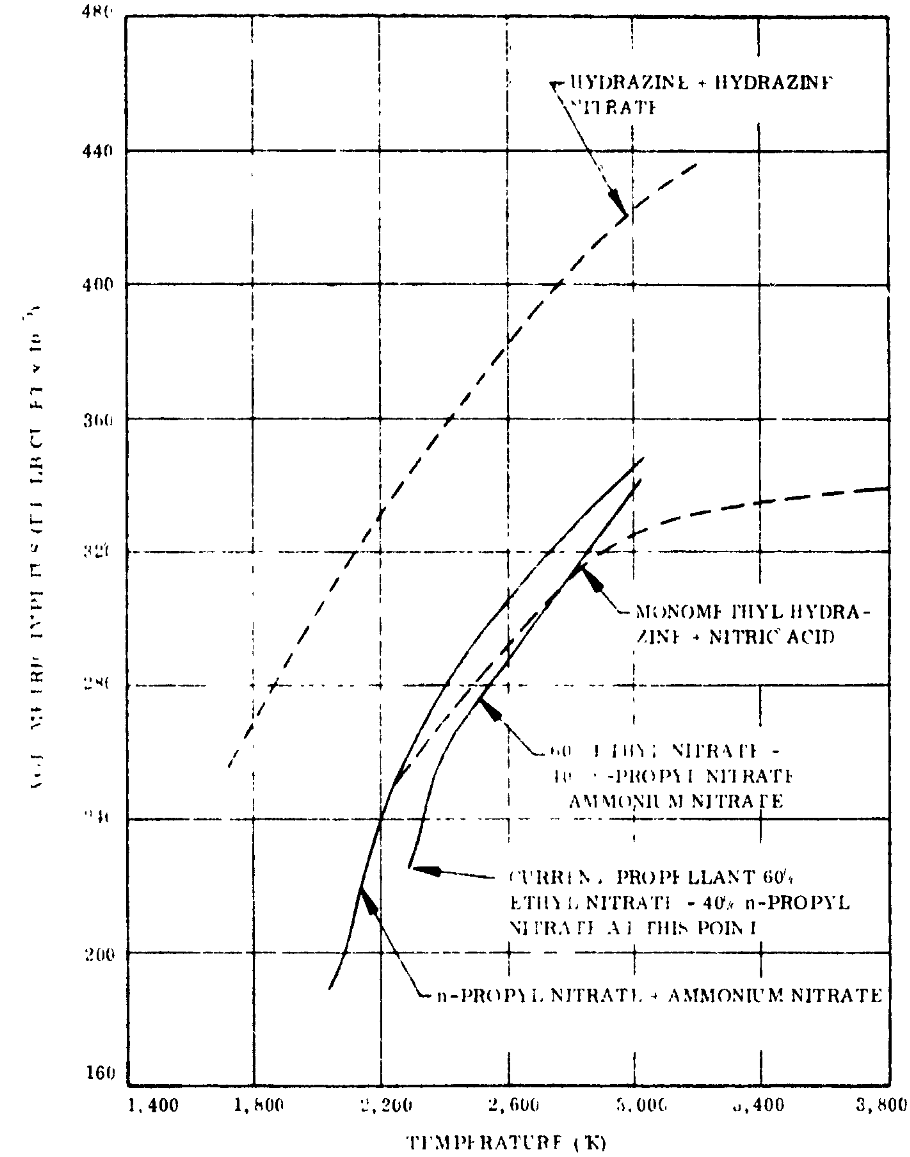


Figure 27. Volumetric Impetus vs Combustion Temperature

Use of an alkyl nitrate monopropellant with an ammonium nitrate fill appeared to be very promising. The freezing point of alkyl nitrates is extremely low (~-100° C) and the boiling point is high (~100° C). The ammonium nitrate is not normally soluble in the alkyl nitrate and should be essentially unaffected by temperature changes. Thus, encapsulation of a slurry or perhaps a gel of ammonium nitrate and alkyl nitrates should result in a high performance round.

