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RUPTURE PRESSURE MEASUREMENTS IN MODIFIED M392 ROUNDS,(U)
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MEMORANDUM REPORT ARBRL-MR-02958

(Supersedes IMR No. 629)

RUPTURE PRESSURE MEASUREMENTS IN MODIFIED M392 ROUNDS

Carl R. Ruth

September 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (meg)

Reduction of the vulnerability of the ammunition storage compartment for a tank is of current concern to the United States Army. The pressure at which cartridge cases containing propellant rupture is required as input for mathematical models used to design and evaluate new concepts in ammunition box design. A limited experimental investigation was conducted to determine what effects initial case volume and increased initial grain surface area have on the rupture pressure for typical metal cartridge cases used in tank ammunition. Detailed pressure-time curves are presented for each of five tests. Case rupture pressure (CONT'D)

393 471

20. **Abstract (Cont'd):**

varied from a low of 30 MPa to a high of 100 MPa.

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I. INTRODUCTION

Reduction of the vulnerability of the ammunition storage compartment for a tank is of current concern to the United States Army[1,2]. When the propellant in a cartridge case is ignited by some external event (shaped charge, kinetic energy penetrator, etc.), the propellant will deflagrate and burn. This primary event has been studied[1] and, in most instances, the ammunition compartment has survived. Secondary reactions can occur in adjacent stored rounds with delays in reaction from milliseconds to an hour or more following the initial attack (primary event). In some instances, these secondary reactions are more severe than the primary event, sometimes destroying ammunition compartments that survived a primary event. The measurement of the severity of these secondary events was determined from copper crusher gage pressure readings. Details on the construction characteristics of an ammunition box that might be considered for the XM1, the type and number of rounds that might be stored in the box, and the possible method of venting the box are described in detail in Reference 1.

In tests conducted at the Ballistic Research Laboratory (BRL) and Materiel Testing Directorate (MTD), rounds confined in an ammunition box were tested in the same manner as those reported in Reference 1. Pressures were measured by placing copper crusher gages at both the base of the case and slug. In several of the tests, case pressures in excess of 207 MPa (30,000 psi) were noted. In tests done at the Propulsion Division (PD), BRL[3], case rupture pressures for unconfined rounds ignited in the standard manner using an M80A1 primer, never exceeded 41 MPa (6,000 psi).

Post test examination of rounds confined in an ammunition box showed that rounds adjacent to destroyed rounds were severely damaged (crushed cartridge cases, damaged propellant grains, etc.). Crushed cases (decreased chamber volume) and shattered and/or broken propellant grains (increased propellant surface area) and the subsequent ignition of the propellant were, probably, the major factors contributing to the exceedingly high case rupture pressures noted earlier. Not surprisingly, the higher the case rupture pressure, the more intense the effects on both the integrity of the ammunition box and its contents.

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1. *Donald F. Menne and F. Tyler Brown, "Vented Ammunition Compartment Tests with Live Ammunition", Ballistic Research Laboratories Memorandum Report No. 2564, December 1975, AD# B008755L.*

2. *Donald F. Menne and F. Tyler Brown, "Sensitivity of 105mm M456A1 Ammunition to Attack by Shaped Charges", Ballistic Research Laboratories Memorandum Report No. 2543, October 1975, AD# B008041L.*

3. *Carl R. Ruth and Jerome M. Frankle, "Rupture Pressure for Metal Cartridge Cases", Ballistic Research Laboratory Memorandum Report No. 2743, April 1977, AD# B018599L.*

The dynamic inter-relationship of the aforementioned parameters which caused the high pressure cannot be determined without extensive test firing under a variety of controlled conditions. However, by altering some of the standard parameters of the 105-mm, M392 round, limited tests can be conducted to isolate the effects of some parameters as possible causes of large increases in case rupture pressure.

The objective of this task was to determine what effects initial case volume and increased initial grain surface area would have on the peak rupture pressure of the M392 round in an unconfined environment.

II. DESCRIPTION OF TEST

All firings were done with rounds modified with pressure gages so that the rupture pressure of the case could be determined. Following is a description of the rounds, the pressure gages and the method in which the firings were conducted.

