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A CONSUMABLE CASE FOR ARTILLERY SYSTEMS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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The inherent lack of rigidity and the complexity of bagged propelling charges and the associated ignition components can lead to incorrect alignment and/or assembly of the charge. Catastrophic failures in the 155-mm howitzer system, for example, have been attributed to incipient ignition problems exacerbated by a poorly assembled charge. A well-designed consumable case could alleviate these problems by assuring ignition system alignment and control of charge location within the chamber while simplifying the fabrication of the charge. To test this concept, a feasibility study has been conducted in the 155-mm

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A howitzer prototype consumable case was fabricated from available felted nitrocellulose components and test firings were conducted. Three types of ignition systems were tested: a base pad and centercore snake of black powder (as used in the M203 Propelling Charge), a centercore snake alone (113 g Class 5 black powder), and an igniter constructed of 113 g of Class 5 black powder placed in three 1-cm diameter plastic tubes within the centercore tube. The results indicated: 1) the consumable case gave performance comparable to the M203 charge; 2) the base pad/snake igniter gave larger pressure waves than the two types of centercore igniters alone; 3) the igniter system based upon the plastic tubes gave the best performance; and 4) there was no significant increase in residue with the consumable case.

A consumable case for large caliber, separate loading, ammunition appears feasible based on the results of these tests. A well designed consumable case should be much less complex than conventional bagged charges. The rigidity of a consumable case and the precision of the manufacturing process should eliminate the persistant problems (e.g., ignition delay, pressure waves, velocity variation, etc.) which are the result of the misalignment of critical ignition train components and poor tolerances inherent to bagged charges. Therefore, major benefits of a consumable case should be improved safety and precision as well as good automatic handling and loading characteristics.

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I. INTRODUCTION

Current consumable* case technology may offer a realistic alternative to conventional bagged propelling charges whose inherent characteristics can lead to performance problems. Bagged charges are currently used in Army 155-mm, 175-mm, and 8-in. cannon systems to be compatible with the requirement for separate loading ammunition. Some of these charges are complex and non-rigid. This results in considerable variation in the interaction of the components, particularly the ignition train, which can lead to severe performance problems. Catastrophic failures in the 155-mm howitzer[1] and 175-mm gun systems, for example, have been attributed to incipient ignition problems exacerbated by misalignment of components in a poorly assembled charge. A well-designed consumable case could alleviate these problems by assuring both an aligned ignition system and a more controlled charge geometry while simplifying the fabrication of the charge.

Performance Problems Associated With Bagged Charges in Artillery

A brief discussion of performance problems associated with bagged charges in artillery systems is given in the following sections.

Complexity. The bagged propelling charge and ignition train form a complex system with many variables. This system is further complicated when placed within the gun chamber and interfaced with the percussion primer as illustrated in Figure 1.

**The term "consumable" is used here to denote materials which are completely decomposed during the interior ballistic cycle. It includes those materials which do not add significant energy to the system (e.g., plastics or kraft paper) and those, such as felted nitrocellulose, which are fairly energetic. The term "combustible cases" is often associated with the latter materials.*

[1]*H. Hassman and A. Yermal, "Controlled Ballistic Firing at Aberdeen Proving Ground Relating to Malfunction Investigation of 155-mm Propelling Charge, XM123E1 in 155-mm Towed Howitzer, XM198," Ammunition Development and Engineering Directorate, Picatinny Arsenal, July 1973.*

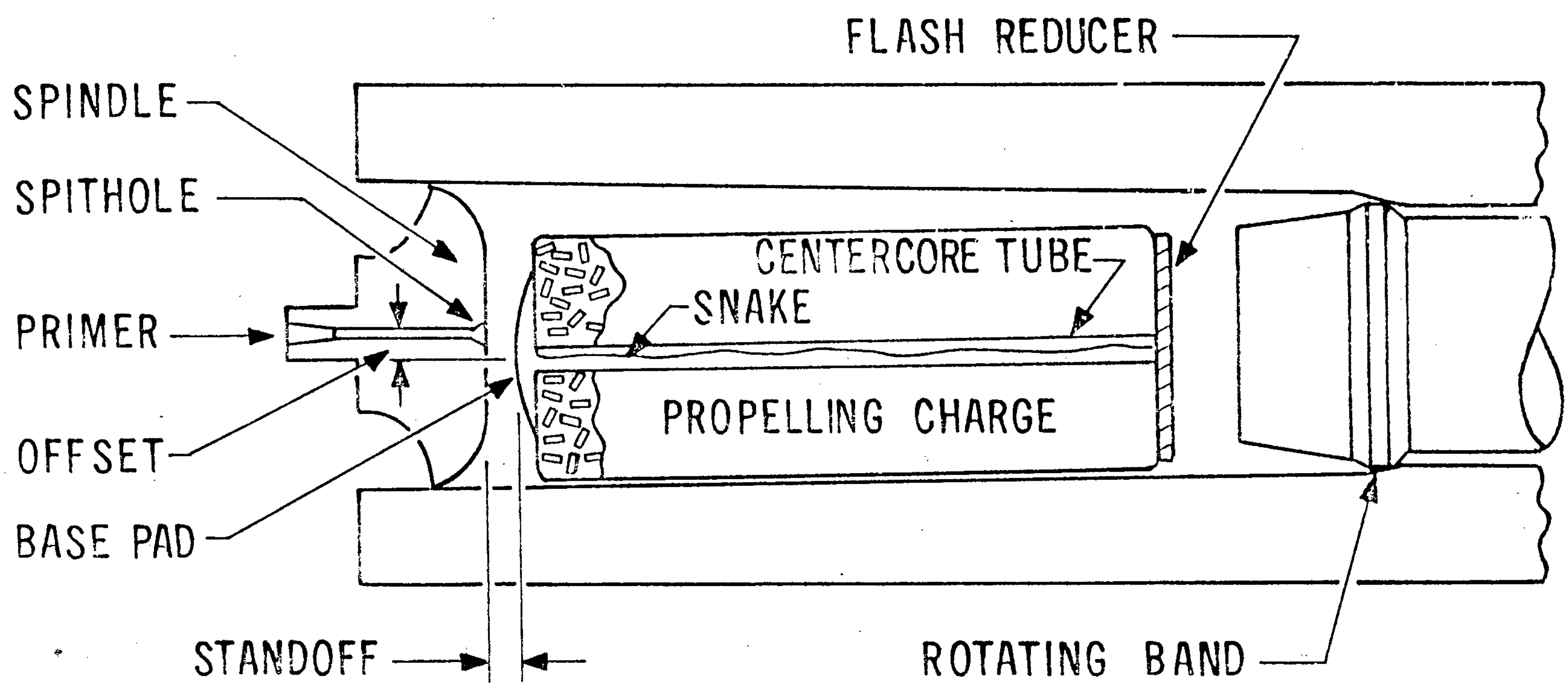

Figure 1. Typical Centercore-Igniter, Bagged Charge in the Gun Chamber

A typical, high performance, bagged charge (Figure 2) consists of a heavy cloth bag to contain the granular propellant. A rigid, felted-nitrocellulose, centercore tube is located along the axis of the charge and it contains igniter material in a cloth bag or "snake". A pad, also containing igniter material, is attached to the base of the charge. A bag containing a flash reducing agent is usually attached to the forward end of the charge. Additional components such as lead foil decoppering agent and a wear-reducing additive liner, consisting of cloth impregnated with titanium dioxide and wax, are also located around the circumference of the charge. A heavy cloth lacing jacket is used to improve rigidity. The charge may be monolithic or may have two or more detachable segments for multiple firing zone applications.

The alignment of the charge is not coaxial with the chamber for two reasons. The charge is made smaller than chamber diameter to facilitate loading and there is a slight forward taper to the chamber. The length of the charge is less than that of the chamber. This results in a variable space or standoff between the spindle and the charge and between the charge and the base of the projectile.

The ignition system and sequence of operation are also complex. The primer (located in the spindle), base pad, centercore tube, and snake form the ignition train. The basepad is an energy transfer medium between the primer and the centercore snake designed largely to improve the reliability of centercore ignition. The ignition sequence begins when the primer is initiated and sends hot gases and particles through the spithole in the spindle into the base pad. The igniter material in the base pad is, in-turn, initiated and provides the ignition stimulus to the centercore snake. Rapid axial flame spread should occur in the snake followed by radial spread of hot gases and particles into the propellant bed. The objective is to provide nearly simultaneous ignition of the propellant along the charge axis[2]. This is to prevent formation of pressure waves which can arise if localized ignition occurs at the base of the charge[3].

Floating Geometry. It is the cloth used to construct bagged charges which, by its very nature, lacks rigidity and therefore leads to a major problem - floating geometry. This means that there can be significant variations in the dimensions of the charge and in the physical alignment between critical components. The most important examples of the geometry problem are given in Table 1. Besides lacking rigidity, bagged charges are complex to assemble and it is difficult to achieve good quality control. To complicate the problem, the charge geometry can change with handling.

[2] *R. H. Kent, "Study of Ignition of 155-mm Gun in Connection with Project KW250 -- Study of the Factors Involved in the Design of Propelling Charges", BRL Report No. 4, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, February 1935.* (AD #PB22090)

[3] *I. W. May, C. W. Nelson, J. J. Rocchio, and K. J. White, "The Role of Ignition in Artillery Propulsion", Proceedings of the 3rd International Symposium on Ballistics, March 1977.*

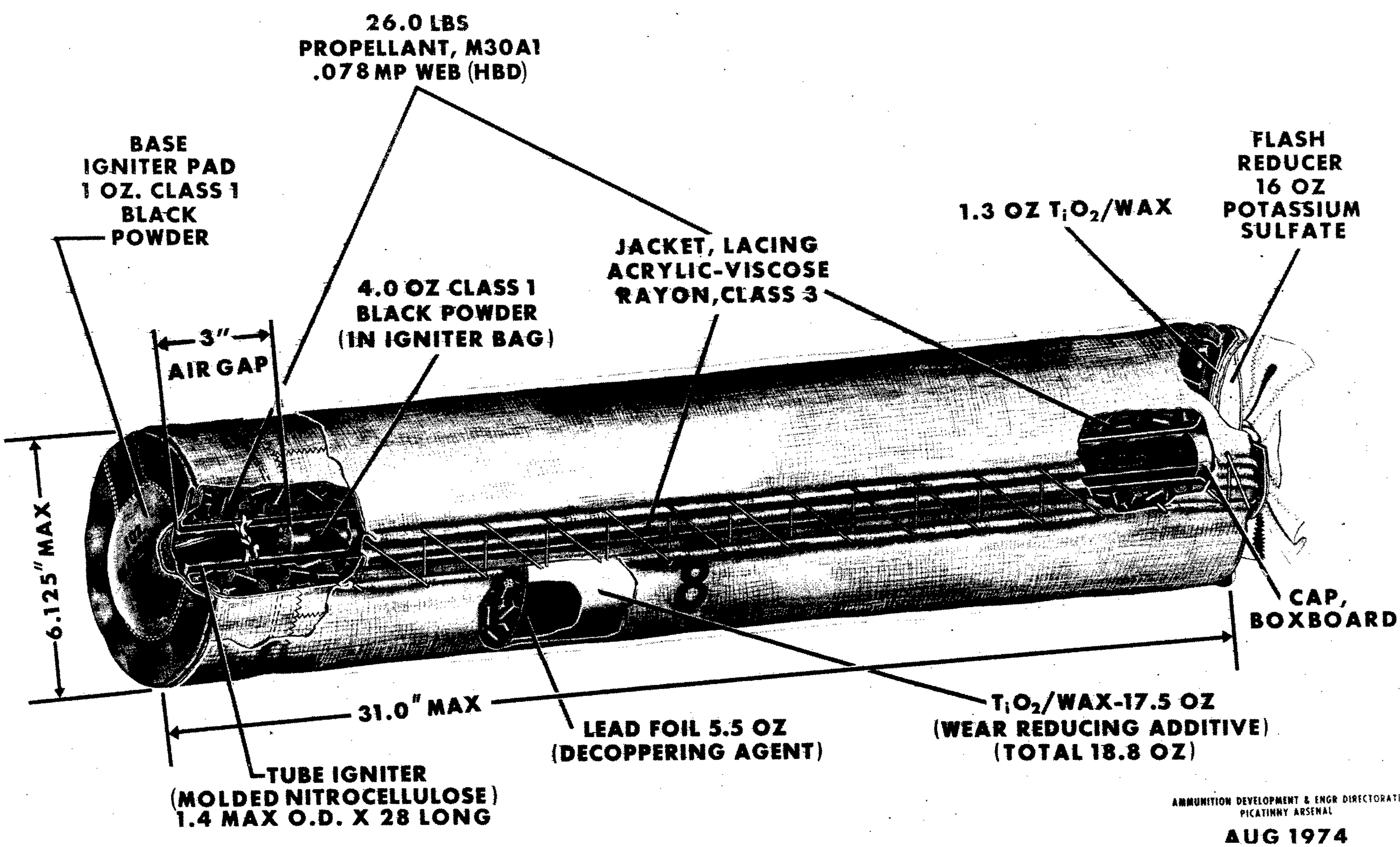

Figure 2. Construction of a Typical High Performance Bagged Charge, the XM123E2 Interim

TABLE 1. VARIATIONS IN BAGGED CHARGE GEOMETRY

Variable	Variation
Charge length	$\pm$ 25 mm, 3%
Charge diameter	$\pm$ 6 mm, 4%
Charge-centercore alignment	$\pm$ 10 mm, 12%
Base pad-centercore alignment	$\pm$ 12 mm, 12%
Primer-base pad alignment	+ 0, - 18 mm

The most critical result of the floating geometry can be malfunction of the ignition train. This can lead to long ignition delays, localized ignition, and ensuing pressure waves, resulting in increased ballistic variability and in some cases catastrophic failure.

An example of the effect of charge rigidity on pressure waves in an 8-in. howitzer is given in Table 2. Charges with the rigidity improved by a full length lacing jacket had qualitatively better ignition system performance under both cold and hot firing conditions. This is evidenced by the trend to lower values of the initial negative pressure difference ($-\Delta P_i$)*.

Pressure differences are the difference in pressure between a pressure gage located in the breech and one located at the forward end of the chamber. ($\Delta P = P_{breech} - P_{forward}$).

The first negative excursion of this value ($-\Delta P_i$) is used as a diagnostic of ignition system performance and pressure wave formation. Large $-\Delta P_i$ are indicative of more localized (at the base) ignition of the propellant bed and more severe ensuing pressure waves[4,5]. See Appendix F for examples.

[4] *I. W. May, and E. V. Clarke, "The Reverse Pressure Gradient: A Tool for Assessing the Effects of Wave Dynamics on the Ballistic Performance of Guns," Proceedings of the 2nd International Symposium on Ballistics, March 1976.*

[5] *A. W. Horst, I. W. May, and E. V. Clarke, Jr., "The Missing Link Between Pressure Waves and Breechblows", ARBRL-MR-02849, USAARRADCOM, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, July 1978.* (AD #A058354)

TABLE 2. EFFECT OF IMPROVED CHARGE RIGIDITY ON PRESSURE WAVE CHARACTERISTICS

	"Loose" Charge		"Rigid" Charge	
T	$-\Delta P_i$	σ	$-\Delta P_i$	σ
(°C)	(MPa)	(MPa)	(MPa)	(MPa)
-45	3.8	1.4	2.5	1.7
63	8.9	8.7	5.0	4.2

Source: DTII Safety Test (1977) M188E1 Propelling Charge for 8-in., M110A1E2, Howitzer
Note: flash reducer moved to end of charge in "rigid" charge

The consumable case offers significant improvements in the floating geometry problem. The geometry of a consumable case can be fixed by design and construction. The strength of the components can be made sufficient to maintain geometry with tolerances on the order of 2.5 mm or better. Quality control should also be improved.

Primer-Ignition System Interaction. The separation between the spindle face and base pad (Figure 1), charge standoff, can vary from 0 to about 150 mm for a top zone centercore charge. Because localized ignition at the base of the charge has occurred at standoffs less than 25 mm, the 155-mm, M198, and 8-in, M201, Howitzers are equipped with metal protrusions on the spindle to assure a minimum 25-mm standoff. Some charges, particularly the shorter ones for lower zones, can be placed well forward in the chamber resulting in larger standoffs. The variability in standoff affects the transmission of the ignition stimulus from the primer to the base pad and, perhaps more significantly, the subsequent transfer to the snake*. Localized ignition, pressure waves, and increased ballistic variability result.

The primer-base pad interaction is also affected by the fact that the primer spithole and the charge are not coaxial (see Figure 1). The effect of this misalignment can be compounded by the variable charge standoff. Table 3 gives an example of the effect of charge-spithole alignment on ignition delay times under cold firing conditions. A significant reduction in the delay times can be achieved by aligning the charge with the spithole. Coaxial alignment can be achieved by modifications to the spindle as has been done in the M198 howitzer. This does not treat the alignment problems due to variations in charge dimensions and geometry.

* *In some howitzer systems, the lower zone charges (lower charge weights) use a base pad igniter alone. These still are affected by variable standoff.*

TABLE 3. EFFECT OF CHARGE-SPITHOLE ALIGNMENT ON IGNITION DELAY TIMES AT -54°C

	Ignition Delay (ms)	
	Normal Charge Misalignment*	Coaxial Alignment
	225	75
	215	104
	246	187
	210	125
	215	164
	(4800) - Hangfire**	236
Mean	222	149

*Charge axis approximately 15 mm below spit hole axis. Data from Picatinny Arsenal Interrupted Burner Tests, March 1975, XM203E1, H. Hassmann, private communications.