An attempt was made to approximate the performance characteristics of capsules containing a gel of alkyl nitrates with ammonium nitrate by gelling a mixture of large capsules and ammonium nitrate within a 7.62 mm cartridge case. The gel offering the best performance consisted of the following:

60/40 ethyl/n-propyl nitrate liquid	80.0%
Carbowax 6000 (polyethylene glycol)	18.6%
Curing and crosslinking agents	1.4%

Figure 2? shows the performance of the gelled alkyl nitrate capsules with 5 grains of ammonium nitrate. Figure 29 shows the results of placing 7.5 grains of ammonium nitrate in the interstices.

These velocities are shown on Figure 30 along with a summary of the 7.62 mm firings conducted during this program. The maximum velocity achieved using only the large capsules was 2,424 fps. A bimodal mixture of large and small capsules containing alkyl nitrates reached velocities of 2,356 fps. Bimodal mixtures of large and small capsules did not perform well, with the one exception of the performance of lot 4-?44.

The highest velocities (up to 3,089 fps) were obtained using gelled mixtures of ammonium nitrate and alkyl nitrate capsules.

B. 20 MM GUN

Anticipating that a larger cartridge case may more fully utilize the capability of encapsulated propellant, Thiokol tested seven rounds having varying charge-to-weight ratios in a 20 mm gun. The breech pressures are shown in Figure 31 and the velocities in Figure 32. Also shown in Figure 32 are the velocities recorded from 20 mm firings conducted by the Air Force Armament Laboratory using encapsulated monopropellant. All firings were performed using only the large diameter propellant capsules as the smaller capsules were not available at the time. Performance of five 20 mm standard rounds from lot LC-Y-20-8100 showed an average velocity of 3,373 fps at a breech pressure of 51,000 psi. The specified performance of these standard rounds is 3,387 fps at 51,000 psi.

The initial samples of small capsules were received and scheduled for testing. Prior to firing bimodal mixtures, rounds were fired at the charge-to-weight ratios shown in Figure 33. Also shown are 20 mm velocities measured eight weeks earlier. It is noted that velocities are from 270 to 350 fps slower than those measured eight weeks earlier. This performance degradation also has been seen in the performar of the 7.62 mm NATO cartridge wherein the average velocity of two 5-round samples

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
33.5-GRAIN LOAD
LOADING DENSITY: 87.7%
PVA WALL