A. Test Hardware

The complete cartridges that were test fired were representative of the APDS, M392A2, rounds for the 105-mm, M68 Tank Gun. Components of these cartridges, as shown in Figure 1, Section A-A, are the Cartridge Case, M115 (brass); Primer, Electric, M80A1; Propellant, M30MP, 1.143-mm (0.045-in.) web, and/or Propellant, M1SP, 0.396-mm (0.0156-in.) web; Liner, Wear-Reducing, Titanium Dioxide; and Proof Slug, T382 (instead of the actual M392A2 Projectile). The proof slugs weighed 5.85 kg (12.87 lb) and the propellant charges varied in weight as indicated in the Results section. The slug, shown in Figure 1, had the undamaged cartridge case crimped over the vulcanized fiber rotating band, which is the standard assembly for this round.

B. Instrumentation

Internal ferrule (IF) pressure gages were used to record pressure versus time at the base of the cartridge case and at the base of the projectile. For the last two rounds tested, a Kistler piezoelectric gage was also installed in the base of the case. The locations for the IF strain gages are shown in Figure 1. A detailed description of the installation of gages of this type in cartridge cases may be found in BRL MR 1879[4] and BRL TN 1344[5]. A 25.4-mm (1-inch) diameter, 17.8-mm

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4. *Jerome M. Frankle, "Interior Ballistics of High-Velocity Guns, Experimental Program - Phase 1", Ballistic Research Laboratories Memorandum Report No. 1879, November 1967, AD# 830408.*

5. *Jerome M. Frankle, "Modification of 115-mm Base Plug for Internal Ferrule Cartridge Case Gages", Ballistic Research Laboratories Technical Note No. 1344, September 1960, AD# 486747L.*