**Not included in Mean.

A consumable case can reduce the variability in the primer-ignition system interaction. A fixed charge standoff and a coaxial primer and centercore can be assured by the design of the consumable case.

Flame Barriers. The materials used to construct the charge and igniter bags can act as barriers to flamespreading through the ignition train and to the granular propellant bed. This effect is related to the nature of the cloth used and the number of layers. The principal problem which results is localized ignition under low temperature conditions.

The flame barrier problem may be alleviated by a consumable case. The density, thickness, porosity, and composition of the material (e.g., felted nitrocellulose) can be used to control the flame propagation characteristics.

Projectile Fallback. The fallback of a projectile from its normal position at the origin of rifling into the chamber is a serious potential problem at high tube elevations, primarily with low zone (short) charges. When the charge is ignited, a projectile in the chamber will be accelerated forward into the bore and will then be decelerated upon encountering the rifling. This deceleration can place large loads on the payload and lead to detonation of high explosive fills in-bore, or failure of sensitive elements of fuzes or guidance packages. A sudden increase in angular acceleration as the projectile engages the rifling may lead to frictional initiation of the fill.

A consumable case could eliminate the fallback problem. The size, shape, and physical strength of the case could be tailored to provide the necessary support should the projectile become dislodged from the origin of rifling.

The Consumable Case Alternative

The consumable case offers a realistic alternative to the bagged propelling charge. The potential benefits of the consumable case in alleviating performance problems of bagged charges were mentioned previously and they are summarized in Table 4.

TABLE 4. POTENTIAL BENEFITS OF CONSUMABLE CASES

- Dimensions controllable to 2.5-mm tolerances
- Fixed standoff
- Controlled alignment between primer and ignition system components
- Simplified ignition system design
- Improved uniformity of ignition and reduced ignition delay times (especially important for soft recoil guns)
- Reduction in potential for projectile fallback
- More adaptable to autoloading and sliding breech mechanisms
- Simplified quality control
- Easier to automate production and loading/assembly/packaging
- Potential lower wear and erosion (case may act somewhat like a wear-reducing additive liner)

There are also some potential problems with the consumable case (Table 5). The basic case design, material strength, and combustion characteristics are interdependent. Performance related design considerations could easily compromise advantageous packing and handling characteristics. Aging, surveillance, and vulnerability characteristics are also important considerations which must not be overlooked.

Table 5. POTENTIAL PROBLEMS WITH CONSUMABLE CASES

- Achieving sufficient case strength without unacceptable residue
- Cost (material and facililization)
- Long-term aging characteristics
- Migration of nitroglycerin from propellant into case
- Moisture migration

There has been a considerable technology base developed for consumable cases in the last ten years as indicated in Table 6. The US did early work which resulted in the consumable case for the 152-mm gun/launcher system. Since that development effort, the major work has been done in Europe with the development of consumable cases for tank guns and for the French GCT 155-mm Howitzer.

TABLE 6. WEAPONS WITH CONSUMABLE CASES

Country	Gun System
US	152-mm Gun/Launcher
UK	120-mm Chieftain Tank Gun
	120-mm Tank Gun (with stub metal case)
GE	120-mm Tank Gun (with stub metal case)
France	155-mm GCT Howitzer
USSR	125-mm Tank Gun

The objective of the present work is to demonstrate the feasibility of a consumable case to alleviate the performance problems inherent to a bagged charge. To accomplish this, a prototype consumable case was fabricated for the 155-mm howitzer, and three simplified ignition systems were designed. Firing tests were conducted in order to compare the maximum pressures, velocities, ignition performances, pressure wave characteristics, and residues from the consumable case charges to those from standard, high performance bagged charges. The tests were conducted in the early summer of 1977 and the results were presented at the 1978 JANNAF Propulsion Meeting[6].

[6] *J. J. Rocchio, C. R. Ruth, I. W. May and K. J. White, "A Consumable Case for Artillery Systems", Proceedings of the 1978 JANNAF Propulsion Meeting, CPIA Publication 293, Vol V, pp 541-544, February 1978.*

II. EXPERIMENTAL INVESTIGATION

For the purpose of this feasibility study, the 155-mm howitzer was selected as the test bed and a simple consumable case was designed for it. Extensive experimental investigations of performance in the 155-mm system have been carried out at the Ballistic Research Laboratory (BRL)[7,8] and, therefore, experience and hardware were available. The Large Caliber Weapons Systems Laboratory (LCWSL), as part of the cooperative program, provided the consumable cases and its expertise derived from the 152-mm consumable case development.

Consumable Case

The consumable case was constructed of felted nitrocellulose. The composition of this material is given in Table 7, and a description and schematic of the production process are given in Appendix A. The case consisted of a cylindrical wall section, two end plates, and a centercore tube (Figure 3). Each end plate had a hole in the center and, on the inside surface, there were cylindrical protrusions which fit inside the centercore tube to support it. There was a slight forward taper to the case to conform to the chamber geometry of the M199, 155-mm cannon. The dimensions of the case and components are given in Table 8.

TABLE 7. CONSUMABLE CASE COMPOSITION

Component	% By Weight
Nitrocellulose, Fibrous (12.6%N)	55
Kraft Fiber	9
Acrylic Fiber	25
Resin Binder (Polyvinyl Acetate)	10
Diphenylamine	1

[7] *J. J. Rocchio, K. J. White, C. R. Ruth, and I. W. May, "Propellant Grain Tailoring to Reduce Pressure Wave Generation in Guns", Proceedings of the 12th JANNAF Combustion Meeting, CPIA Publication 273, Vol. I, pp. 275-301, December 1975.*

[8] *J. J. Rocchio, C. R. Ruth, and I. W. May, "Grain Geometry Effects on Wave Dynamics in Large Caliber Guns", Proceedings of the 13th JANNAF Combustion Meeting, CPIA Publication 281, Vol I, pp 369-382, December 1976.*

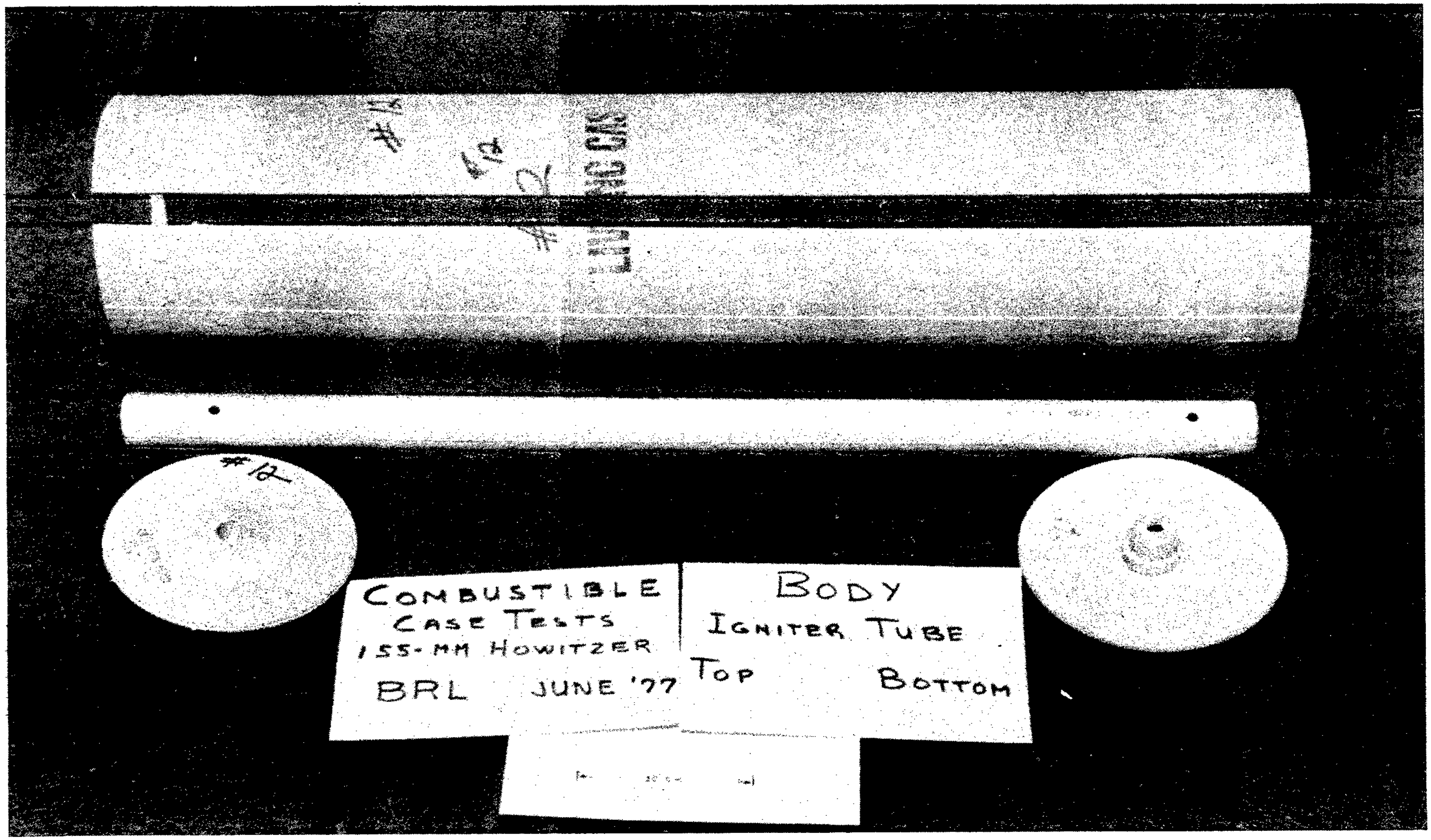

Figure 3. Components of Prototype Consumable Case

TABLE 8. DIMENSIONS OF CONSUMABLE CASE AND COMPONENTS

Case length		737 mm
Case diameter	- base	165 mm
	- forward	158 mm
Wall thickness		3.2 mm
Base plate diameter		159 mm
Forward plate diameter		151 mm
Centercore tube	- length	711 mm
	- outside diameter	32 mm
	- inside diameter	25 mm

The components of the prototype case were produced by modifying parts available from another test program. The tapered cylindrical geometry, for example, was achieved by cutting a section from a larger right circular cylinder. When this was fastened around the end plates with heavy duty tape, the finished geometry resulted. Figure 3 is a photograph of the components before assembly; additional photographs of the components and assembled cases are in Appendix B. A data card for the components is given in Appendix C.

The consumable cases were tapered to fit the chamber. This gave a snug fit so there was little clearance between the case and the chamber wall. For simplicity, a fixed standoff was not built into the prototype design as it would be in a fielded case. The standard 25-mm standoff was manually established by the firing crew during loading into the chamber.

All the consumable cases were assembled with a flash reducer bag (450 g of K_2SO_4) external to the forward end closure of the case. Lead decoppering foil and TiO_2/wax wear-reducing liners were not used with the prototype cases in these feasibility tests.

It should be noted that the overall length of the prototype case plus 25-mm standoff is about 762 mm. This should allow it to be compatible with the chambers of both the M185 and M199 cannons, even when firing the M549 projectile (available chamber length 767 and 822 mm, respectively). Interoperability between these two cannons would be an important bonus for a consumable case. This would not eliminate the potential fallback of the M549 in the M199 cannon although it would place a limit of about 60 mm on the fallback distance.

Ignition Systems

The design of the ignition system was a key part of the feasibility study. One of the more significant benefits of a consumable case is that it should permit a simplified ignition system design by assuring optimum interaction of the ignition train components. Because the prototype design fixed the centercore tube to be coaxial with the primer spithole, we believed that the base pad was not necessary to transfer the ignition stimulus from the primer to the centercore snake. To test this hypothesis, three ignition systems were designed as described in Table 9.

TABLE 9. IGNITION SYSTEM CONFIGURATIONS

Configuration	Igniter Composition
1. Ignition Train from M203, Base Pad and Snake	142 g, Class 1, Black Powder
2. Snake Without Base Pad	113 g, Class 5, Black Powder
3. Three 8-mm Plastic Tubes in Centercore	113 g, Class 5, Black Powder

A base pad and centercore snake from the M203 charge was selected as one design. This allowed a comparison of a standard ignition system with the more simple designs in the same type of charge. The base pad was placed externally to the base plate of the consumable case, with the snake in the centercore tube (see Appendix B).

Class 5 black powder was selected for the other two ignition systems. This was done on the basis of data from Schulman, et. al.,[9] which indicated this material had better flamespreading properties than the Class 1 black powder used in the standard system. Better flamespreading would improve the simultaneity of ignition.

The simplified ignition systems consisted of the centercore igniter alone. In one system, a standard cloth snake was used to hold the black powder. The other simplified system used three plastic tubes* (8.5-mm diameter, 0.13-mm wall thickness, 635-mm length) to contain the igniter. The objective was to improve the axial flamespreading and the plastic tubes would help direct the initial flow of hot gases and particles from the end initially ignited by the primer toward the forward end of the charge. The plastic tubes were placed in the centercore tube so that they were spaced at 120-degree intervals on the inner circumference. This gave an open area down the center for primer and igniter gases to flow unimpeded. Photographs of the assembled tubes are shown in Figure 4 and Appendix B.

Propellants

Two different granulations of M30A1 propellant were used in the firing tests. The first was the standard 7-perforation (0.078-in. web) grain used in the M203 charge. It was selected so a direct comparison to its

**FEP Teflon; Central Plastics, Hanover, New Jersey*

[9] L. Shulman, C. Lenchitz, and L. Bottei, "Laboratory Studies to Develop Reduced Ignition Delays in the 155-mm Howitzer", Proceedings of the 1974 JANNAF Propulsion Meeting, CPIA Publication 260, Vol I, pp 607-620, December 1974.

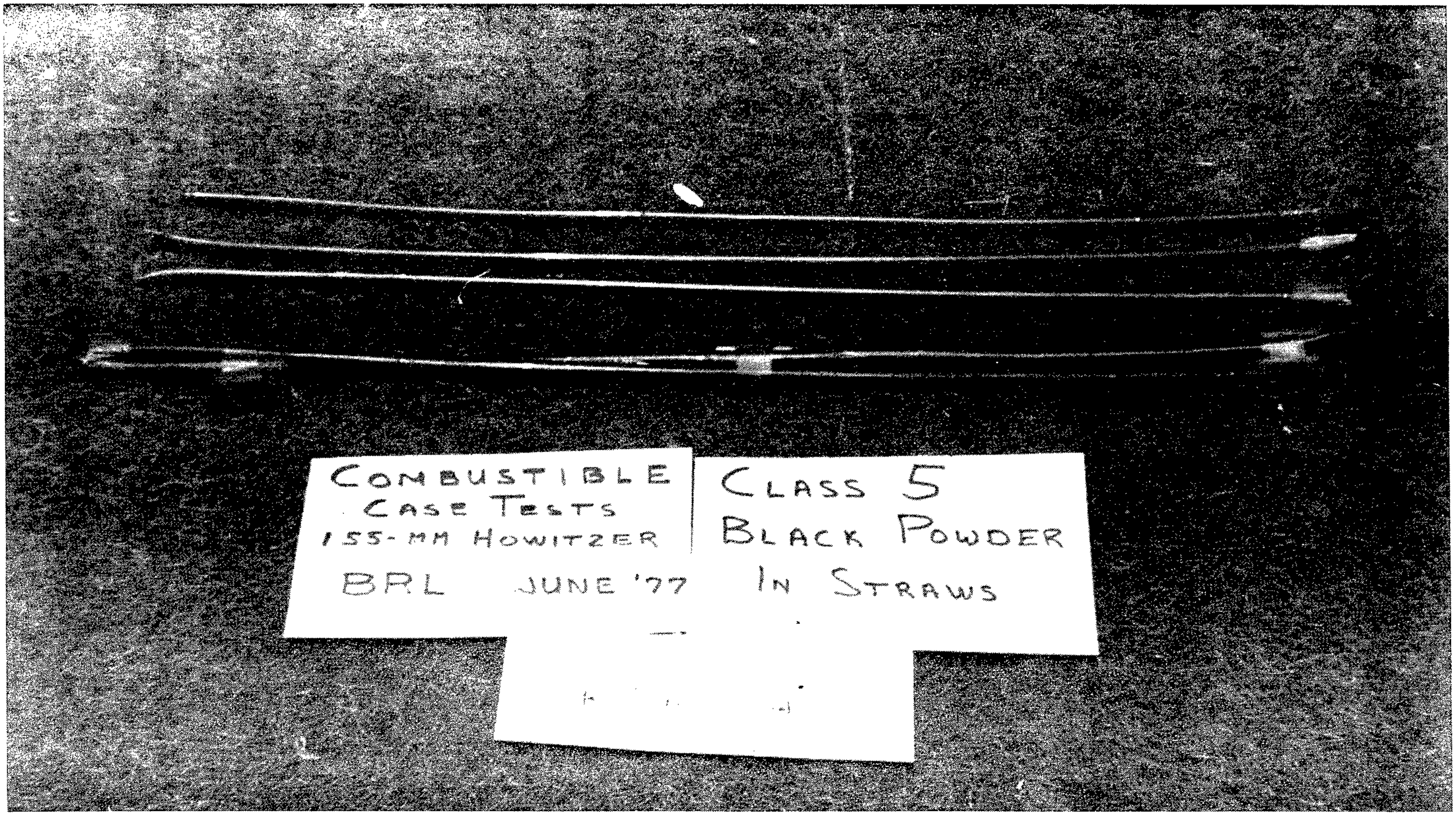

Figure 4. Plastic Tubes Containing Black Powder for Ignition System

performance in the standard bagged charge could be made. A 19-perforation (19MP-CY) grain was also used for limited testing. The objective was to determine if there were any significant differences in the pressure wave characteristics between the two grain geometries in a centercore-ignited, consumable case[5,7,8,10]. The description sheets for these propellant lots may be found in Appendix C.