AMMONIUM NITRATE

SILANE COATING
50 TO 700 μ DIA
5-GRAIN LOAD

GEL

9.8 GRAINS ALKYL NITRATE
2.3 GRAINS CARBOWAX 6000
1.1 GRAINS OTHER

PRIMER

REMINGTON 9-1/2

CARTRIDGE

7.62 MM
150-GRAIN BULLET

PRESSURE SCALE

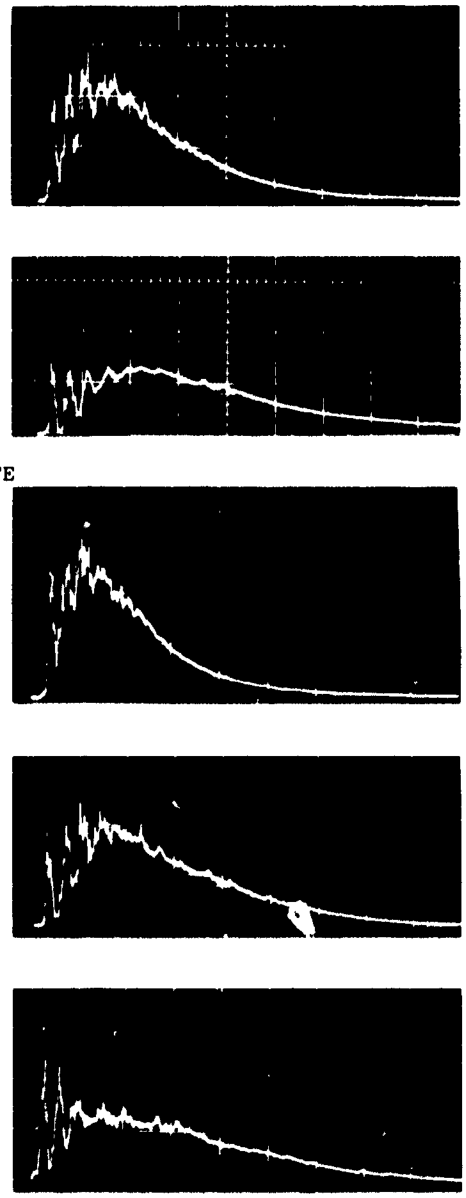
20,000 PSI/CM

TIME SCALE

0.2 MSEC/CM

AVERAGE VELOCITY

2,662 FPS



PROJECTILE VELOCITY (FPS)

2,716
ROUND 575

NO TIME
ROUND 576

2,732
ROUND 577

2,676
ROUND 578

2,523
ROUND 579

Figure 28. Breech Pressure, 33.5 Grains Monopropellant, 5 Grains Ammonium Nitrate, 9.8 Grains Gelled Monopropellant

<u>CAPSULES</u>

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
33.5-GRAIN LOAD
LOADING DENSITY, 87.7%
PVA WALL

<u>AMMONIUM NITRATE</u>

SILANE COATING
40 TO 700 μ DIA
7.5-GRAIN LOAD

<u>GEL</u>

9.8 GRAINS ALKYL NITRATE
2.3 GRAINS CARBOWAX 6000
1.1 GRAINS OTHER

<u>PRIMER</u>

REMINGTON 9-1/2

<u>CARTRIDGE</u>

7.62 MM
150-GRAIN BULLET

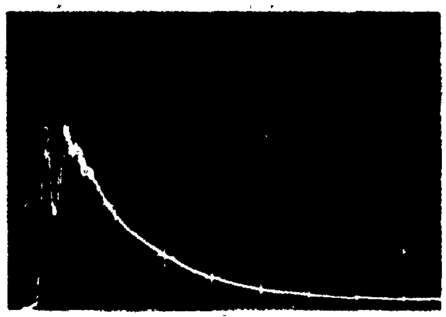
<u>PRESSURE SCALE</u>

20,000 PSI/CM

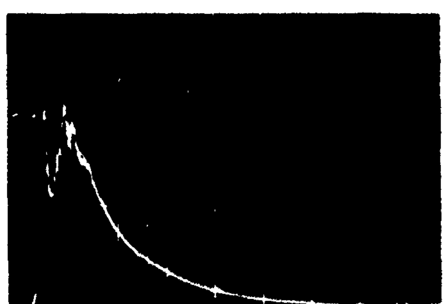
<u>TIME SCALE</u>

0.2 MSEC/CM

PROJECTILE VELOCITY (FPS)



2,843
ROUND 585



2,844
ROUND 586

Figure 29. Breech Pressure, 33.5 Grains Monopropellant, 7.5 Grains Ammonium Nitrate, 9.8 Grains Gelled Monopropellant