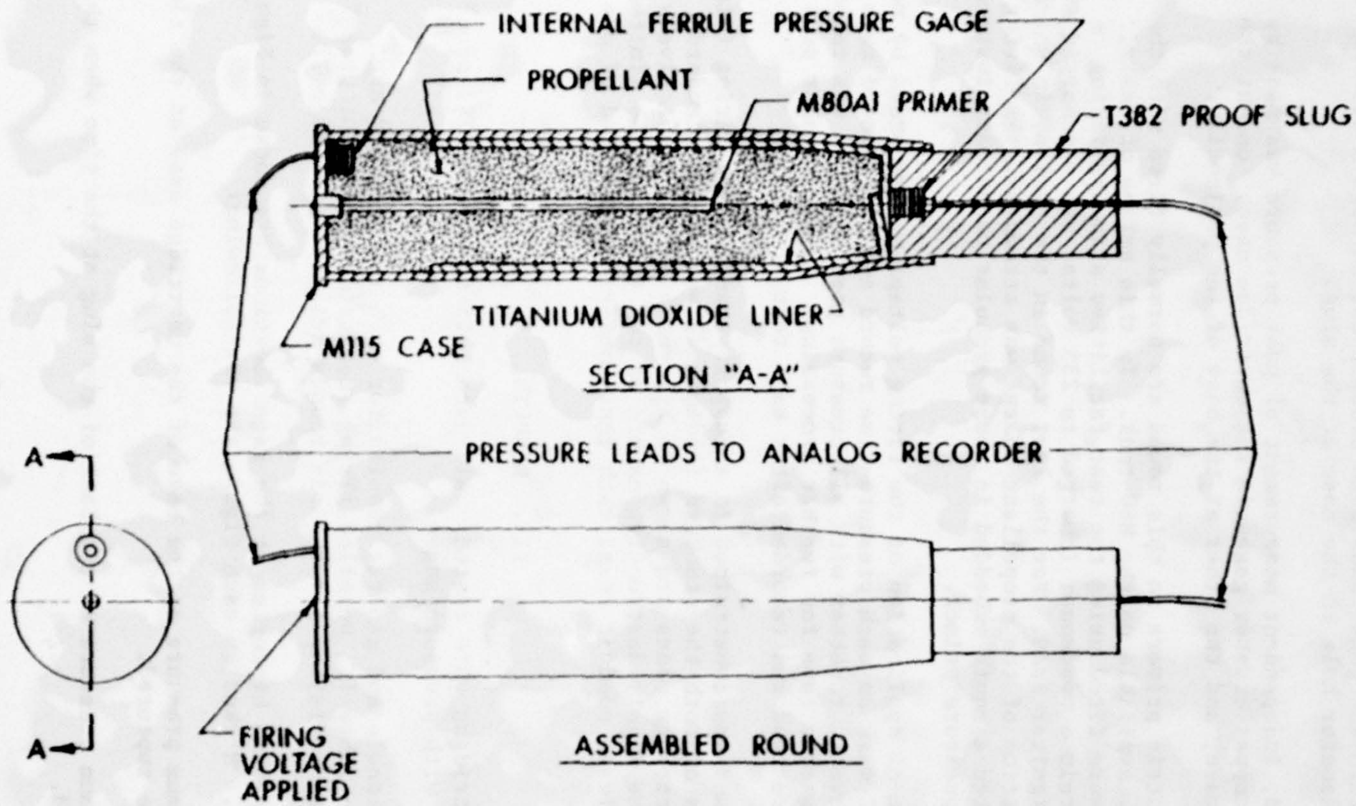


Figure 1. Assembled M392 Round with Gages (Undamaged Case)

(0.7-in.) deep hole was machined into the base of the proof slug to accommodate the pressure gage used to measure pressure at the base of the projectile. The gage leads were brought out through a 6.35-mm (0.25-in.) diameter hole to the nose of the slug.

A second, independent measurement of peak pressure was made by placing two copper crusher gages in the cartridge case: one at the base of the case, and the other at the base of the projectile.

The electric primers in this round are normally fired with the 24 volts d.c. available on the M60 tank. In this series of tests, the primers were fired using the test facilities standard firing circuit, wherein a condensor (charged to 235 volts) was discharged through the igniter head. For the last round in the series, in which external ignition of the propellant charge was attempted, the firing voltage ignited a squib embedded in loose granular propellant instead of the high pressure primer.

The time of application of the firing voltage was recorded by means of a fiducial mark on each pressure-time record and represented zero time. This event, together with all pressure gage outputs, was recorded on analog magnetic tape for further processing. Copper crusher peak pressures were read and recorded after each test.

Each round was constrained in a support stand before firing (Figure 2). Examples of both the standard (undamaged) and the nonstandard (damaged) cartridge cases are shown in Figures 1 and 3, respectively. Because of the highly destructive nature of the tests and the limited time available to conduct them, each test condition consisted of one round.

III. RESULTS

Six cartridges were tested. All used M115 cases and T382 proof slugs instrumented with pressure gages.

The rationale and general results for each round tested are summarized in Table I. Detailed firing results and pertinent propellant and case characteristics for the six rounds are given in Table II.

Pressure-time histories at the gage locations are shown in Figures 4 through 20. Marked on each figure are the following:

- Maximum pressure at the base of the cartridge case at the time when the case ruptured.

- Maximum pressure at the base of the slug at the time when the case ruptured.