Firing Residues

It is imperative that any consumable charge (bagged or cased) leave behind little or no residue and, more important, any residue should be extinguished. Smoldering residue could ignite the next charge before the breech is closed, while large amounts of extinguished residue could impair the operation of the breech (particularly with a sliding breech block) and require more frequent swabbing.

Residue measurements were made on each round in the consumable case series as well as with several XM123E2-Interim charges, the prototype of the M203 charge. Cheesecloth was cut into squares, washed to remove sizing, dried, and the masses were recorded. The clothes were moistened with 50-50 alcohol-water solvent and placed in sealed cans. The cloths were then used to swab out the chamber, were dried, and the final masses determined. The increase in mass of the cloth plus any solid material was recorded as the charge residue for each round.

Instrumentation and Test Procedures

All test firings for this program were conducted at the BRL Sandy Point Firing Facility on Spesutie Island. The howitzer used in these tests was an M185 cannon which had been modified to have a chamber geometry similar to the M199 cannon (chamber drawing and dimensions are given in Appendix D). It was instrumented for pressure gages as shown in Figure D-2. Six Kistler, Model 607-C3, piezo gages were used in the chamber: two in the spindle, two at mid chamber, and two in the projectile base region. One of the spindle gages and one of the base region gages were calibrated for low pressures and used to record ignition-related phenomena. Differential pressures (spindle - projectile base) were also recorded. Velocities were measured with solenoid coils located at 21.3 m from the muzzle. A microwave interferometer (15-GHz) was also used to measure projectile displacement vs. time.

The setup of the pressure measuring instrumentation is shown schematically in Figure D-3. The data were recorded by an FM magnetic tape recorder (Honeywell Model 96). The analog data were digitized using

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[10] *A. W. Horst, T. C. Smith, and S. E. Mitchell, "Experimental Evaluation of Three Concepts for Reducing Pressure Wave Phenomena in Navy 5-inch, 54-Caliber Guns: Summary of Firing Data, IHMR 76-258, August 1976.*

a PDP11/20 laboratory computer with a 10-bit analog-to-digital converter and then reduced to finished tabular and plotted format.

An electric-primer-operated firing pin actuator[11] was used to initiate the standard M82 percussion primers used in these tests. Ignition delays were measured from the application of the firing voltage to the electric primer (response time of actuator system is about 1 ms) until the pressure at the breech reached approximately 0.7 MPa above the base line pressure.

At the beginning of each firing day, two warmer rounds (M119 or M4A1 charges with M101 or M107 projectiles) were fired. All rounds were conditioned at ambient temperature (298 - 300 K) before firing and were fired with the gun horizontal.

Test Matrix

The three ignition system designs for the consumable case were test fired at a charge mass of 10.89 kg (Series 13 - 15). This is less than the 11.79-kg charge mass for the M203, Zone 8 charge for the 155-mm howitzer. The lower charge mass was selected because previous experience had shown that an ignition system failure is less likely to result in catastrophic pressure waves at the lower charge mass[8]. Based on the data from these firings, one of the ignition systems was selected for a five-round series to evaluate uniformity of performance at the full 11.79-kg charge mass (Series 16). Two 19-perforation charges were also fired at the 11.79-kg charge mass (Series 17).

III. RESULTS AND DISCUSSION

The prototype consumable cases gave interior ballistic performances similar to those of the standard bagged charges. Significant differences between the three types of igniter systems were exhibited. No significant difference in residue was found between the consumable case and the bagged charge. A summary of the firing data is given in Table 10. For the individual rounds, all the pertinent experimental data are listed in Appendix E and breech, forward, and ΔP pressure-time traces are given in Appendix F.

Ignition System Performance

Of the three ignition systems, the standard base pad and snake (Series 13) gave the largest $-\Delta P_i$ values (Table 10). The spindle,

[11] *J. J. Rocchio, R. A. Hartman, and N. J. Gerri, "An Electric Primer - Operated Firing Pin Actuator for Large Caliber Guns", ARBRL-MR 02897, January 1979.* (AD #A069109)

Table 10. Summary Of Performance Data From Consumable Case Firing Tests

Test Series	Charge Configuration*	Ignition System Configuration**	Number Of Rounds		Maximum Breech Pressure (MPa)	Maximum Forward Chamber Pressure (MPa)	$-\Delta P_i$ (MPa)	Velocity (m/s)	Ignition Delay (m/s)
13	A	1	2	Avg	294	284	-18.9	814	48
				Range	7	7	1.2	4.6	4
14	A	2	1	Avg	297	281	-1.6	819	29
15	A	3	2	Avg	324	282	-1.4	808	44
				Range	13	9	2.8	6.1	16
16	B	2	5	Avg	359	345	-7.4	869	36
				Std Dev	10.3	9.9	2.5	5.9	7
				Range	23	21	6.0	12.2	19
17	C	2	2	Avg	348	332	-9.6	857	35
				Range	23	25	10.2	15.9	18.5

*Charge Configurations:

A 10.89 kg, M30, 7MP, RAD-E-14-1973

B 11.79 kg, M30, 7MP, RAD-E-14-1973

C 11.79 kg, M30, 19MP-CY, RAD-PE-480-16

**1. M203 base pad and snake; 142g, Class 1, black powder.

2. Centercore snake, 113g, Class 5, black powder.

3. Three 8-mm plastic tubes, 113g, Class 5, black powder.

projectile base, and ΔP pressure-time traces are given in Figures F-1 and F-2. It can be seen that there is some structure in both pressure traces which is reflected in the significant pressure waves as shown by the ΔP trace.

The simplified ignition system composed of Class 5 black powder in the centercore snake without a base pad (Series 14) exhibited a smoother pressure-time curve (Figure F-3) and lower $-\Delta P_i$ (Table 10) than the standard ignition system. This indicates better simultaneity of ignition along the charge axis was attained without the base pad.

The best performance was demonstrated by the ignition system composed of Class 5 black powder in the plastic tubes (Series 15, Table 10). One set of pressure traces was perfectly smooth (Figure F-4) with a zero $-\Delta P_i$. The second round in this series gave very low pressure waves (Figure F-5). These results indicate that confining the igniter in the plastic tubes may improve the axial flamespreading thereby improving simultaneity of ignition.

Uniformity Series

The 11.79-kg charge for the 5-round uniformity series (Series 16) utilized the ignition system composed of Class 5 black powder in the cloth snake. Based upon the data presented above, we would have preferred to use the plastic tube igniter system. However, insufficient tubes were available to assemble the test charges. The data from Series 16 are also presented in Table 10, and are compared to the performance of the XM123E2 Interim (the prototype of, and essentially the same as, the M203) charge in Table 11. Pressure-time traces are shown in Figures F-6 thru F-10. The base and forward pressure traces are smooth, and small $-\Delta P_i$ were exhibited.

The data indicate that the performance of the prototype consumable charge with a simplified ignition system was quite good. The pressures and velocities for this series were higher than those for the standard charge. This is attributed to the extra energy added by the nitrocellulose in the case (0.7 to 0.9 kg) to the energy of the standard propellant charge.

Ignition Delays

The ignition delays for the consumable cases were shorter than the nominal values for the standard charge. For the uniformity series, the average ignition delay was about half that of the XM123E2 Interim charges fired earlier in the test at BRL [12] as shown in Table 11.

[12] *J. J. Rocchio and C. R. Ruth, "An Investigation of the Interior Ballistic Performance of a 19-Perforation Propellant Granulation in the Zone 8 Charge of the 155-mm, M198 Howitzer,* ARBRL-MR *in preparation.*

TABLE 11. COMPARISON OF PERFORMANCE OF THE CONSUMABLE CASE WITH THAT OF THE XM123E2 INTERIM CHARGE

		Consumable Case*	XM123E2 Interim**
Maximum Pressure (MPa)	$\bar{X}$	359	330
	σ	10.3	3.6
Muzzle Velocity (m/s)	$\bar{X}$	869	831
	σ	5.9	0.2
$-\Delta P_i$ (MPa)	$\bar{X}$	-7.4	0
	σ	2.5	0
Ignition Delay (msec)***	$\bar{X}$	36	90
	σ	7	12
Number of Rounds		5	3

* Consumable case data from Test Series 16 (Table 10 and Appendix E).

** Data presented were for XM123E2 Interim charges fired at BRL[12]. This charge was the prototype for the M203 charge and is almost identical to it.

*** Ignition delays are very dependent on lot of black powder used.

Void Space

The void space which normally exists along the length of a bagged charge, between the charge and the chamber wall, is a result of the charge being of smaller diameter than the chamber. It is often cited as having a role in alleviating pressure wave problems because it should help equilibrate the pressure along the chamber axis[13]. Because of the full bore diameter of the consumable case charges, there is no void space. It is therefore quite significant that the pressure waves in the consumable case tests were so small.

The consumable case with 25-mm standoff is 49 mm shorter than the available chamber length with the M101 projectile in the M185-MOD chamber. It is thus possible for the case to move forward and this may have occured in Series 13 which used a base pad along with the centercore igniter. Localized ignition by the base pad could lead to charge motion and compaction against the projectile which would result in the higher level of pressure waves observed with this ignition system.

[13] *A. W. Horst and P. S. Gough, "Influence of Propellant Packaging on Performance of Navy Case Gun Ammunition", Journal of Ballistics Vol. 1, No. 3, pp. 229-258, 1977.*

Nineteen-Perforation Propellant

There were no important differences in performance of the centercore-ignited, consumable-cased charges due to the propellant geometry (7MP vs 19MP-CY). The slightly lower pressure and velocity of the 19MP-CY charges (Series 17, Table 10) relative to the 7MP charges (Series 16, Table 10) are due to the web of the 19MP-CY grains being a bit too large to be an exact match to the 7MP grain at the same charge mass (11.79 kg). The 19MP-CY charges showed the same increase in pressure and velocity in going from a bagged charge to a consumable case as did the 7MP charge[12].

Residue

Post firing residues from the consumable cases were slightly less than those from the XM123E2 Interim charges. This is shown in Table 12 along with residue data from other experimental charges. No smoldering residue was observed either in the chamber and bore or on the ground in front of the cannon for the consumable cases or bagged charges.

An interesting observation is that the two "experimental" charges in Table 12 were constructed from XM123E2 Interim charge components[12]. The first charge also used the complete XM123E2 ignition system, while the second charge utilized only a base pad filled with CBI (Clean Burning Igniter). The replacement of black powder appears to have caused a significant reduction in the amount of post-firing residue.

IV. SUMMARY

Prototype consumable case charges for Zone 8 were fabricated and test fired in a 155-mm howitzer. The construction of the case made it possible to use a simplified ignition system consisting of a centercore igniter without a base pad. Two versions of this system were tested and shown to be superior to a base pad and centercore snake configuration. A novel centercore igniter consisting of Class 5 black powder in plastic tubes was shown to give better performance (as indicated by low $-\Delta P_i$) than the design with Class 5 black powder in a cloth snake. The performances of the prototype consumable cases were shown to be similar to those of the bagged charges. The consumable cases did not exhibit a problem with post-firing residues.

V. CONCLUSIONS AND RECOMMENDATIONS

A consumable case for large caliber, separate loading, ammunition appears feasible based on the results of these tests. A well designed consumable case should be much less complex than conventional bagged charges. The rigidity of a consumable case and the precision of the manufacturing process should eliminate the persistant problems (e.g. ignition delay, pressure waves, velocity variation, etc.) which are the result of the misalignment of critical ignition train components and poor tolerances inherent to bagged charges. Therefore major benefits of a

TABLE 12. RESIDUE AFTER FIRING

Charge	Charge Configuration*	Ignition System Configuration**	Average Residue(g)/Round
XM123E2 Interim	A	1	13
Experimental	B	1	13
Experimental	B	4	4
Consumable Case	C	1	10
Consumable Case	C	2	8
Consumable Case	C	3	3
Consumable Case	A	2	7
Consumable Case	B	2	5

*Charge Configuration:

A 11.79 kg, M30 7MP RAD-E-14-1973

B 11.79 kg, M30 19MP-CY RAD-PE-480-16

C 10.89 kg, M30 7MP-CY RAD-E-14-1973

**Ignition System Configuration:

1. Class 1 Black Powder, base pad and snake (standard system)
2. 113 g Class 5 Black Powder, snake alone
3. 113 g Class 5 Black Powder, three 8-mm diameter plastic tubes
4. 71 g CBI, base pad alone

consumable case should be improved safety and precision as well as good automatic handling and loading characteristics.

Considerable work must still be done. More extensive firing data are necessary, particularly at -45 and +63°C. An improved prototype should be designed and manufactured for future tests in order to evaluate production-related variables.

ACKNOWLEDGEMENTS

The authors are indebted to several individuals who made contributions to this test program: Mr. Vernon C. Goetz and Mr. James E. Bowen, the Sandy Point firing crew; Mr. James W. Evans and Mr. John L. Stabile, our instrumentation wizards; Mr. Steward W. Jones of the Material Testing Directorate, Aberdeen Proving Ground and his crew who assembled the experimental charges; Mr. Franz R. Lynn who developed digitization and data plotting software; Mr. Roger E. Bowman who developed the residue measuring technique and conducted the residue study; and Mr. Robert A. Wires who provided able assistance.

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11. J. J. Rocchio, R. A. Hartman, and N. J. Gerri, "An Electric Primer - Operated Firing Pin Actuator for Large Caliber Guns", ARBRL-MR-02897, January 1979. (AD #A069109)

12. J. J. Rocchio and C. R. Ruth, "An Investigation of the Interior Ballistic Performance of a 19-Perforation Propellant Granulation in the Zone 8 Charge of the 155-mm, M198 Howitzer, ARBRL-MR in preparation.

13. A. W. Horst and P. S. Gough, "Influence of Propellant Packaging on Performance of Navy Case Gun Ammunition," Journal of Ballistics, Vol. 1, No. 3, pp. 229-258, 1977.

APPENDIX A

PRODUCTION PROCESS FOR CONSUMABLE CASES

The consumable cases used in these tests were made by a pulp molding process. Other names for this process are "molded fibers" or "felting". Briefly, the fibers and emulsion resins are slurried together in large volumes of water and pumped into a storage tank where it is further diluted with water to about 0.15-percent solids. This mixture, constantly under mild agitation, is transferred to a much smaller tank where the initial forming or felting takes place. The felting die consists of a hollow, perforated, contoured metal cylinder covered with a screen. A vacuum line is attached to the inside of the die. The die is then lowered into the felting tank and vacuum applied. Water is drawn through the die by the vacuum, depositing the fibers and resin on the screen. After a predetermined time, the die is raised from the felting tank, vacuum continuing to remove water. The vacuum is then shut off and a mild, quick pressure pulse is applied to the inside of the die. This slightly stretches the preformed part permitting the fibers and resin to let go, allowing the part to be readily removed from the form. The part is then placed over the male portion of a pair of matched metal molds and the female die is slowly lowered, closing the molds. The molds are heated and pressure is applied. Vacuum is also applied through a fitting in the bottom of the male mold. The vacuum draws off water and steam leaving a dry part. The part is further dried and cured. It is then removed from the die, allowed to come to equilibrium, trimmed, and packed. This completes the process which is shown schematically in Figure A-1.