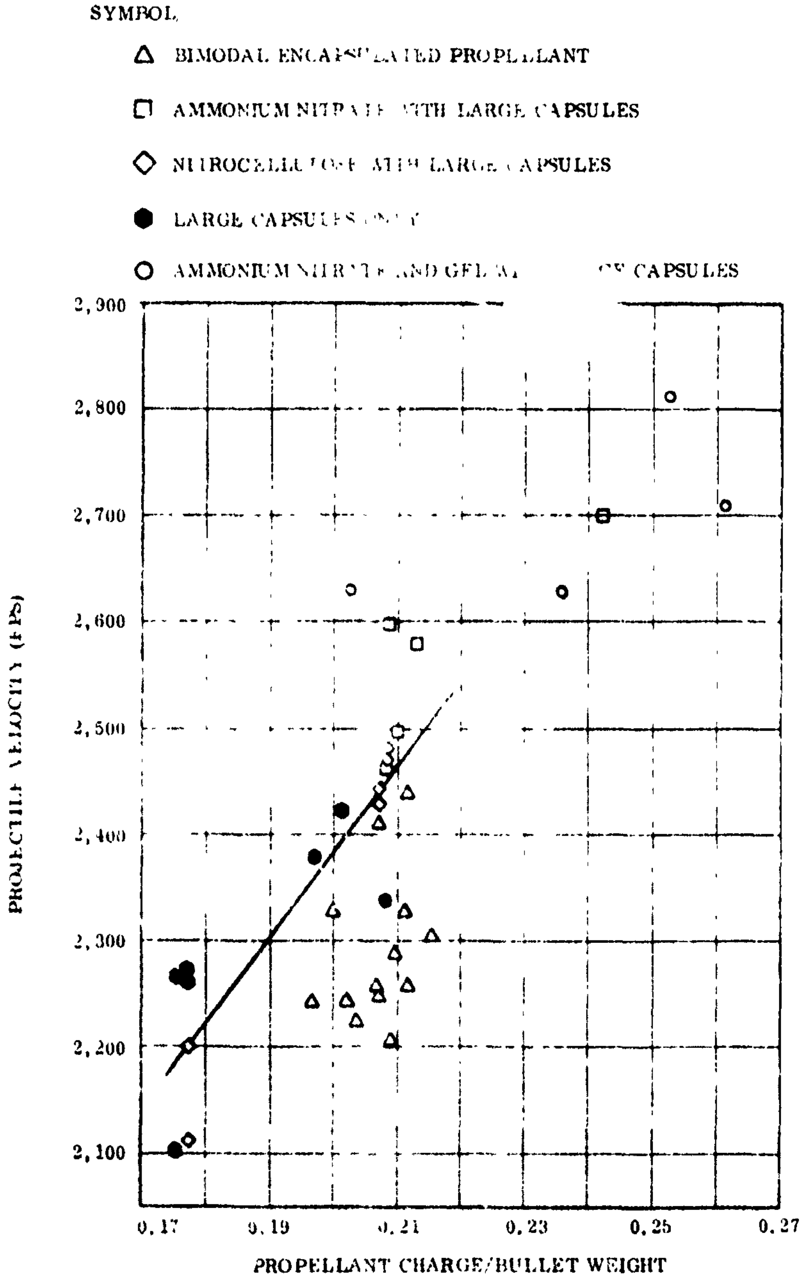


Figure 30. Summary of Encapsulated Monopropellant Performance

CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410 μ DIA
LOADING DENSITY: 87.7%
PVA WALL

PRIMER

MILITARY .50 CALIBER
(PERCUSSION)