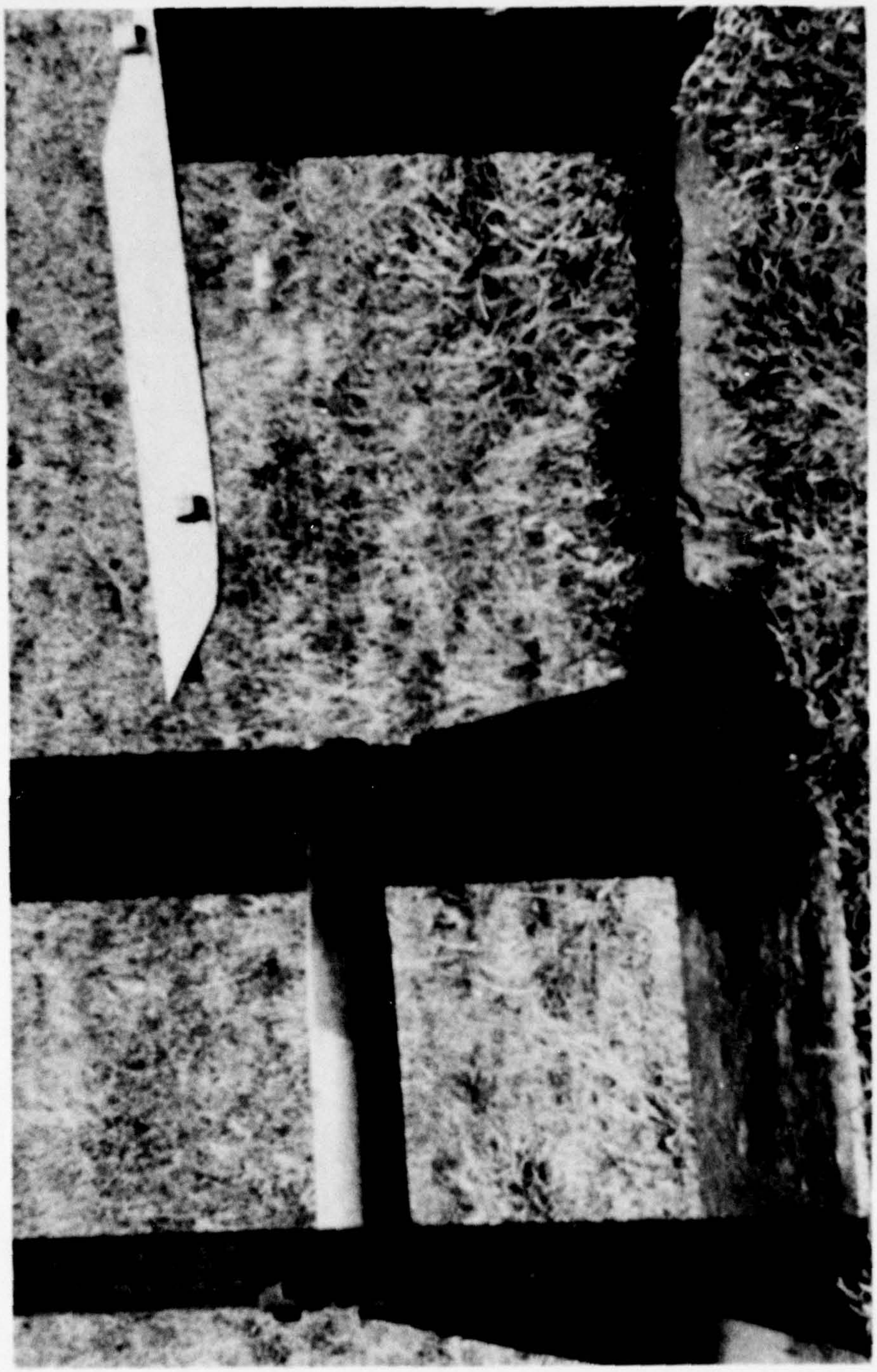
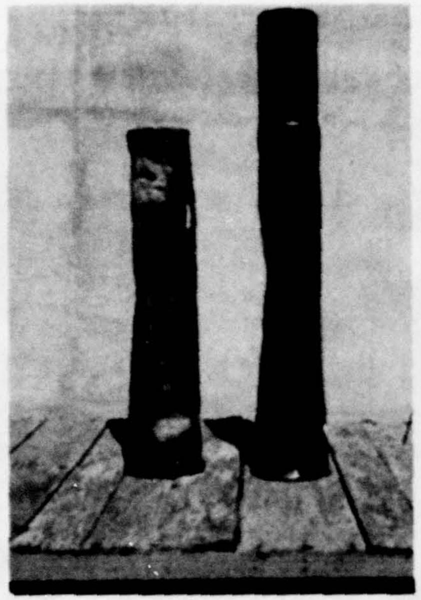


Figure 2. Constrained M392 Round Before Firing



Lightly Damaged

Severely Damaged

Figure 3. Damaged M392 Rounds Before Firing

TABLE I. Test Rationale and Results

Round No.	Test Rationale[1]	Results[2]
1,2	Will reduced case volume (crushed cases) and increased initial propellant surface area (slightly larger than a standard M30MP charge) increase case rupture pressure above that specified in Reference 3?	Case rupture pressure essentially unchanged from values reported in Reference 3.
3	Using a standard case, will doubling the initial propellant surface area of Rounds 1 and 2 increase case rupture pressure?	Case rupture pressure is approximately two times that of Rounds 1 and 2.
4	Using a standard case, will quadrupling the initial propellant surface area of Rounds 1 and 2 increase case rupture pressure?	Case rupture pressure is approximately three times that of Rounds 1 and 2.
5	Using the same type of charge as in Round 4, will encasing the charge in a loose-fitting plexiglass sleeve and not allowing the projectile to debullet increase case rupture pressure?	Case rupture pressure slightly higher than that of Round 4.
6	Using the same type of charge as in Round 4, will fast heating of the charge before ignition, increase the case rupture pressure?	Case rupture pressure was much less than that of Rounds 1 and 2. Apparently, spot ignition of the charge occurred before the propellant could be heated to a fairly high temperature.