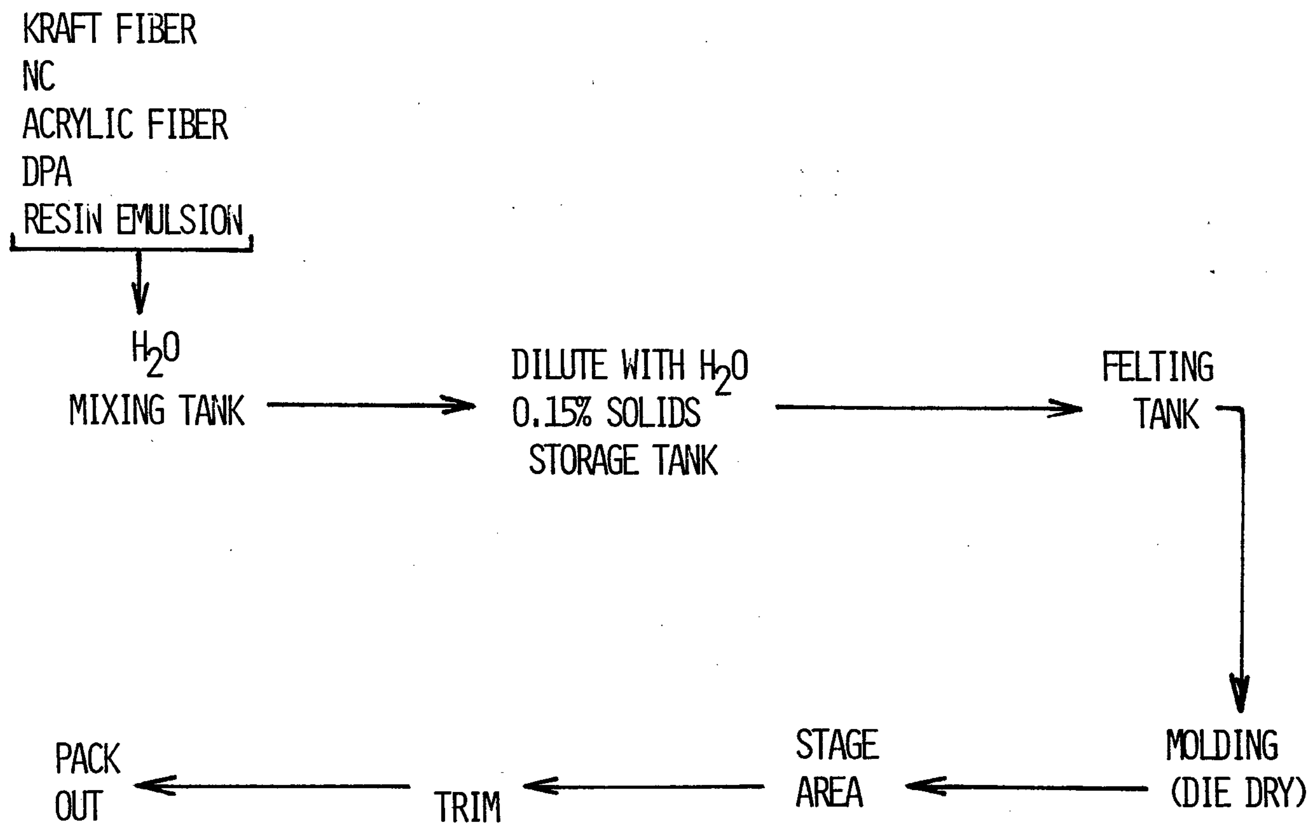


Figure A-1. Schematic of Consumable Case Production Process

APPENDIX B

PHOTOGRAPHS OF CONSUMABLE CASE COMPONENTS, SIMPLIFIED IGNITION SYSTEM, AND ASSEMBLED CONSUMABLE CASES

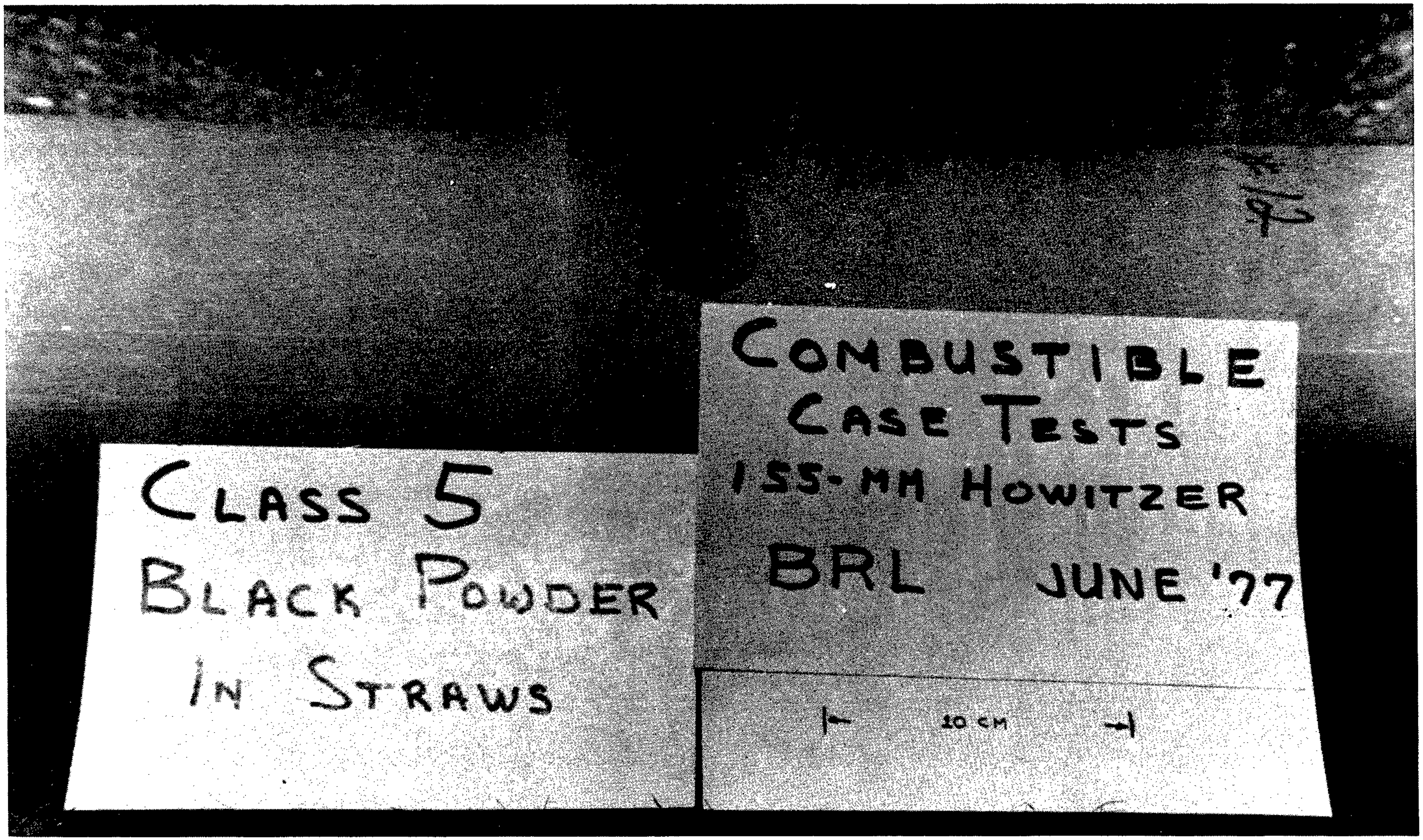


Figure B-1. End View of the Consumable Centercore Tube Showing the Orientation of the Three Plastic Tubes Containing Class 5 Black Powder.

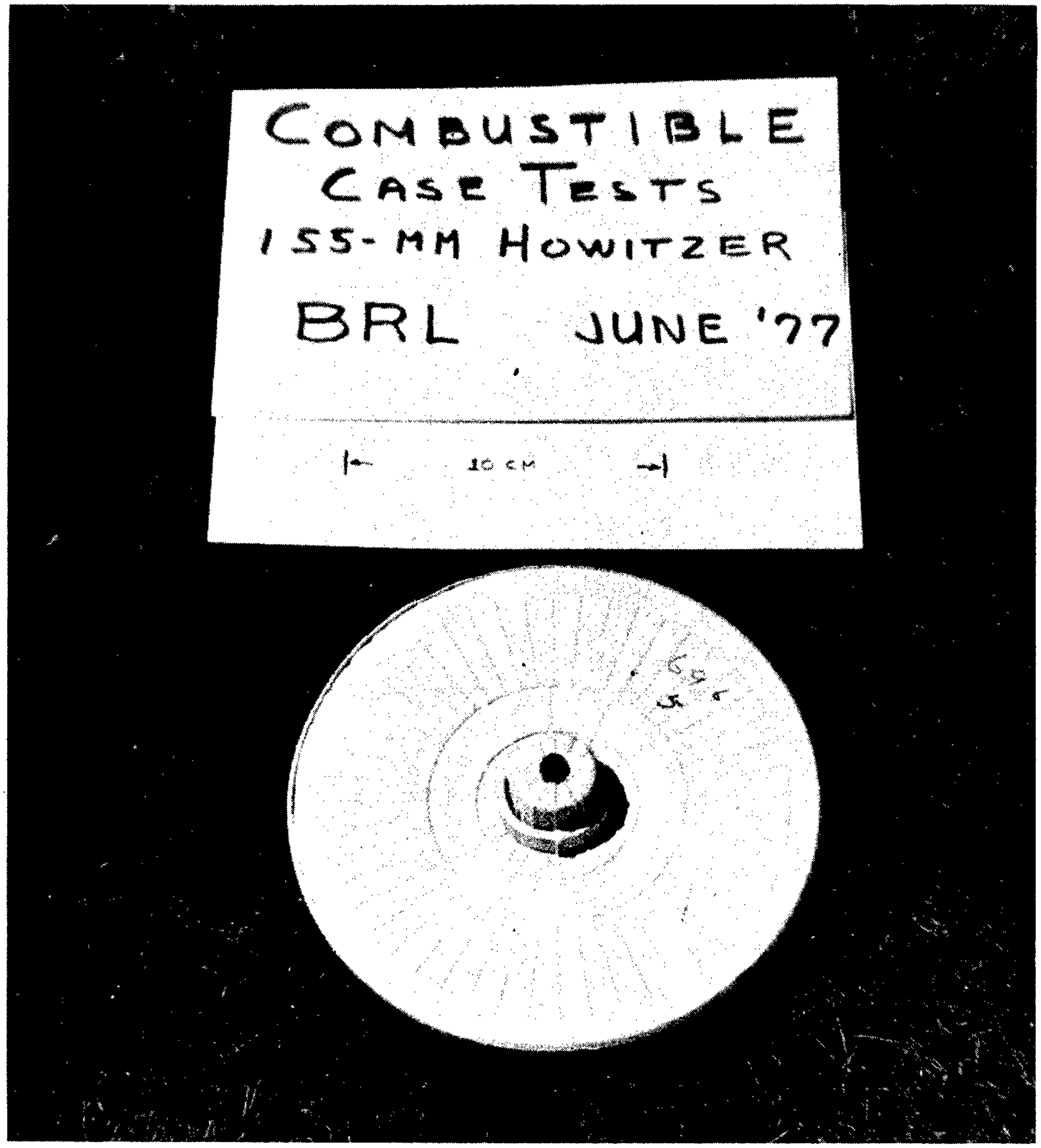


Figure B-2. Interior Face of End Piece of Consumable Case.

Figure B-3. End View of Consumable Case Sidewall, End Piece, and Centercore Tube Before Assembly.

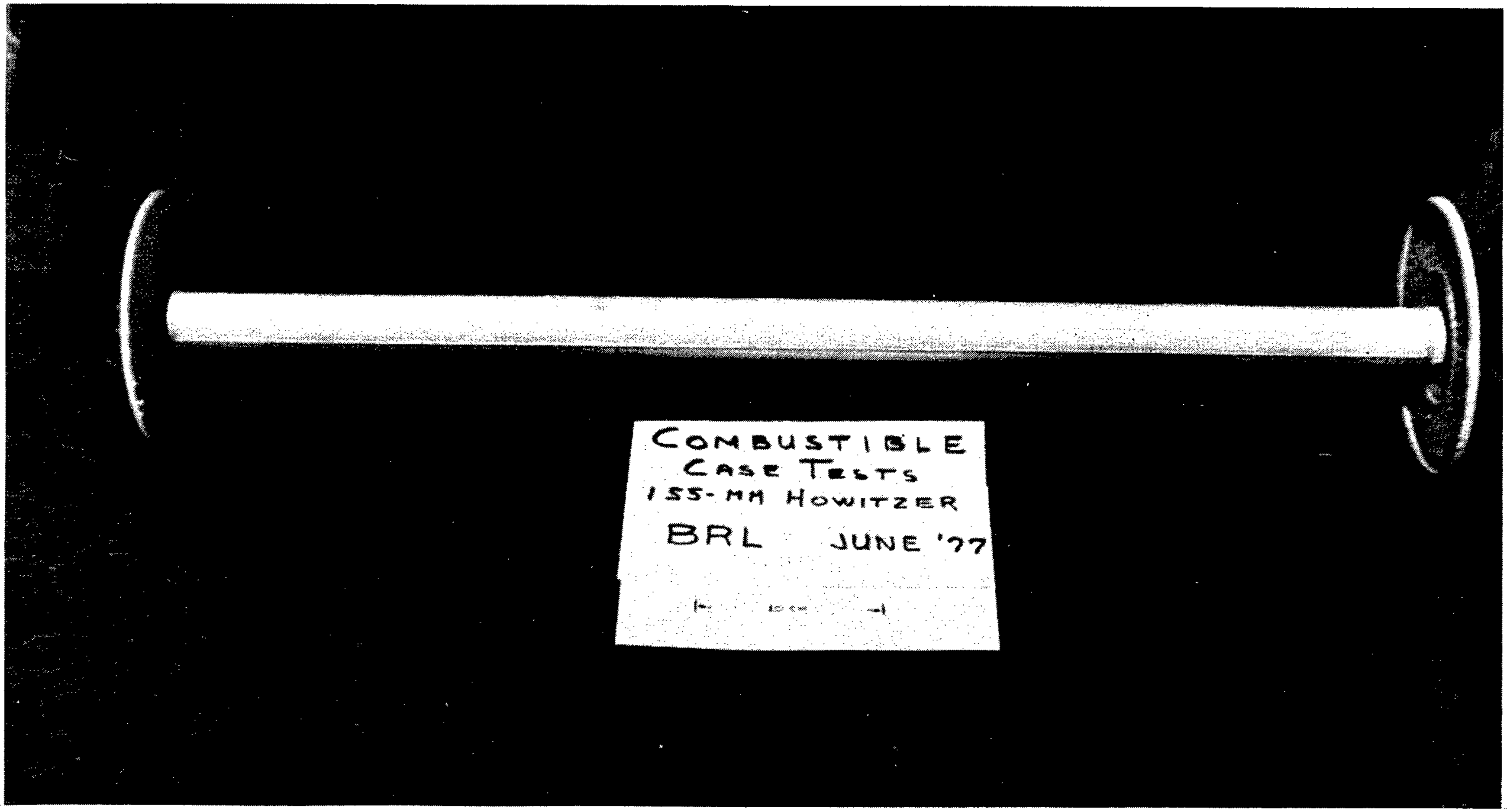


Figure B-4. View of the Consumable Centercore Tube as Supported by the End Pieces of the Consumable Case.

Figure B-5. Side View of an Assembled Consumable Case Charge.

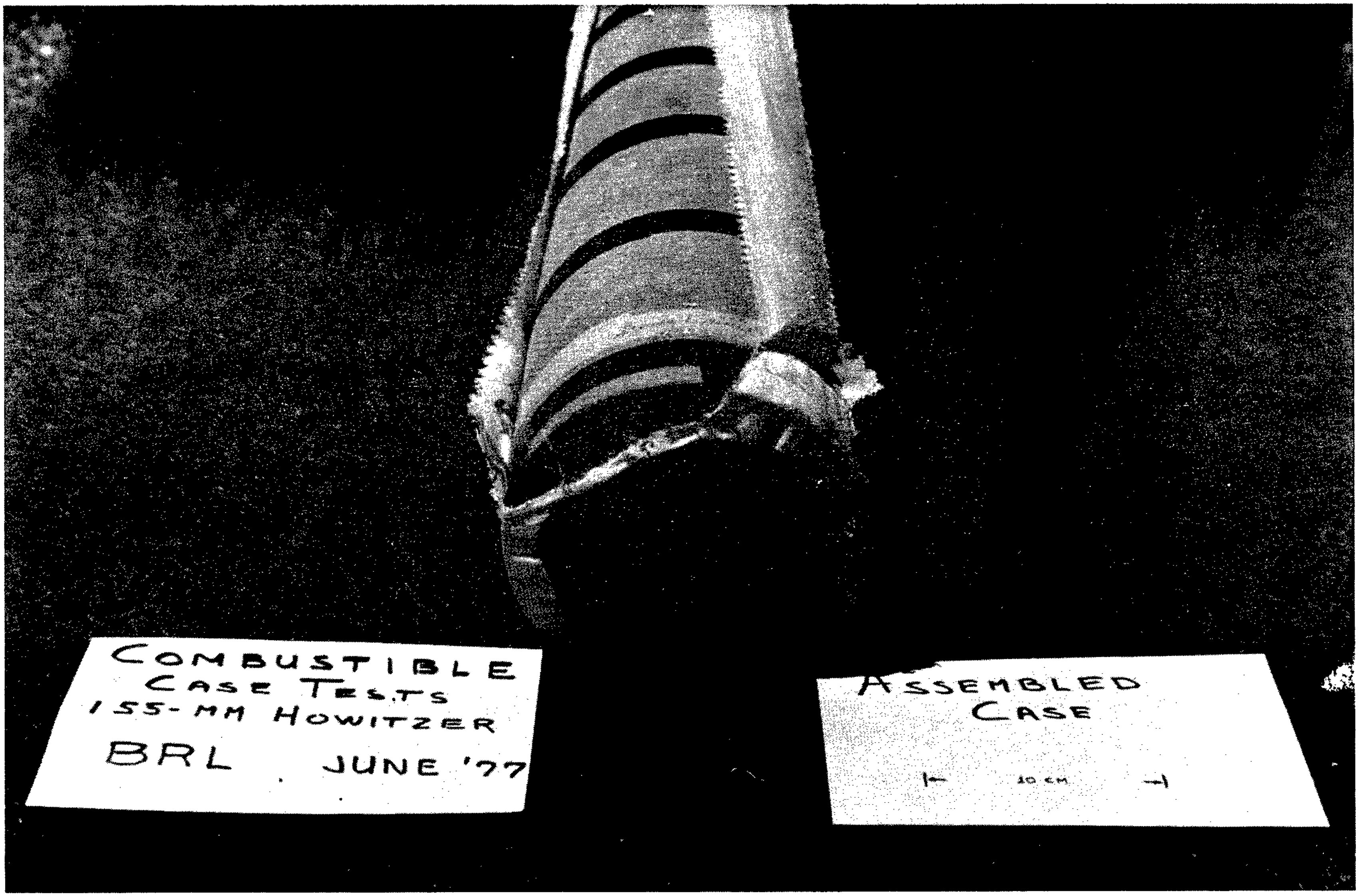


Figure B-6. End View of an Assembled Consumable Case Charge Showing the Attachment of the Base Pad as Used in Series 13.