CARTRIDGE

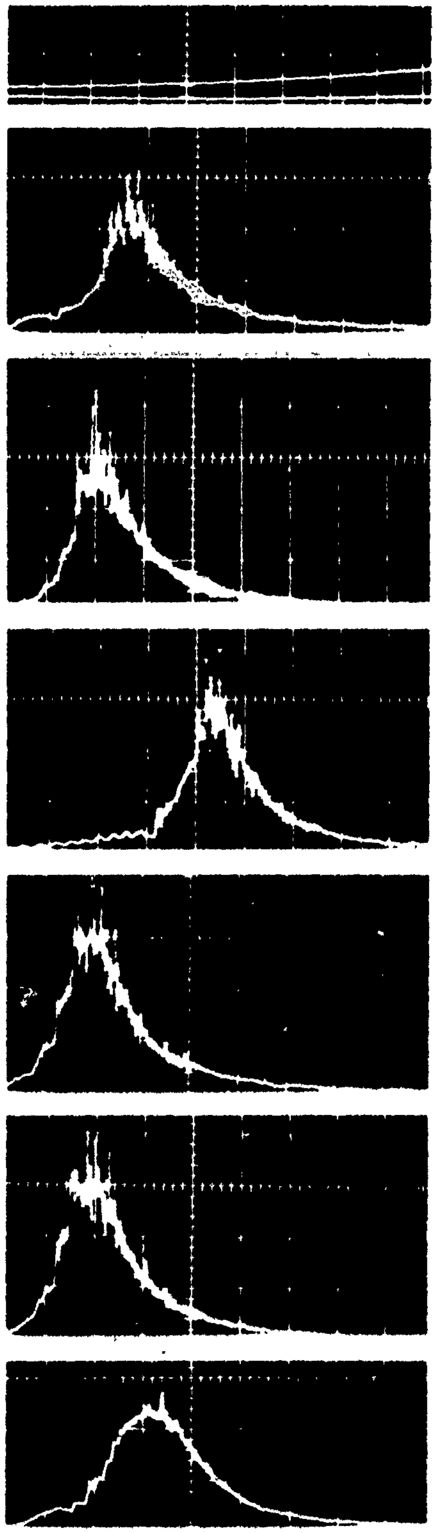
20 MM M103
XM 221E1 PROJECTILE

PRESSURE SCALE

10,000 PSI/CM

TIME SCALE

0.2 MSEC/CM



PROJECTILE VELOCITY (FPS)