1 - The projectile was free to debullet in all rounds except Round 5.
2 - Specific values on each round are detailed in Table II.

TABLE II. Round-By-Round Data

Rd. No.	Type	Web mm (in.)	Wt kg[1] (lb)	Grain Condition	Initial[2] Surface, Area, cm^2 ($in.^2$)	Volume of[3] Case, cm^3 ($in.^3$)	Base of Case: Internal Ferrule Gage	Base of Case: Kistler Gage	Base of Case: Copper Crusher Gage	Base of Projectile: Internal Ferrule Gage	Base of Projectile: Copper Crusher Gage	Comments
	PROPELLANT CHARACTERISTICS					CASE CONDITION	EXPERIMENTAL PRESSURES[4], MPa (psi)					
1	M30MP M30MP	1.143 (0.045) 1.143 (0.045)	4.35 (9.6) 1.13 (2.49)	Standard Broken, Split Crushed	41,935 (6,500)	6,060(370) Damaged Case	34.4(4,990)	Not Used	Gage Lost	8(1,160)	17.2(2,490)	M80A1 Initiation. Projectile debullets.
2	M30MP M30MP	1.143 (0.045) 1.143 (0.045)	4.14 (9.12) 1.34 (2.95)	Standard Broken, Split Crushed	41,935 (6,500)	5,820(355) Damaged Case	30.4(4,410)	Not Used	34.5(5,000)	8.8(1,280)	17.2(2,490)	Same as Rd 1.
3	M30MP M1SP	1.143 (0.045) 0.396 (0.0156)	3.54 (7.8) 1.59 (3.50)	Standard Standard[5]	81,350 (12,600)	6,640(405) Undamaged Case	64(9,280)	Not Used	Gage Lost	17(2,470)	Gage Lost	Same as Rd 1.
4	M1SP	0.396 (0.0156)	4.54 (10.0)	Standard	155,120 (24,045)	6,640(405) Undamaged Case	87(12,615) Average Value	Not Used	Gage Lost	34(4,930)	68.7(9,960)	Same as Rd 1.
5	M1SP	0.396 (0.0156)	4.54 (10.0)	Standard	155,120 (24,045)	6,640(405) Undamaged Case	100(14,500) Average Value	Lost Data	133.1 (19,300)	60(8,700)	Gage Lost	M80A1 Initiation. Projectile could not debullet. Loose fitting plexiglass sleeve around case.
6	M1SP	0.396 (0.0156)	4.54 (10.0)	Standard	155,120 (24,045)	6,640(405) Undamaged Case	Noise	14.4(2,090)	11.7(1,700)	7.2(1,040)	11.7(1,700)	Initiation by burning 5.4 kg (12 lb) of M30MP propellant under rd. Projectile debullets.

1 - Total propellant in case limited by loading density.
2 - *Initial surface area calculated. For Rounds 1 and 2,* calculation was based on 5.4 kg (12.09 lb) of undamaged propellant grains. Actual surface area was slightly larger than that indicated because of the damaged grains.
3 - Case volume measured for Rounds 1 and 2. For other rounds, value cited is from literature.
4 - *Firings done at Range 18 during Mar-July, 1976.*
5 - Although M1 is less energetic than M30, the smaller web M1 with its corresponding high initial surface area dictates a mass gas generation rate greater than M30. For the same charge weight, M1 gives higher peak pressure than M30.