APPENDIX C

PROPELLANT AND COMBUSTIBLE CASE COMPONENT DATA SHEETS

DEPARTMENT OF DEFENSE **AMMUNITION DATA CARD**			Form Approved Budget Bureau No. 22-R0269
1 Non-Metallic Side-Wall Assembly for LCSR, 155MM		2 FSN N/A	3 LOT NUMBER PA-77A000E320
4 MANUFACTURING LOADING OR ASSEMBLING ACTIVITY Picatinny Arsenal, Dover, NJ		5 NET QUANTITY 13	6 PACKING OF LOT Plastic Bag/ Fiber Board Box
7 CONTRACTOR P.A.	8 CONTRACT OR ORDER NO. 8074-50-006	9 DRAWING OR REVISION * 9296721 dtd 5-9-70	10 SPECIFICATION & REVISION SARPA-QA-A-P dtd 18 Jan. 77
11 DATE STARTED Aug. 75	12 DATE COMPLETED 27 Jan. 77	13 DATE INSPECTED 27 Jan. 77	14 LINE 427 / 15 ZONE WT SHELL
16 CHARGE WEIGHT	16a INDEX OF POWDER	16b. MPD IN INCHES	16c PPDR IN INCHES
16d. EXPLOSIVE WEIGHT PER PKG	17 EXPECTED MUZZLE VELOCITY	18 EXPECTED PRESSURE	19 SHELL WEIGHT
20 NUMBER OF TEST SAMPLES	21 SENT TO	22 DATE AND MODE OF SHIPMENT	

23 COMPONENTS *(Continue on reverse, if necessary)*

COMPONENT	DRAWING NO.	MODEL	MANUFACTURER	DATE MFG	LOT NO	QUANTITY

24 DISPOSITION	25 TYPED NAME OF GOVERNMENT INSPECTOR
Accepted for Test	JOSEPH FOMA
	SIGNATURE Joseph Foma

DD FORM 1 FEB 68 1650

23A. COMPONENTS *(Continued)* PA-77A000E320

COMPONENT	DRAWING NO.	MODEL	MANUFACTURER	DATE MFG	LOT NO.	QUANTITY
EXPLOSIVES:						
Side-Wall Case		Non-Metallic	Picatinny Arsenal	Aug. 75	PA-76H000E255	
Tube		Igniter	EFMC	Jun. 76	None	
Base		Case	EFMC	Jun. 76	FOE6-4	

24. REMARKS *(Identify by appropriate symbols: *Changes in process; **Deviations from drawing or specification; ***Unusual occurrences or difficulties)*

CATEGORY II
"This is a Provisional Package" #23-76A dtd 6-8-76.
This package is only for the purpose facilitating conus movement of items in accordance with DOT Tariff No. 30.

*Dwg. used as guide.
Sketch ref. SARPA-IB-8899A used for assy.

[illegible]

U.S. Army Lot No. RAD-E-14 of 19 73 Composition No. M30A1 FOR 155MM HOW., XM198 F/PROP. CHG. XM123

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 301,619 lbs

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. MIL-STD-652B, Change 1 & 2 and RAAPPD 3650

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

A-35,212; 251; 255; 260; 261; 262

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.68 %	45+ Mins	30+ Mins
Minimum	12.55 %	Mins	30 Mins
Average	12.61 %	Mins	30+ Mins
			Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound XX/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds ACETONE per 100 Pounds Solvent

Percentage Remix to Whole 10

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
Ambient	140	LOAD FAD AT AMBIENT TEMPERATURE		
		INCREASE TEMPERATURE APPROXIMATELY 5°F PER HOUR UNTIL 140°F IS REACHED		
	140	HOLD TEMPERATURE		70

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION

Constituent	Percent Formula	Percent Tolerance	Percent Measured
NITROCELLULOSE	28.00	±1.30	28.21
NITROGLYCERIN	22.50	±1.00	22.86
NITROGUANIDINE	47.00	±1.00	46.34
ETHYL CENTRALITE	1.50	±0.10	1.55
POTASSIUM SULFATE	1.00	±0.30	1.04
TOTAL	100.00		100.00
TOTAL VOLATILES	0.50	MAX.	0.23
GRAPHITE	0.15	MAX.	0.10

STABILITY AND PHYSICAL TESTS

	Formula	Actual
Heat Test S.P. 120°C	NO CC 40'	60'
NO FUMES	———	60'
Form of Propellant		CYLD
NO. OF PERFORATIONS		7

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-E-14	+90	98%	100%
	RAD-E-14	-40	94%	98%
Standard	RAD-E-1	+90	100.00%	100.00%

Remarks

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 700 CC CLOSED BOMB. The 90°F RQ AND RF SHALL BE 100 ± 2 PERCENT.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.949	0.9566	6.25 MAX.	0.96
Diameter (D)		0.470	0.4233	3.125 MAX.	1.15
Perf. Dia. (d)		0.039	0.0335		
WEB					
INNER		0.093	0.0787		
OUTER		0.085	0.0805		
AVERAGE	0.073 Nom.	0.089	0.0796		
Web Difference/ in % of Web Average	15 MAX.		2.3		
L/D	2.10 to 2.50		2.26		
D/d	5.0 to 15		12.7		

DATES

Packed	1-8-73
Sampled	1-8-73
Test Finished	1-17-73
Offered	1-29-73
Description Sheets Forwarded	1-31-73

Type of Packing Container FIBER DRUMS PER MIL-STD-652B

Remarks

THIS LOT MEETS ALL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

Contractor's Representative: P. W. STEELE [signature] 1-29-73

Government Quality Assurance Representative: JAMES E. BLAND [signature]

[illegible]

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-PE-480-16 of 1976 Composition No. M30A1, 19 MP f/XM198

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 685 lbs.

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR letter SARRA-TE, dated 6/24/76

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
C 35151	Maximum ___ %	___ Mins	___ Mins
	Minimum ___ %	___ Mins	___ Mins
	Average 12.68 %	45+ Mins	30 Mins
			Explosion ___ Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds acetone per 100 Pounds Solvent.

Percentage Remix to Whole 0

Temperatures °C From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load forced air dry at ambient temperature		
Ambient	140	Increase temperature 5°F per hour		12
140	140	Hold at temperature		100

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	28.00	± 1.30	28.52	Heat Test SP, 120°C	No CC 40'	60'+
Nitroglycerin	22.50	± 1.00	21.50	No Fumes	--	1 hr
Nitroguanidine	47.00	± 1.00	47.37	Form of Propellant		Cyld
Ethyl Centralite	1.50	± 0.10	1.56	No. Perforations		19
Potassium Sulfate	1.00	± 0.10	1.05	Density, gm/cc	N/A	1.680
TOTAL	100.00		100.00			
Total Volatiles	0.50	max	0.28	Heat of Explosion,		
Graphite Glaze	0.2	max	0.13	cal/gm	N/A	978.5

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-480-16**	+90	100.63	98.54
	RAD-PE-480-16*	+90	99.83	98.23
Standard	RAD-E-1 **		100.00%	100.00%
Remarks	RAD-E-1 *		100.00	100.00

Fired in accordance with MIL-STD-286B, Method 801.1, in a nominal size 700cc closed bomb. Test for informational purposes only.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)	1.59, nom	1.595	1.58	N/A	1.30
Diameter (D)		0.703	0.614	N/A	--
Perf Dia. (d)		0.044	0.0392		
Web, Avg.	0.072, nom	0.0822	0.0697		
Inner		0.0930	0.0674		
Outer (1)		0.0880	0.0696		
Outer (2)		0.0655	0.0721		
Web Difference/Std. Dev. in % of Web Average	10% max	0	6.74		
L/D	2.5 nom	2.27	2.57		
D/d	15.5 nom	15.98	15.66		

DATES
- Packed 7/22/76
- Sampled 7/22/76
- Test Finished 8/4/76
- Offered 8/5/76
- Description Sheets Forwarded 8/5/76

Type of Packing Container Fiber Drums

Remarks * Closed bomb test at loading density of 0.1 gm/cc.
** Closed bomb test at loading density of 0.2 gm/cc.

This lot meets all the chemical and physical requirements of the applicable specification.

Contractor's Representative
R. A. Williams

Government Quality Assurance Representative
James E. Bland

SMU FORM 1047R MARCH 1971

APPENDIX D

TEST FIXTURE AND INSTRUMENTATION

TABLE D-1. COMPARISON OF 155-MM CANNONS

	M185	M185-MOD	M199
Forcing Cone Taper (in./in.)	0.2	0.2	0.1
Distance From Rear Face of Tube to:			
Start of Full Rifling (in.)	39.35	40.94	41.50
Spindle Face (in.)	2.57	2.57	2.57
Tube Interior Diameter:			
Initial (in.)	6.69	6.67	6.67
Mid-Chamber (in.)	6.69	6.50	6.50
Tube Length (in.)	238.05	238.05	239.95

NOTE: Dimensions are in inches (Watervliet Arsenal Drawing No. WTV F24730)