1,956
ROUND 1001
165.8 GRAINS

2,203
ROUND 1002
184.2 GRAINS

2,403
ROUND 1003
202.1 GRAINS

2,470
ROUND 1004
220.6 GRAINS

2,618
ROUND 1005
239.0 GRAINS

2,688
ROUND 1006
257.2 GRAINS

2,639
ROUND 1007
275.7 GRAINS

Figure 31. Breech Pressure, 20 mm, 87.7% Capsule Loading Density

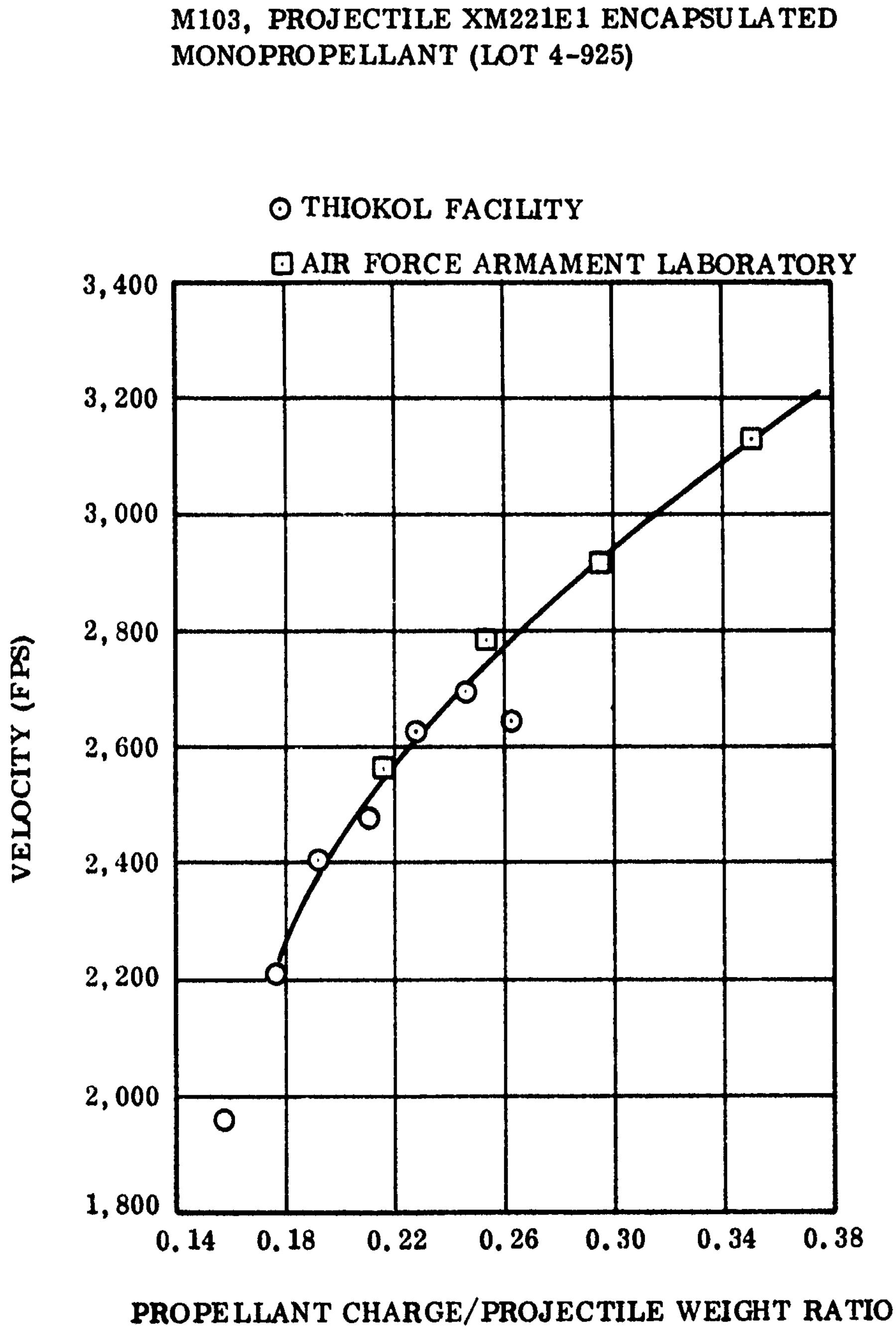


Figure 32. Projectile Velocity, 20 mm Gun

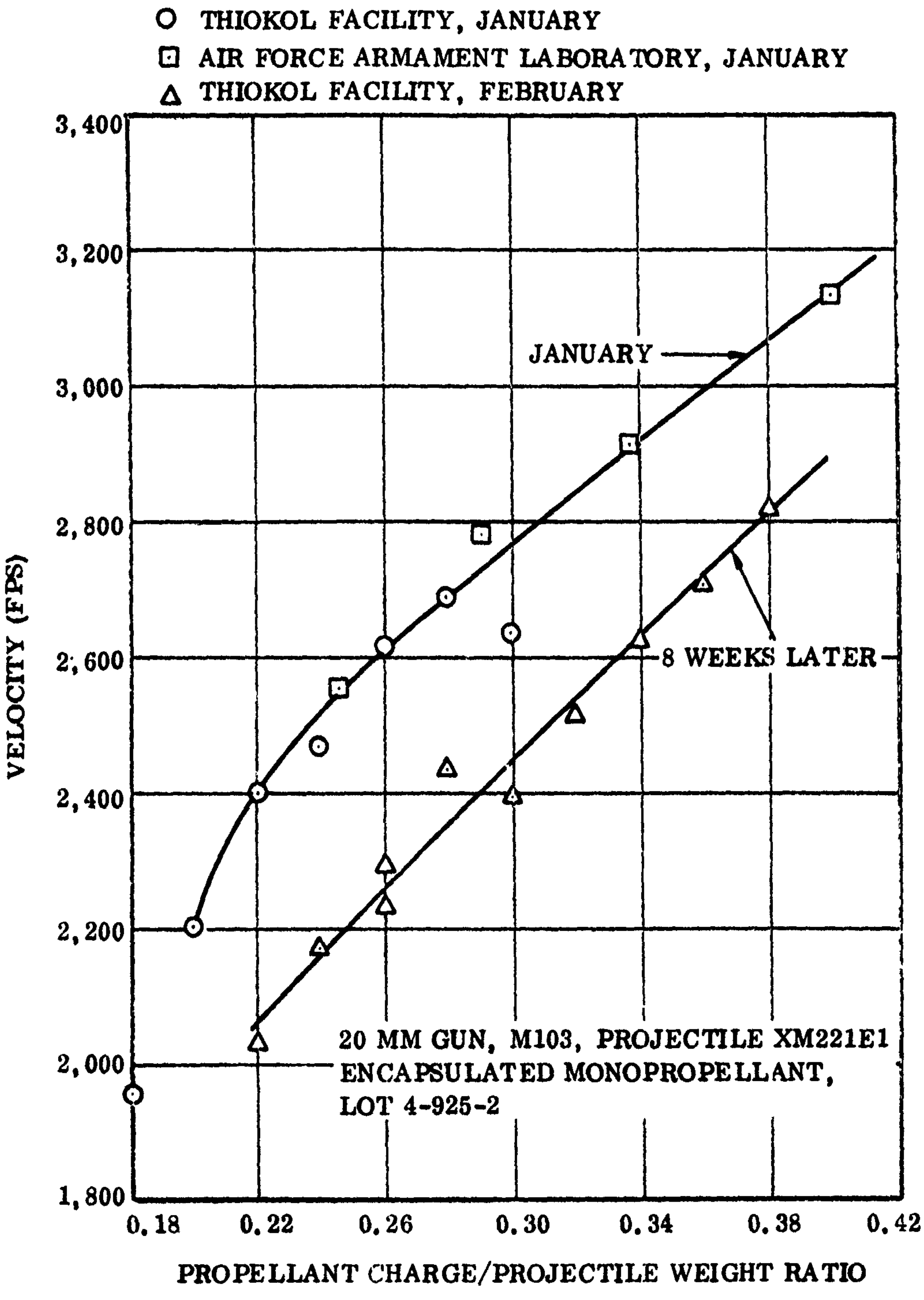


Figure 33. Projectile Velocity Decrement Over Eight-Week Period

decreased 82 fps in a one-month period. This decrement in performance is apparently due to a propellant vapor loss through the capsule wall, which in turn is lost to the atmosphere when the propellant storage container is opened.

There are several ways to prevent this performance loss. The obvious way to prevent propellant loss is to load the propellant into the cartridge case immediately after propellant manufacturing. The sealed cartridge case would retain any propellant which might permeate through the capsule wall. This loss should be small because a loss of propellant would increase the pressure in the case slightly until a vapor-liquid phase equilibrium was attained.

Additionally, the permeability of the capsule wall probably can be decreased by changing either the basic wall materials or varying the composition of the existing wall materials. The propellant within the capsule may be rendered less volatile by gelling the propellant within the capsule.

Bimodal propellant mixtures were fired in the 20 mm gun. We found that mixing small diameter capsules (ca 60 microns diameter) with the large capsules (840 to 1,410 microns diameter) produced no measurable increase in velocity. Two representative samples of the pressure-time traces are shown in Figure 34.

Again, the small propellant capsules probably did not burn and were blown through the barrel as inert material. During 7.62 and 20 mm bimodal firings, the small diameter propellant occasionally remained unburned in the cartridge after firing. In addition, previous testing showed that smaller diameter capsules (250 to 500 microns) did not perform as well as capsules with diameters greater than 500 microns. The small capsules are less prone to rupture than larger capsules when in a bimodal mixture and therefore are more difficult to ignite.

Improved performance of the smaller capsules should occur with an increase in the capsule fill percent. With the capsule diameter remaining constant, an increase in the fill percent will occur by decreasing the thickness of the capsule wall allowing a greater propellant volume within the capsule sphere. A thinner, more fragile capsule wall would fracture easier during cartridge ignition and combustion, allowing the enclosed propellant to burn.