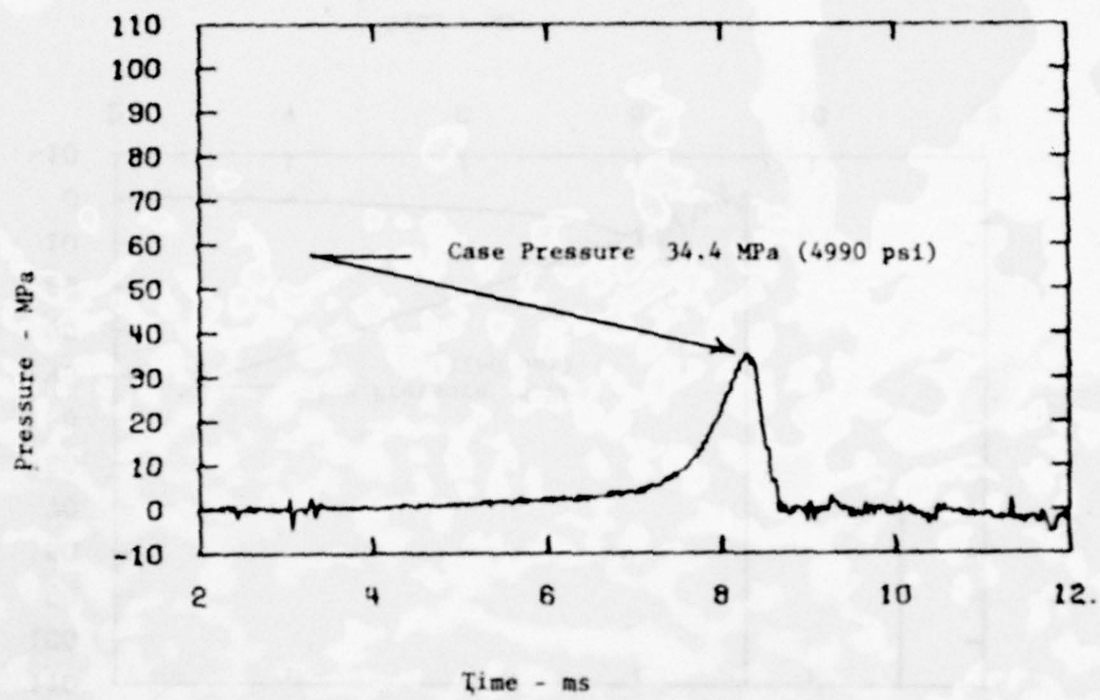


Figure 4. Pressure-Time History for Round 1, Case Pressure, IF Gage

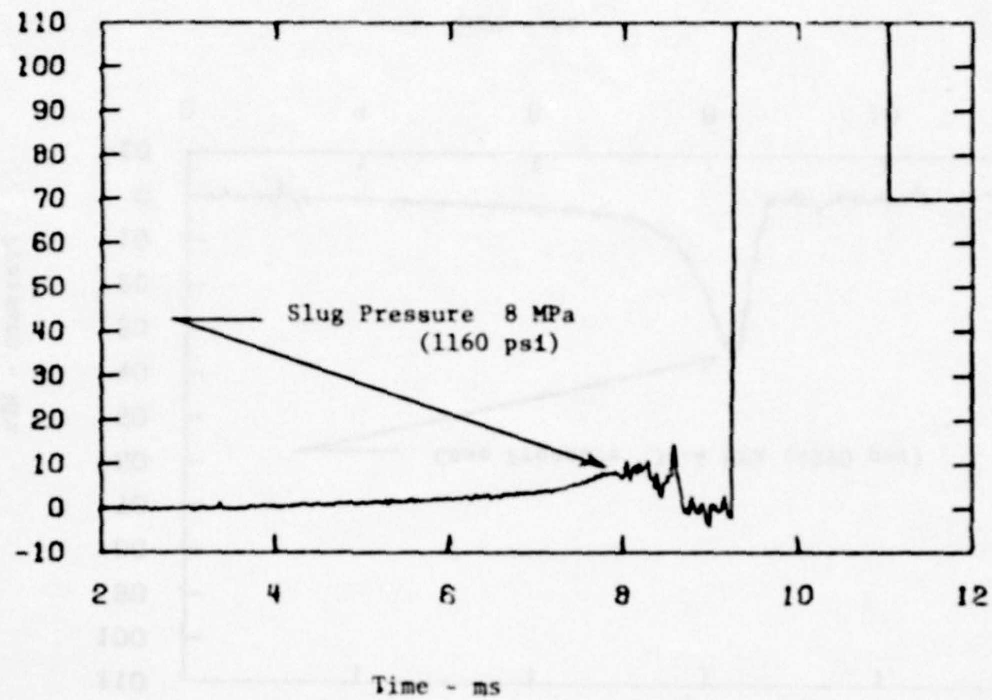


Figure 5. Pressure-Time History