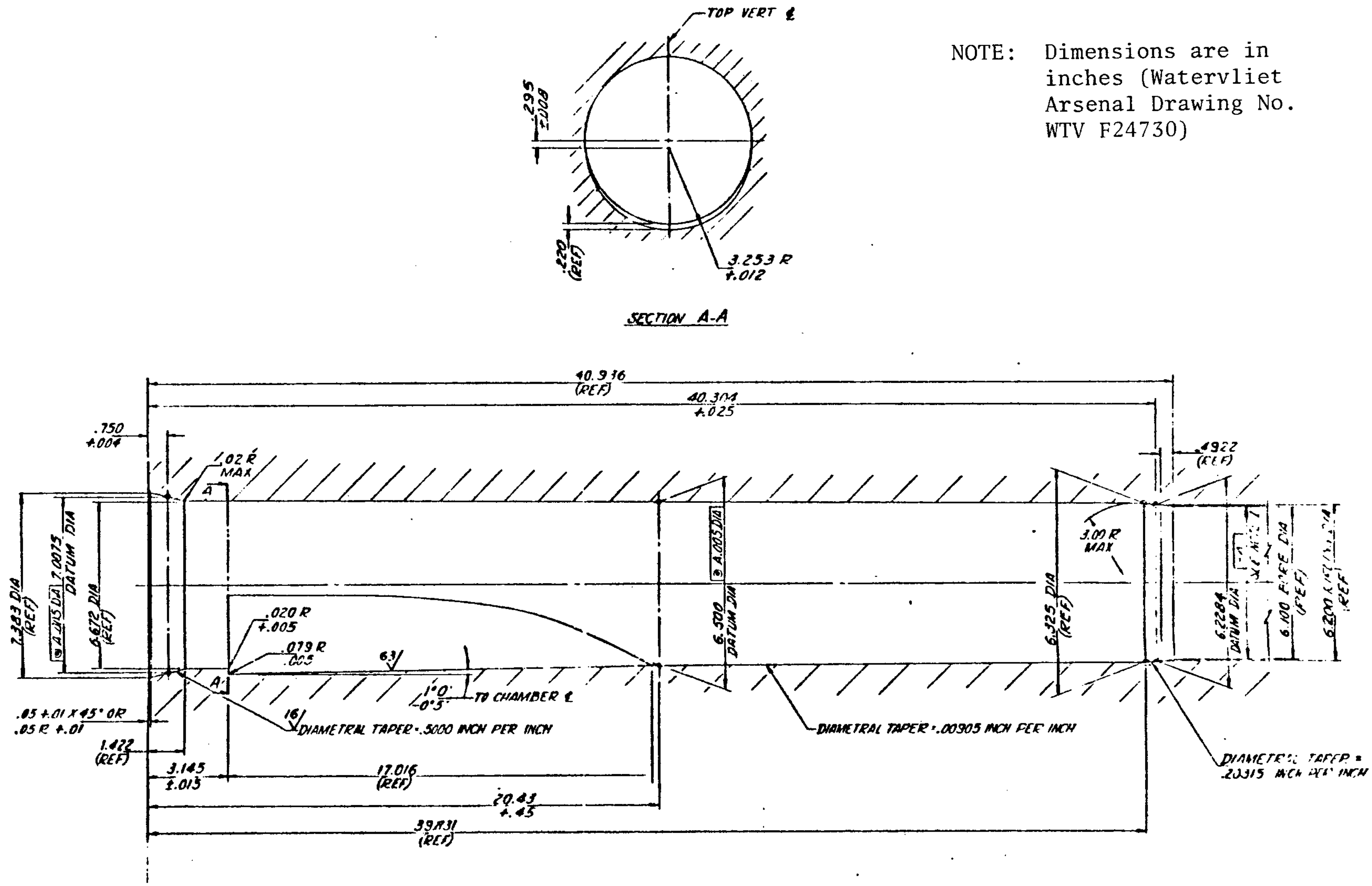


Figure D-1. Chamber Dimensions of Modified M185 Cannon Used in the Firing Tests

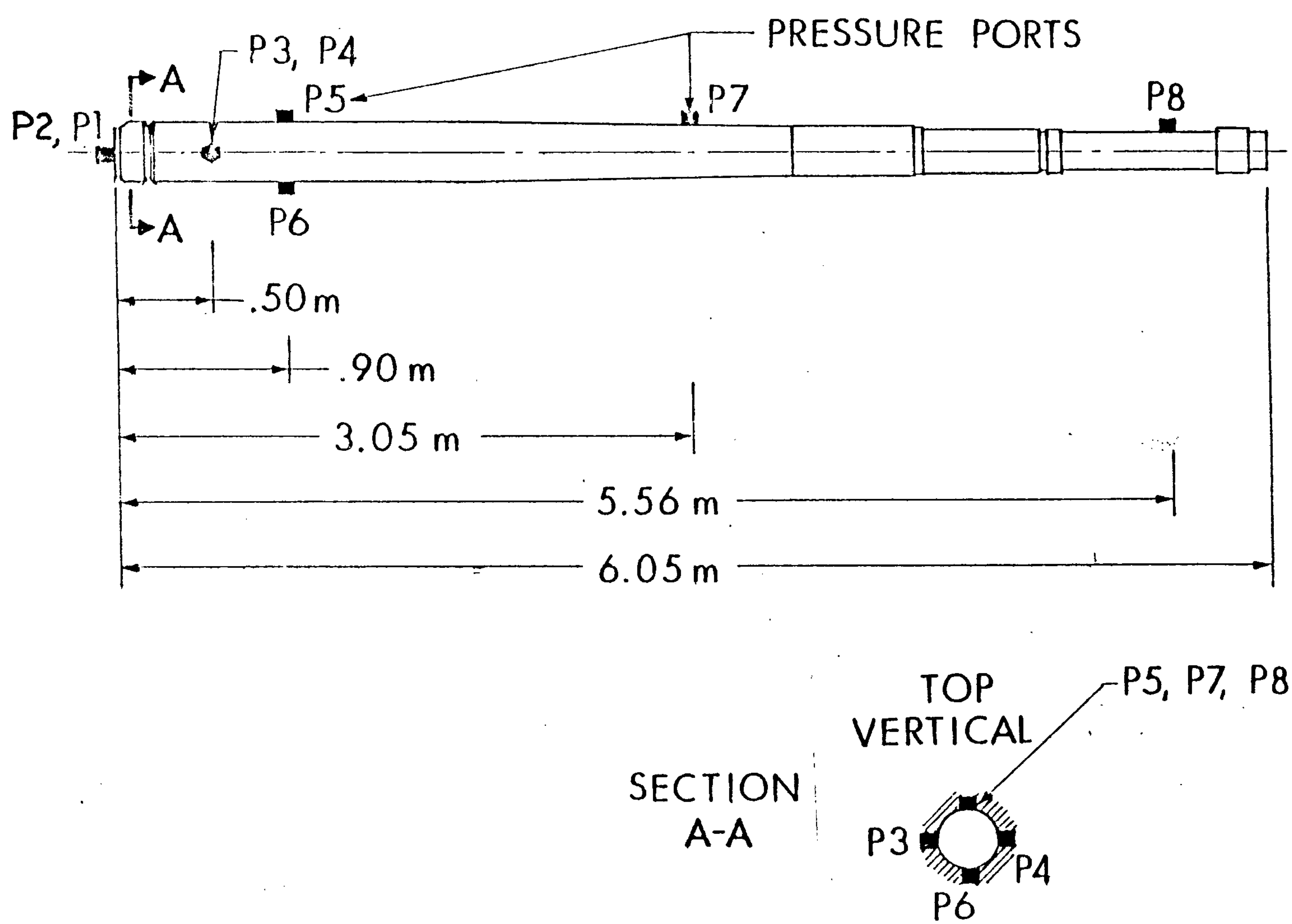


Figure D-2. Gage Locations in 155-mm M185-MOD Cannon

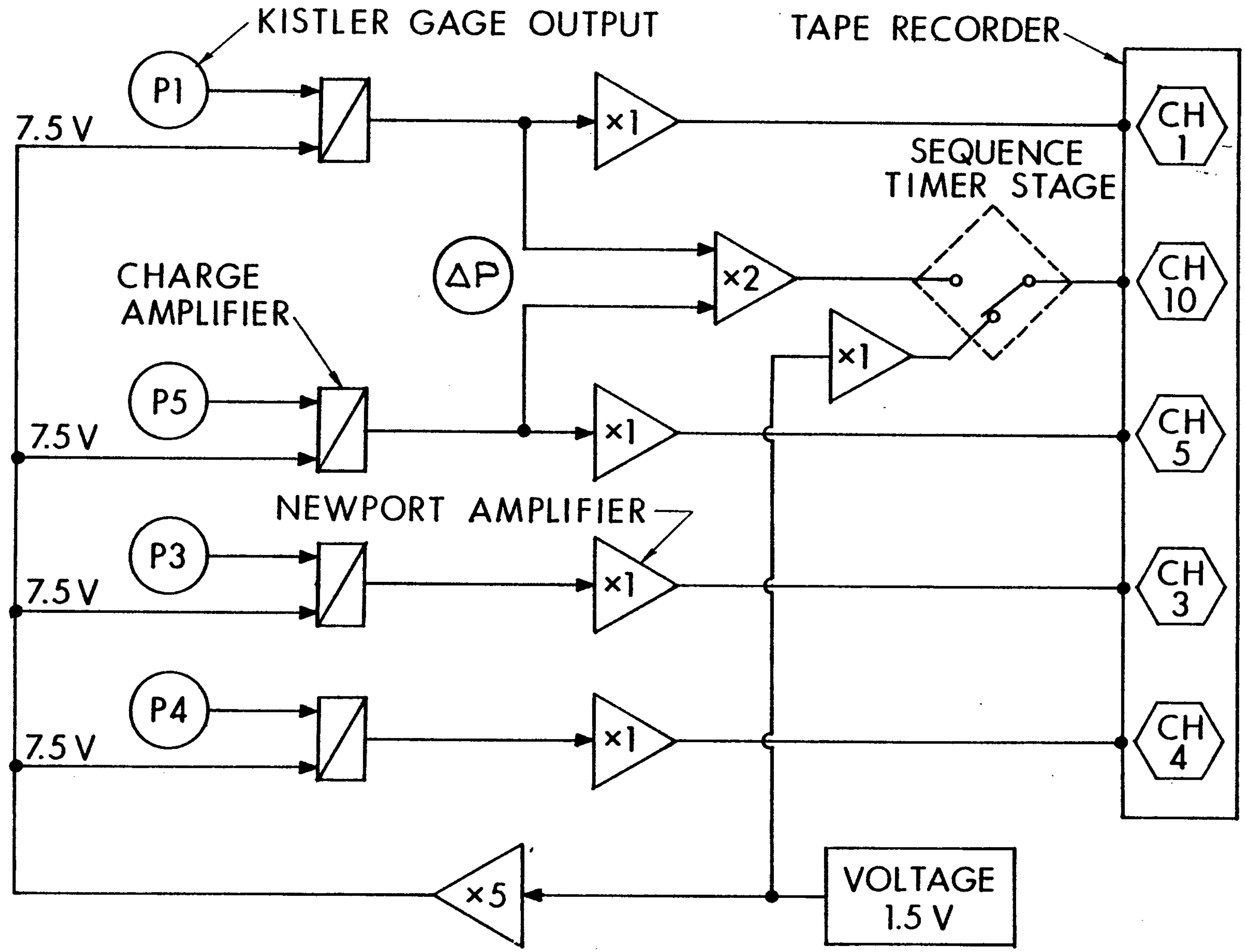


Figure D-3. Setup of Pressure-Measuring Instrumentation

APPENDIX E

LISTING OF EXPERIMENTAL DATA FOR THE INDIVIDUAL TEST ROUNDS

Table E-1. Listing of Experimental Data for the Individual Test Rounds

Series	ID	Date Fired	Projectile	Projectile Mass (kg)	Projectile Seating Distance (mm)	Charge Standoff (mm)	Consumable Case No.	Consumable Case Mass (kg)	Propellant Lot	Igniter Configuration
13	246/50	6 Jun 77	M101	42.46	895	25	127	0.885	RAD-E-14-1973	1
13	246/51	6 Jun 77	M101	42.32	897	25	8	0.758	RAD-E-14-1973	1
14	246/52	6 Jun 77	M101	42.59	897	25	47	0.776	RAD-E-14-1973	2
14	246/53	6 Jun 77	M101	42.46	895	25	130	0.925	RAD-E-14-1973	2
15	246/56	7 Jun 77	M101	42.41	895	25	123	0.993	RAD-E-14-1973	3
15	246/57	7 Jun 77	M101	42.41	895	25	12	0.785	RAD-E-14-1973	3
16	246/60	10 Jun 77	M101	42.37	895	25	272	1.034	RAD-E-14-1973	2
16	246/61	10 Jun 77	M101	42.37	895	25	382	1.252	RAD-E-14-1973	2
16	246/62	10 Jun 77	M101	42.28	895	25	155	0.993	RAD-E-14-1973	2
16	246/63	10 Jun 77	M101	42.41	895	25	381	1.211	RAD-E-14-1973	2
16	246/64	10 Jun 77	M101	42.28	897	25	384	1.207	RAD-E-14-1973	2
17	246/65	10 Jun 77	M101	42.32	895	25	48	0.767	RAD-PE-480-16	2
17	246/66	10 Jun 77	M101	42.32	897	25	375	1.275	RAD-PE-480-16	2

IGNITER CONFIGURATIONS:

1. 142 g, Class 1 Black Powder in base pad (28.5 g) and snake (113.5 g)
2. 113 g, Class 5 Black Powder, in snake alone
3. 113 g, Class 5 Black Powder in three 8-mm diameter plastic tubes

Table E-1. Listing of Experimental Data for the Individual Test Rounds (Continued)

ID	Charge Mass (kg)	Charge Temperature (K)	Breech Pressure* (MPa)	Forward Chamber Pressure (MPa)	ΔP_i (MPa)	Velocity** (m/s)	Ignition Delay (ms)	Post Firing Residue (g)
246/50	10.89	298	298	287	-19.5	815.9	49.5	8.5
246/51	10.89	298	291	280	-18.3	811.3	45.5	10.6
246/52	10.89	298	L	L	L	L	L	6.5
246/53	10.89	298	297	281	-1.6	819.3	29.0	10.2
246/56	10.89	298	330	286	0	811.3	35.5	3.3
246/57	10.89	298	317	277	-2.8	805.2	51.5	3.0
246/60	11.79	298	350	336	-4.8	862.5	44.5	5.8
246/61	11.79	298	369	357	-10.8	874.4	25.5	5.6
246/62	11.79	298	346	336	-6.0	862.2	38.5	7.5
246/63	11.79	298	364	342	-6.4	871.7	35.5	6.5
246/64	11.79	298	366	354	-9.2	872.6	34.0	8.3
246/65	11.79	298	336	320	-14.7	848.8	44.5	4.7
246/66	11.79	298	359	345	-4.5	864.7	26.0	5.7

* Pressures are not corrected for variations in projectile mass   L = Lost Data
** Velocities are coil velocities, 21.3 m from muzzle
Projectile Lot LOP-SR-3-64