LARGE CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
840 TO 1,410μ DIA
376 GRAIN LOAD
(330 GRAINS LIQUID)
LOADING DENSITY: 87.7%
PVA WALL
LOT 4-925 #4

SMALL CAPSULES

60% ETHYL NITRATE
40% N-PROPYL NITRATE
105 TO 250μ DIA
125 GRAIN LOAD
(57.8 GRAINS LIQUID)
LOADING DENSITY: 46.3%
PVA WALL
LOT 4-956

PRIMER

Electrical

CARTRIDGE

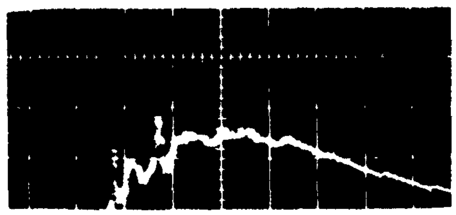
20 MM M103
XM 221E1 PROJECTILE

PRESSURE SCALE

20,000 PSI/CM

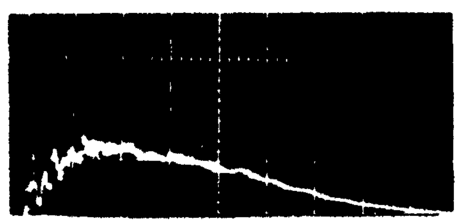
TIME SCALE

0.2 MSEC/CM



PROJECTILE VELOCITY (FPS)

2,595
ROUND 1028



2,657
ROUND 1029

Figure 34. Breech Pressure, 20 mm Bimodal Firings

SECTION VIII
CONCLUSIONS

1. Good repeatability was demonstrated by encapsulated monopropellant rounds.
2. Near standard velocities were achieved with 20 mm rounds using only encapsulated alkyl nitrate propellant.
3. Standard velocities were difficult to achieve with the 7.62 mm cartridge when using current encapsulated alkyl nitrates because of the low volumetric impetus.
4. Greater propellant volumetric impetus is required to obtain standard velocities in both the 7.62 mm and 20 mm rounds.
5. Ammonium nitrate combined with the alkyl nitrates appears to provide the means to increase the volumetric impetus of the propellant with only modest increases in combustion temperature.
6. Standard velocities were obtained with the 7.62 mm NATO cartridge using encapsulated alkyl nitrates, plus an interstitial fill of polyethylene glycol gels of alkyl nitrates, plus ammonium nitrate.
7. Small capsules as currently fabricated will not burn because of high permeation losses during drying, and comparatively thick, strong walls which inhibit capsule fracturing.

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11 SUPPLEMENTARY NOTES

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13 ABSTRACT

Ammunition containing bulk loaded liquid monopropellant has the desirable characteristics of low flame temperature, high energy, reduced smoke and flash, and reduced fouling and longer barrel life. However, liquid monopropellants do not burn stably under the conditions existing in bulk loaded cartridges. High and erratic pressures are accompanied by high frequency, high amplitude pressure excursions. Extensive experimentation has not solved this problem. The results of this study showed that the problems of bulk loaded monopropellant can be overcome by encapsulation of the monopropellant into small spheres. Test firings in 7.62 mm NATO cartridges demonstrated good repeatability, and standard velocities were obtained while using polyethylene glycol gels of encapsulated alkyl nitrates plus ammonium nitrate. Standard velocities were difficult to achieve with the 7.62 mm cartridge when only using current encapsulated alkyl nitrates because of low packing fractions. The use of bimodal encapsulated propellants did not provide the expected performance gains. The small capsules, as currently fabricated, would not burn because of (1) high permeation losses during the drying cycle of the fabrication process and (2) comparatively thick, strong capsule walls which inhibit fracturing during firing. Near standard velocities were achieved with 20mm rounds using only encapsulated alkyl nitrate propellant. It is recommended that further research be completed to increase performance by using capsules contained gelled alkyl nitrates encapsulated with ammonium nitrate.

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Alkyl nitrate						
Capsule size						
Capsule wall material						
Primer						
7.62 mm NATO ammunition						