for Round 1, Slug Pressure, IF Gage

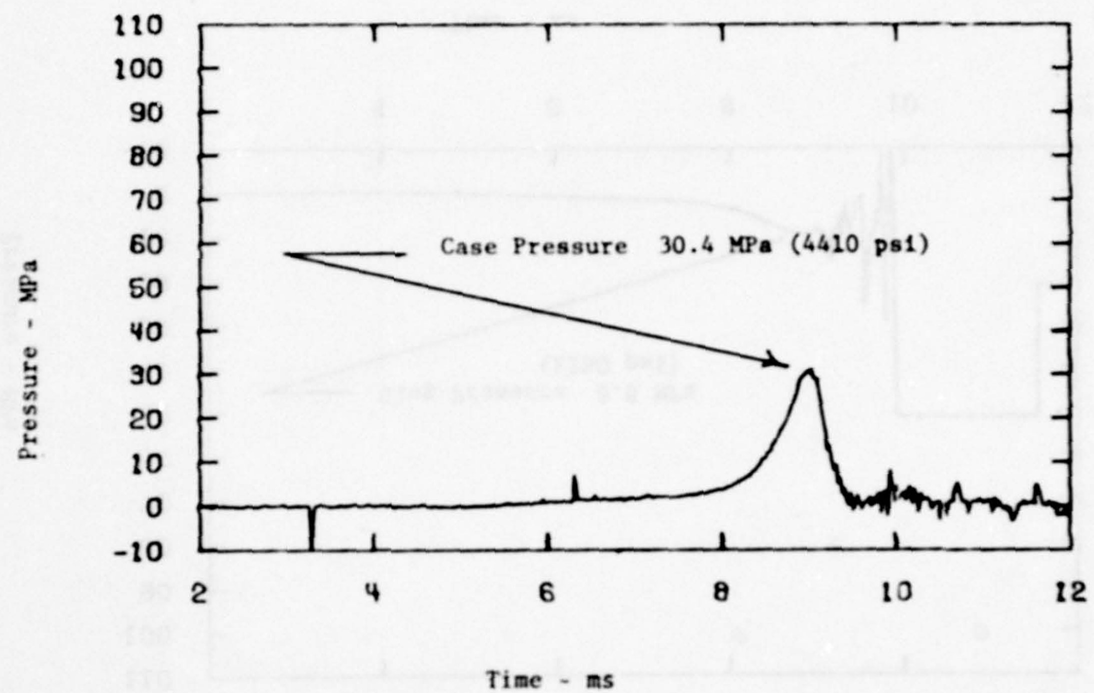


Figure 6. Pressure-Time History for Round 2, Case Pressure, IF Gage

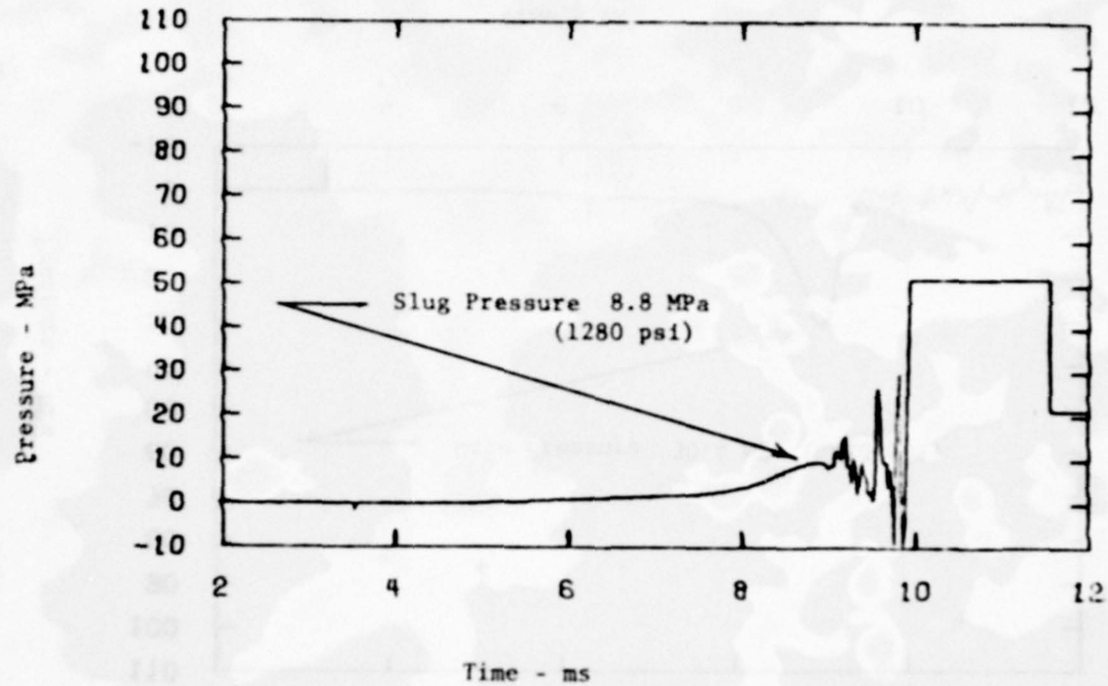