APPENDIX F

SPINDLE, FORWARD CHAMBER, AND ΔP PRESSURE VS. TIME PLOTS FOR THE INDIVIDUAL TEST ROUNDS

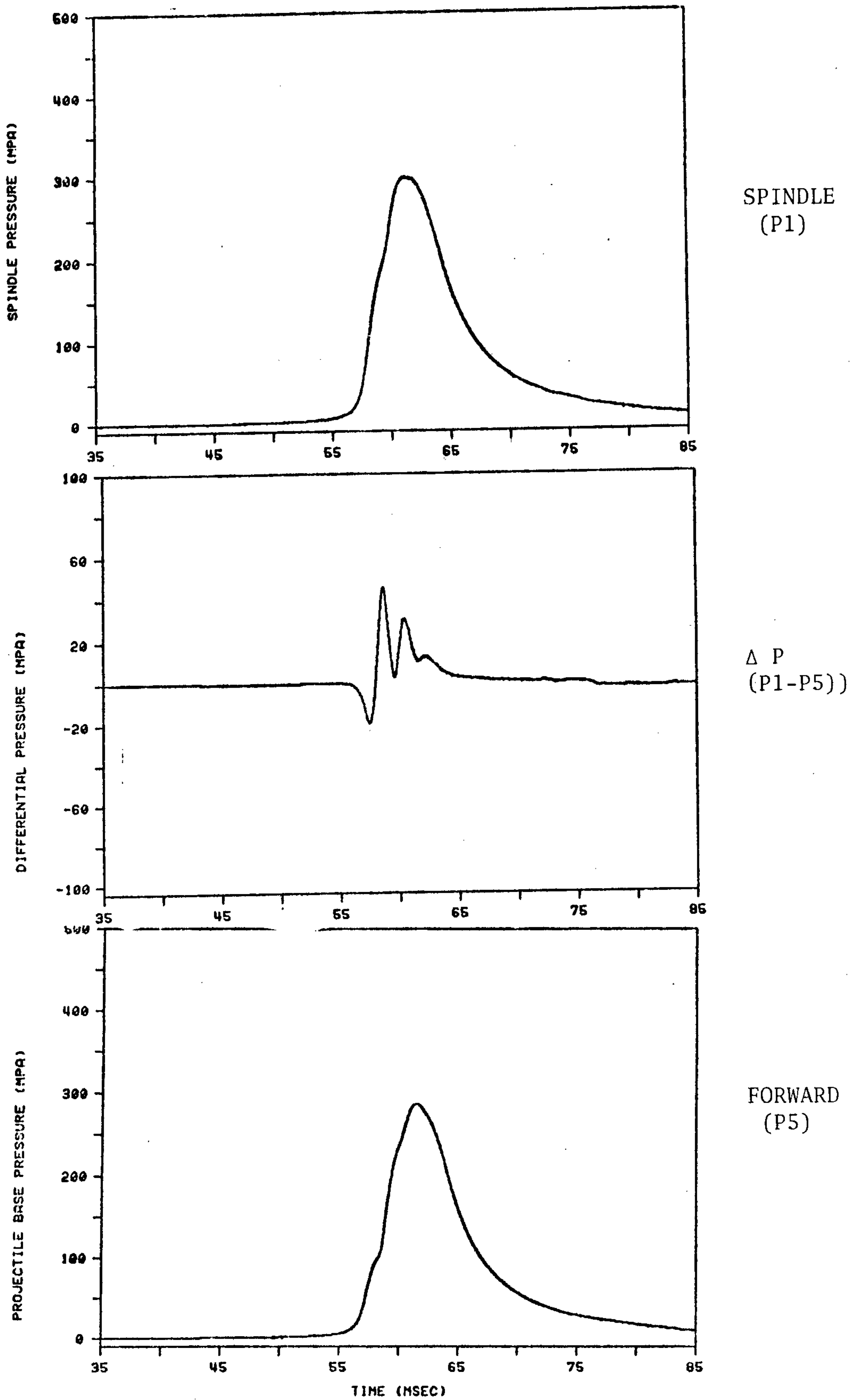


Figure F-1. Pressure vs. Time Traces, Series 13, ID 246/50

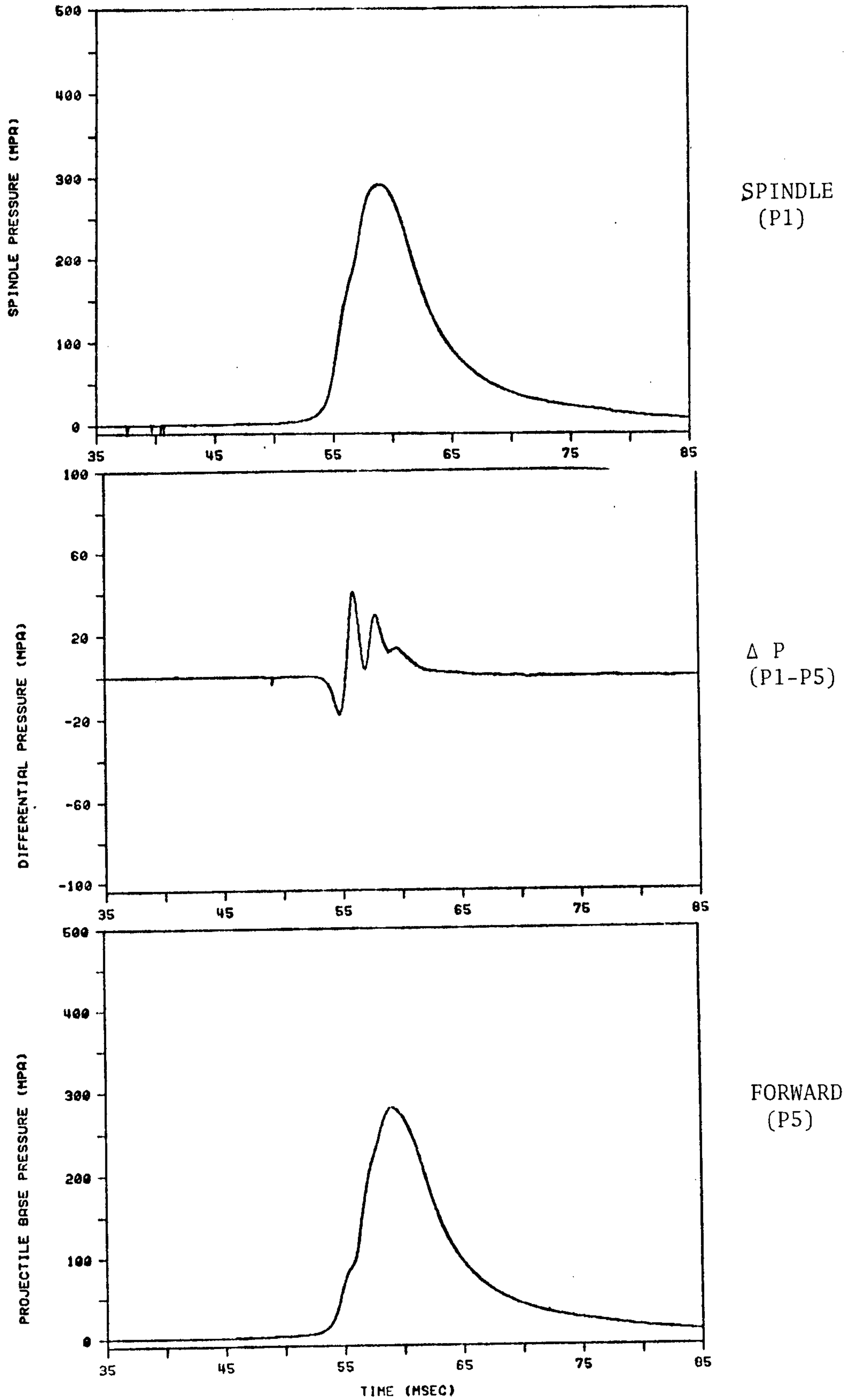


Figure F-2. Pressure vs. Time Traces, Series 13, ID 246/51

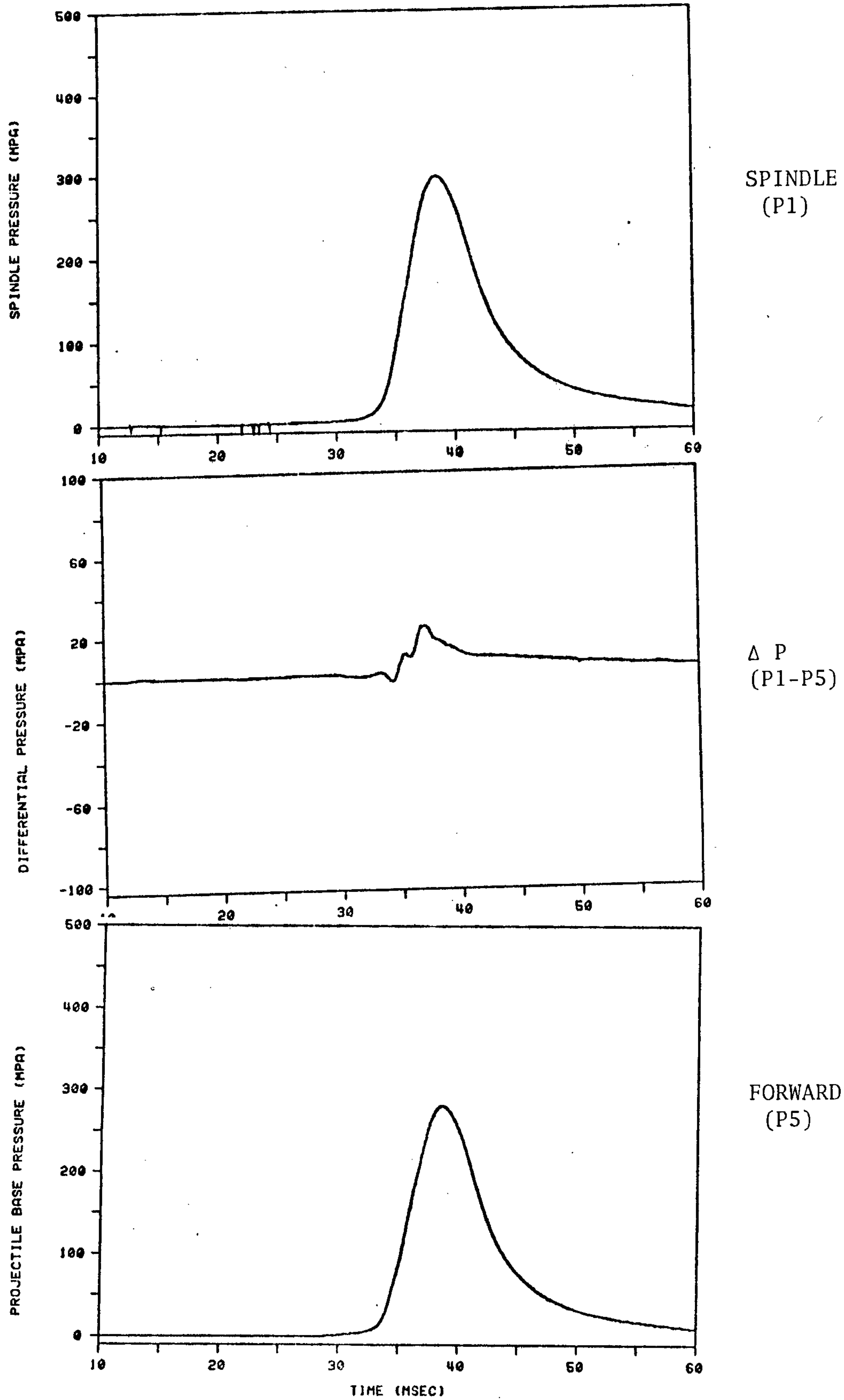


Figure F-3. Pressure vs. Time Traces, Series 14, ID 246/53

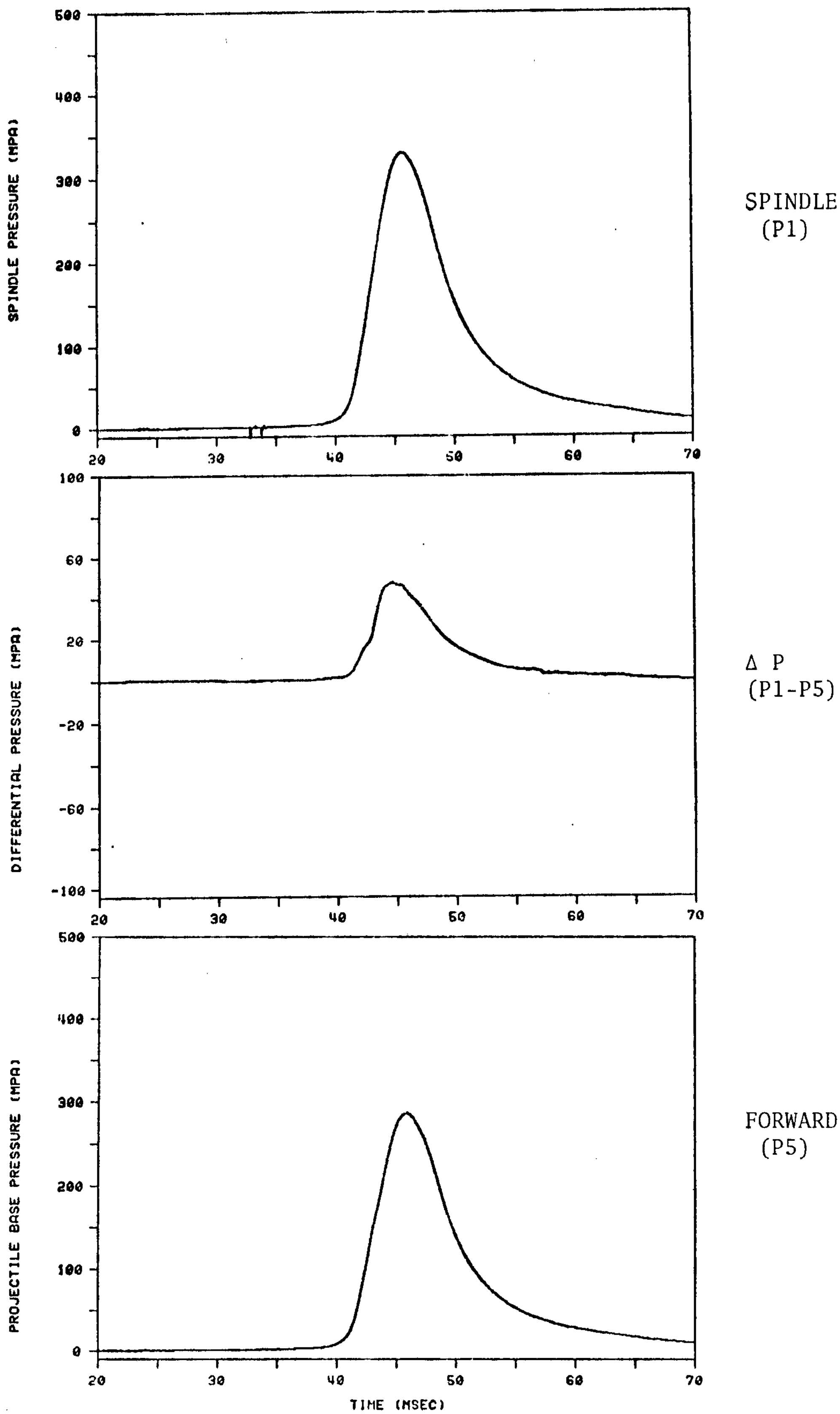
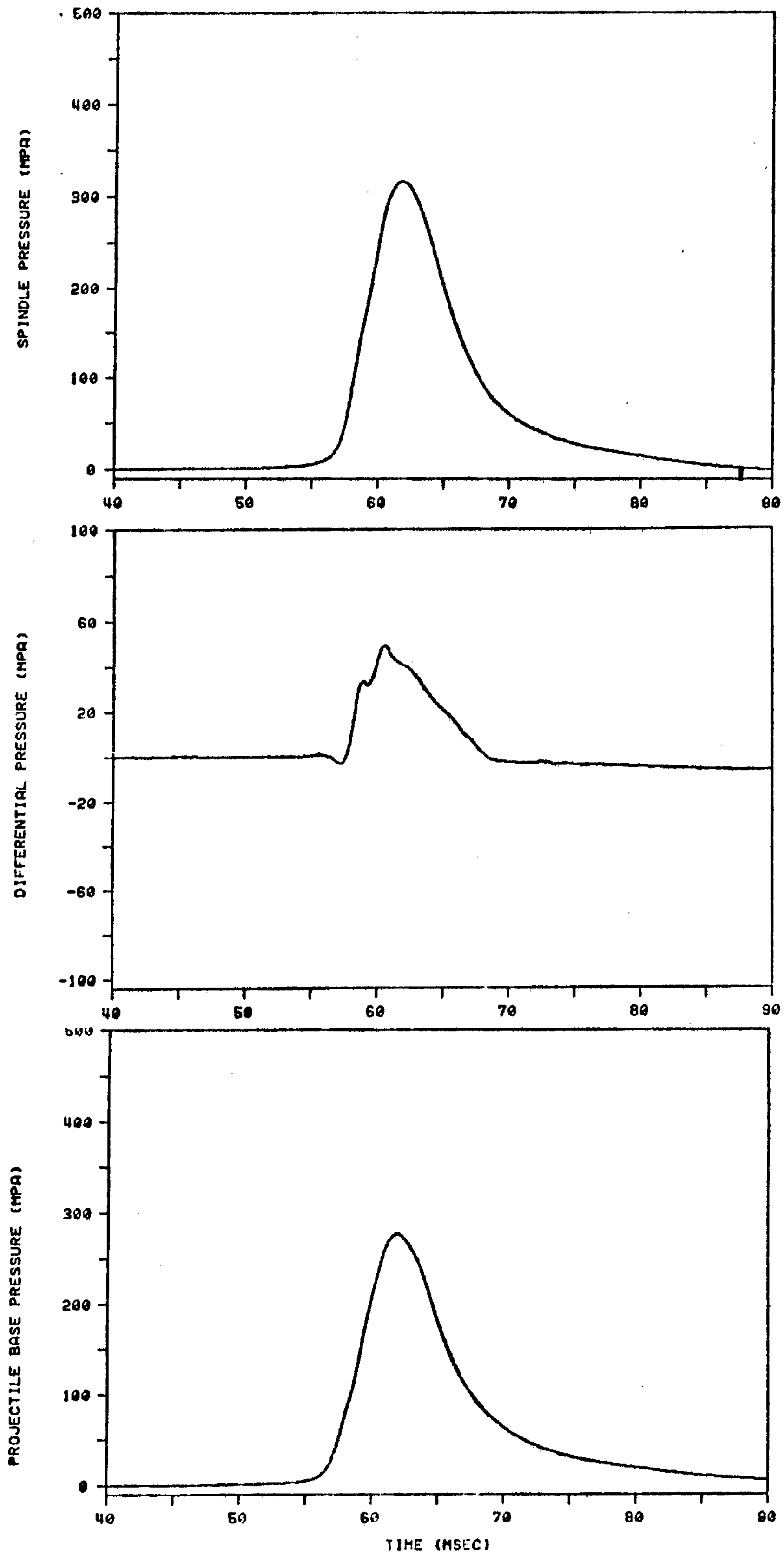


Figure F-4. Pressure vs. Time Traces, Series 15, ID 246/56



SPINDLE (P1)

Δ P (P1-P5)

FORWARD (P5)

Figure F-5. Pressure vs. Time Traces, Series 15, ID 246/57

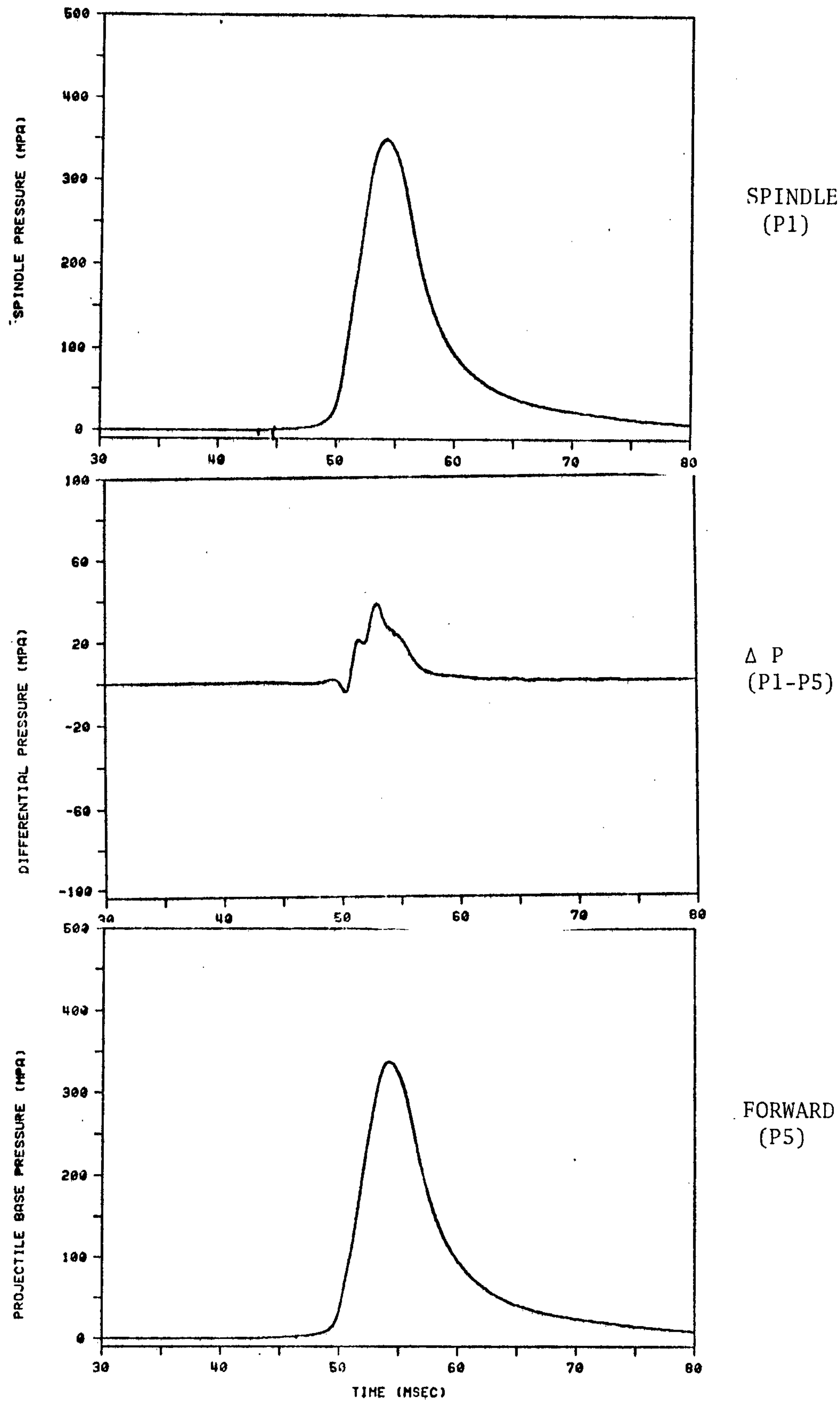


Figure F-6. Pressure vs. Time Traces, Series 16, ID 246/60

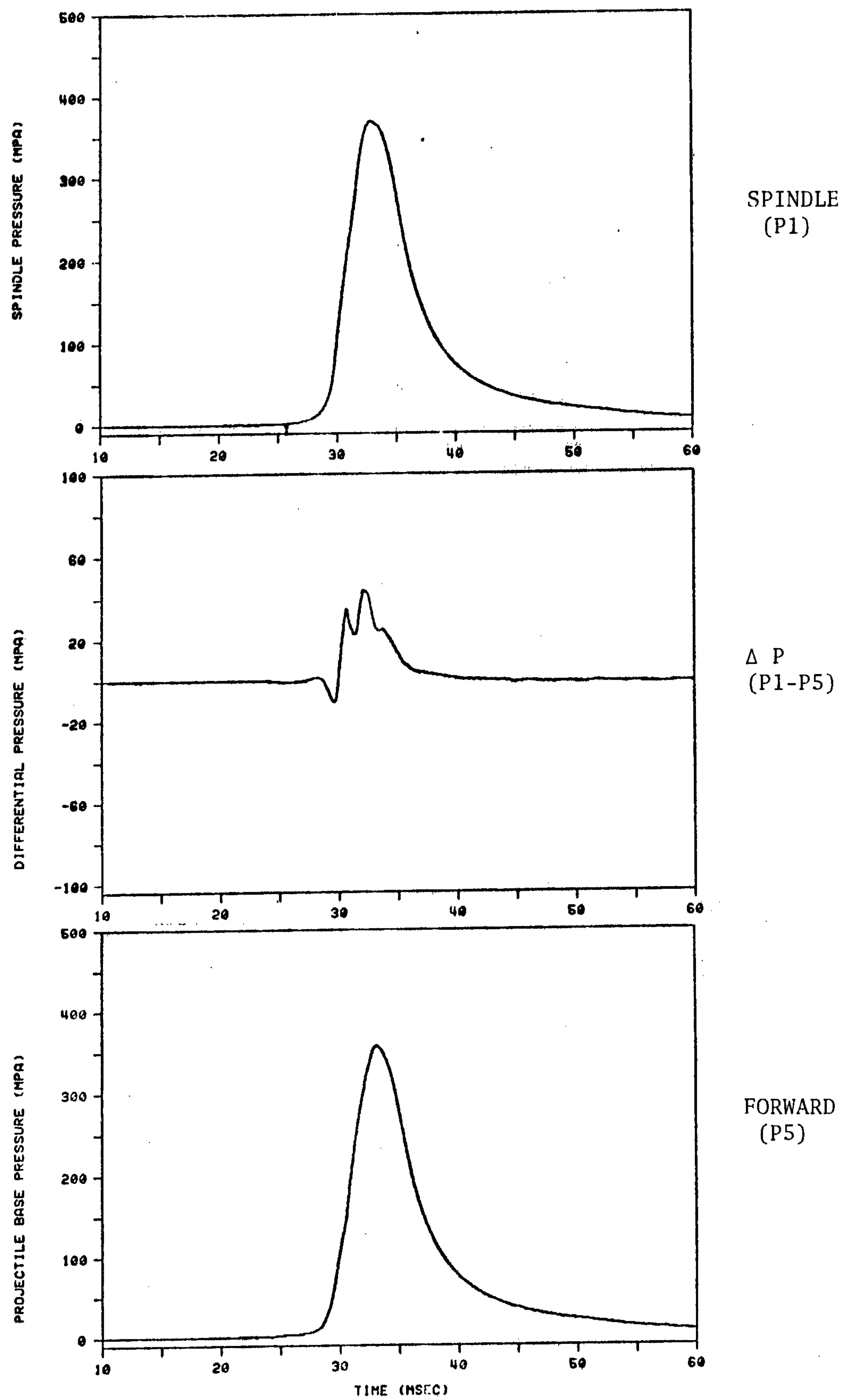


Figure F-7. Pressure vs. Time Traces, Series 16, ID 246/61

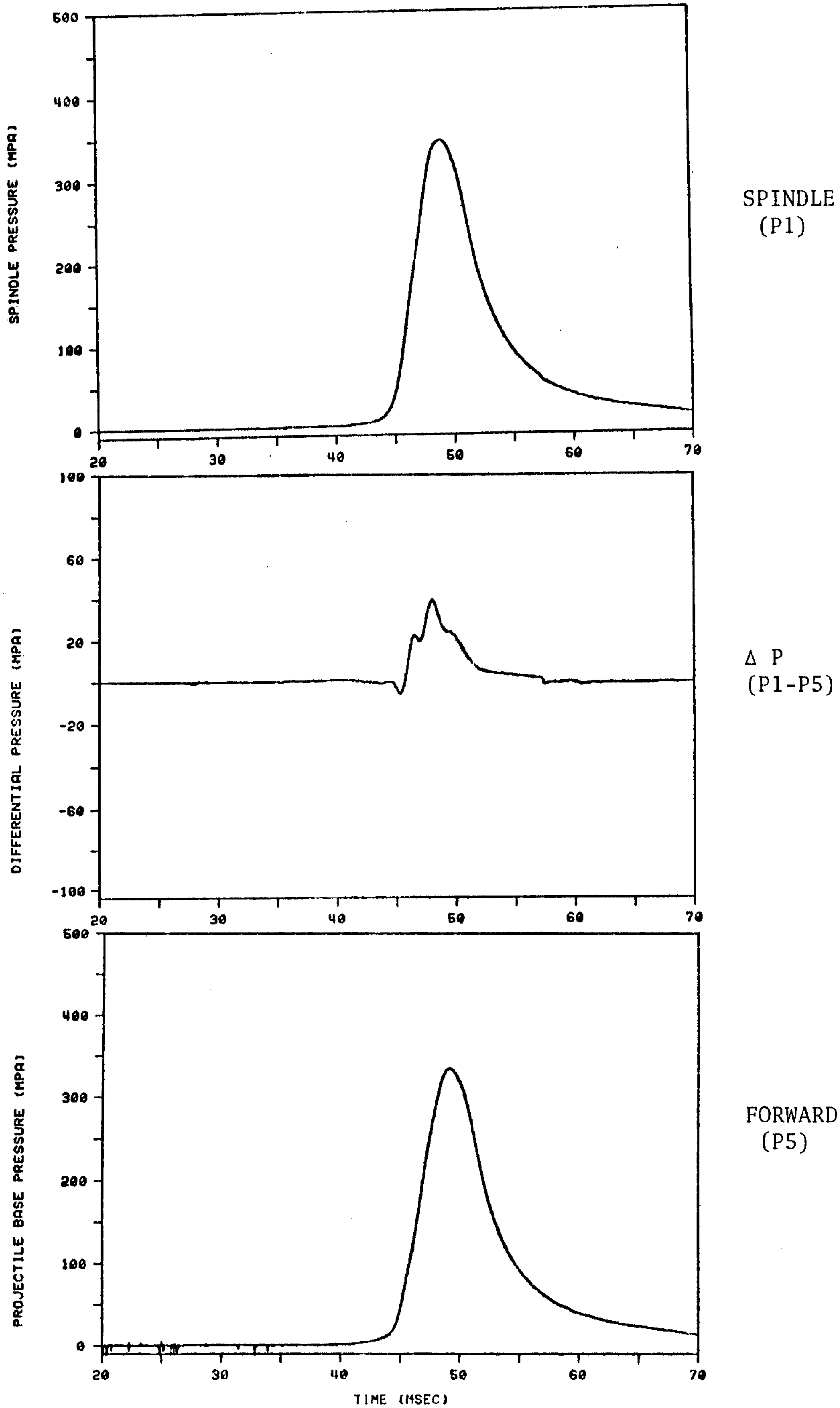


Figure F-8. Pressure vs. Time Traces, Series 16, ID 246/62

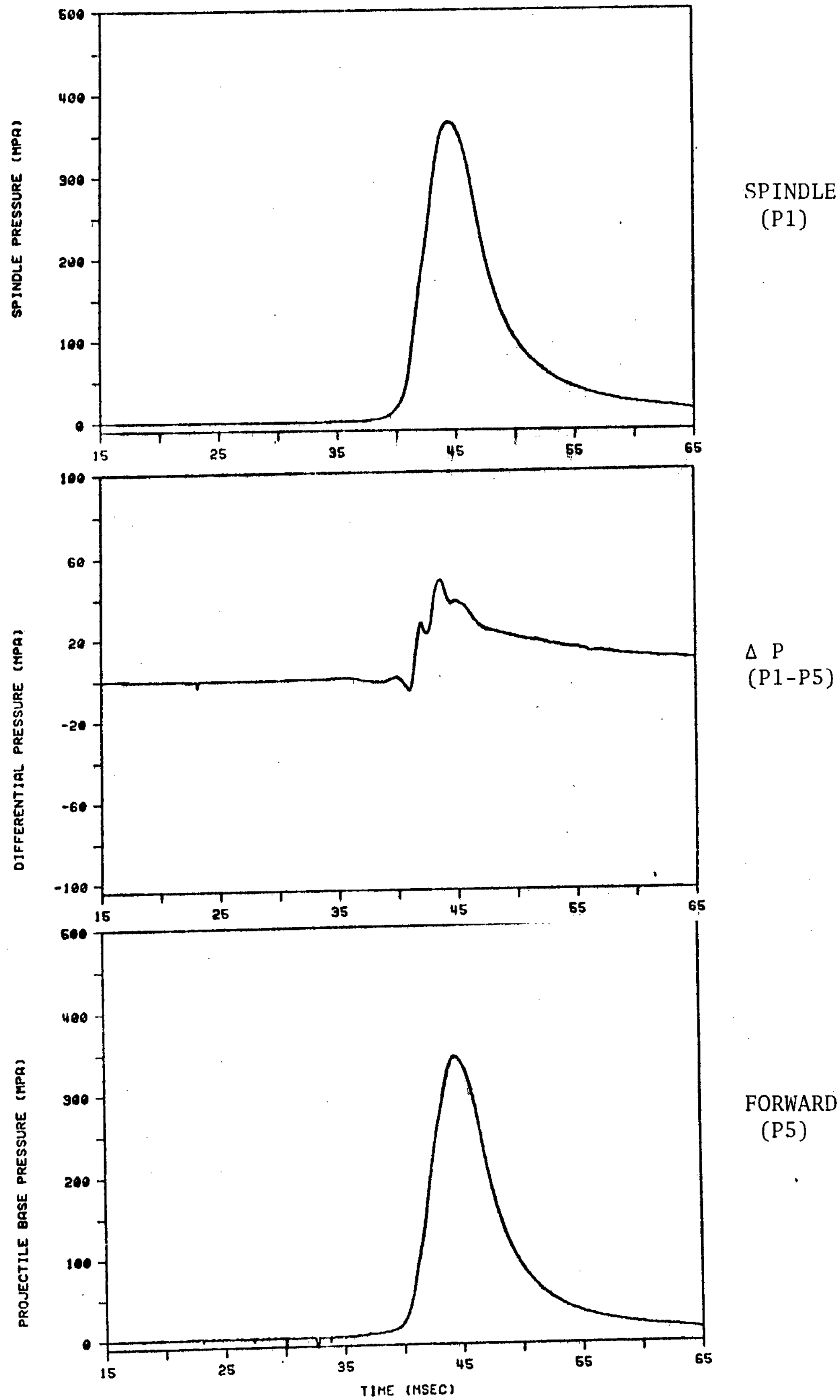


Figure F-9. Pressure vs. Time Traces, Series 16, ID 246/63

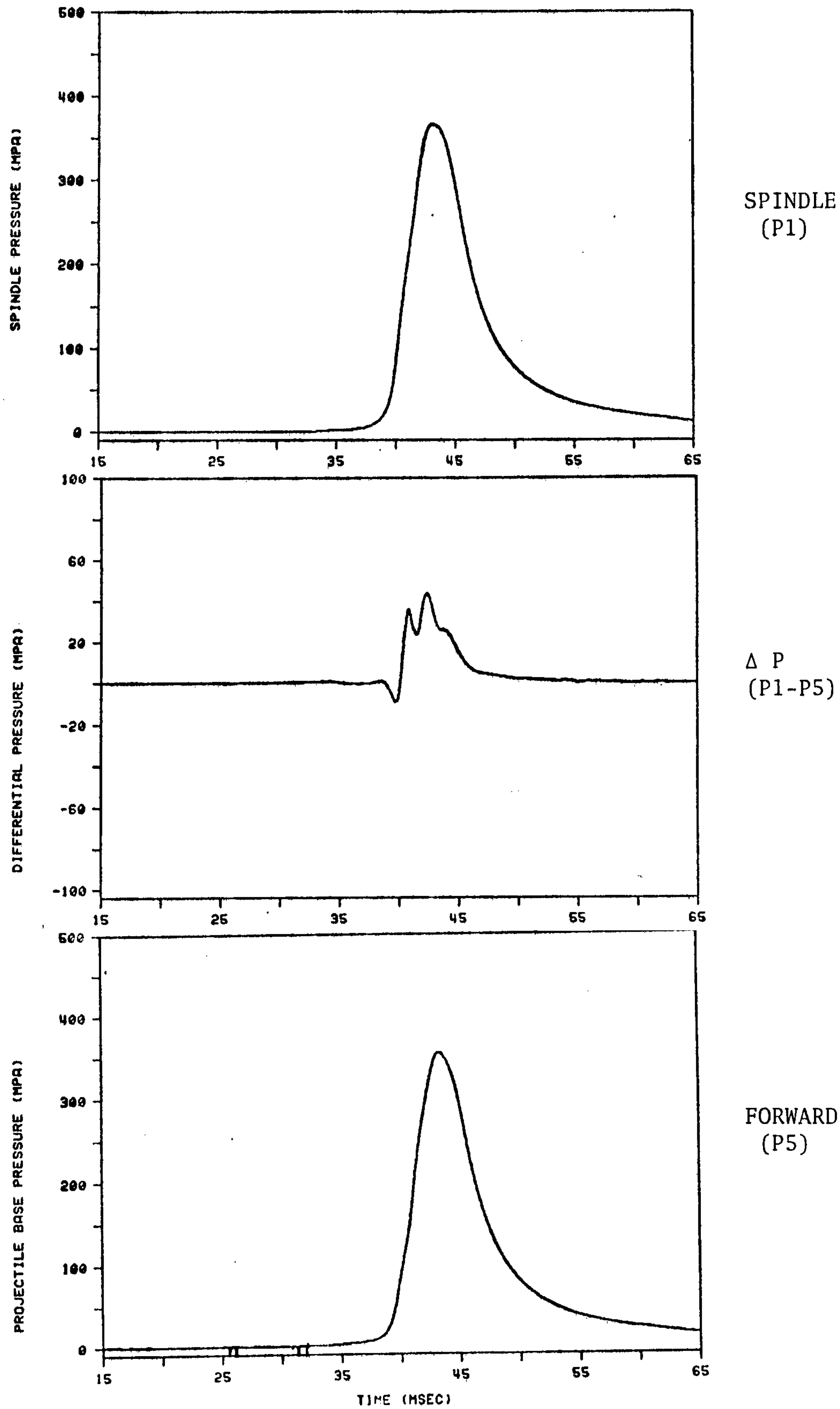


Figure F-10. Pressure vs. Time Traces, Series 16, ID 246/64

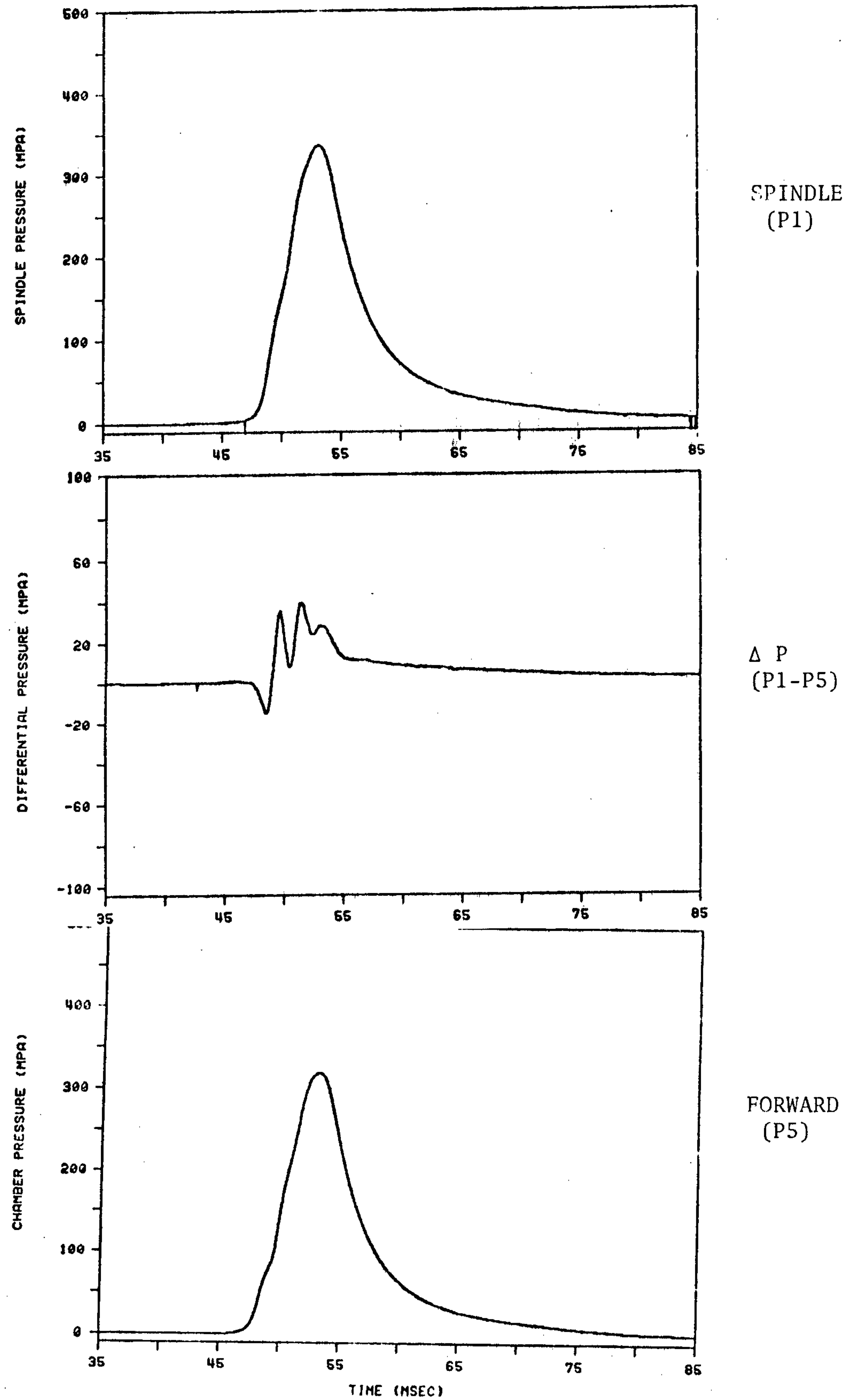


Figure F-11. Pressure vs. Time Traces, Series 17, ID 246/65

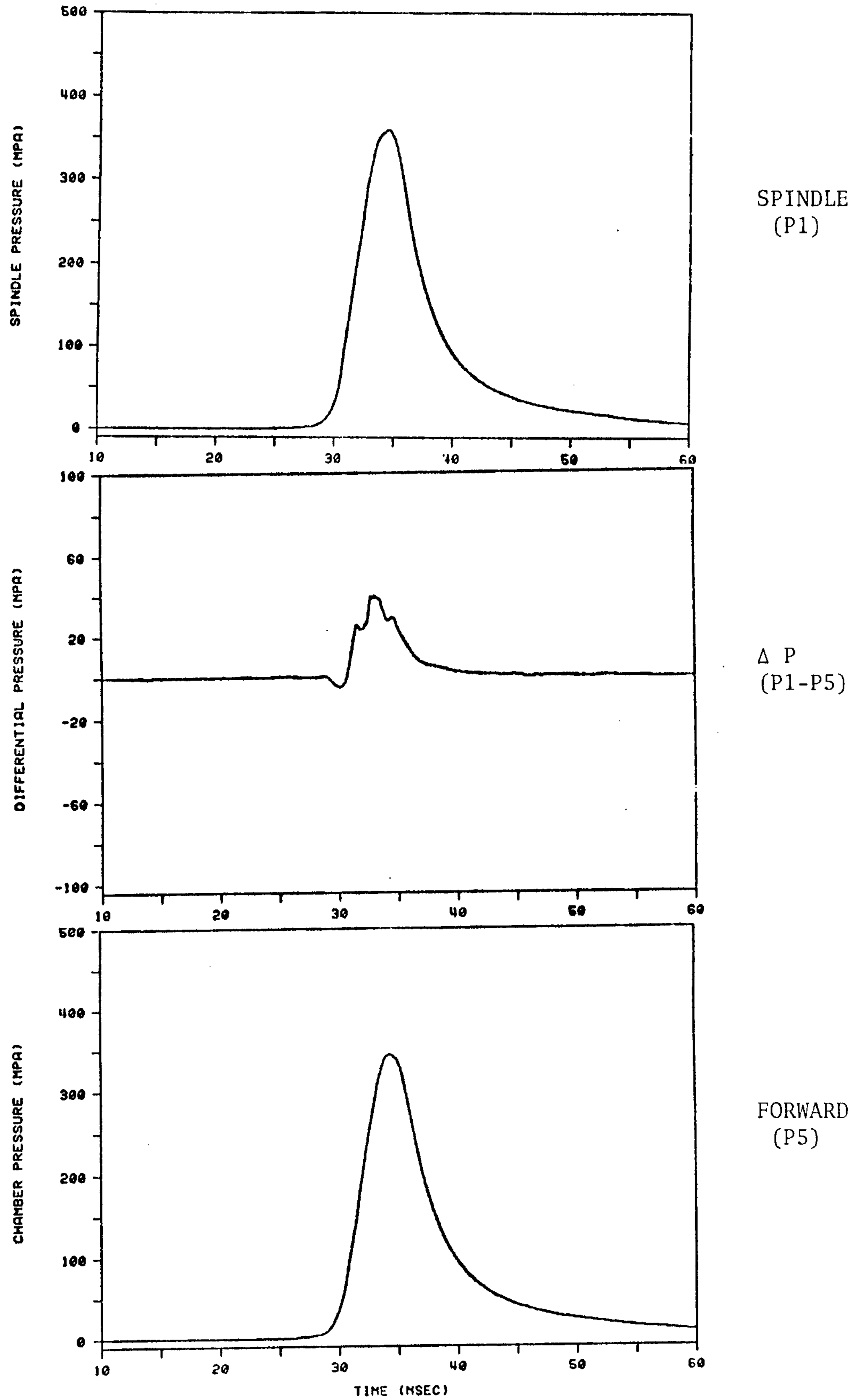


Figure F-12. Pressure vs. Time Traces, Series 17, ID 246/66

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