Figure 7. Pressure-Time History for Round 2, Slug Pressure, IF Gage

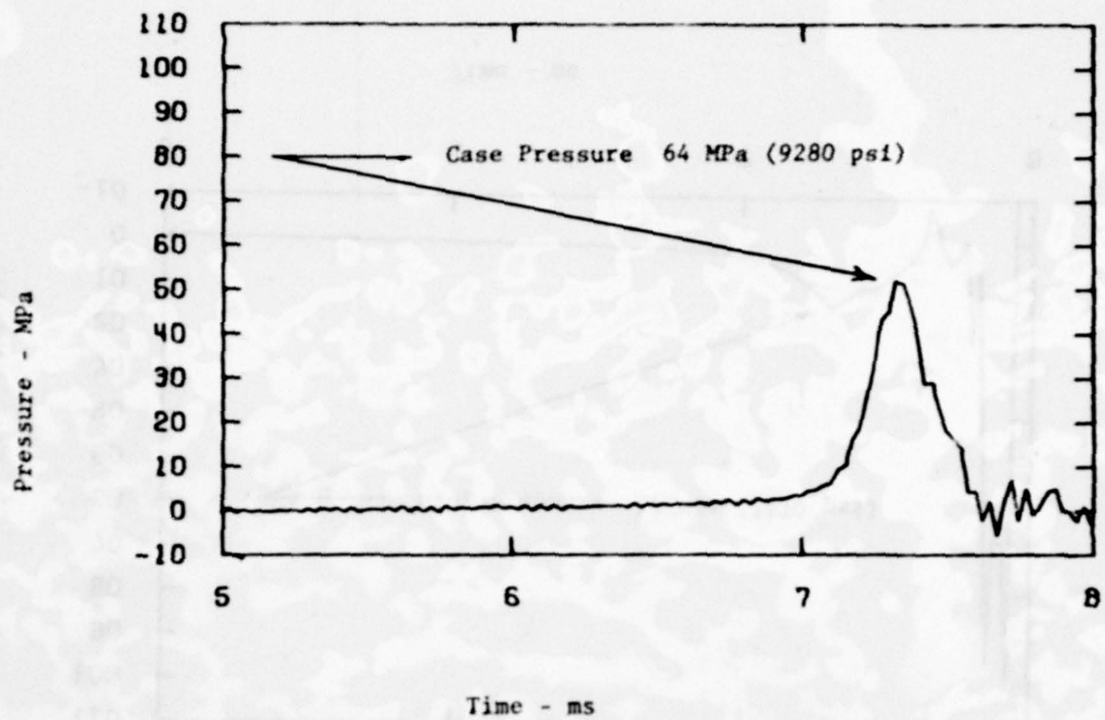


Figure 8. Pressure-Time History for Round 3, Case Pressure, IF Gage

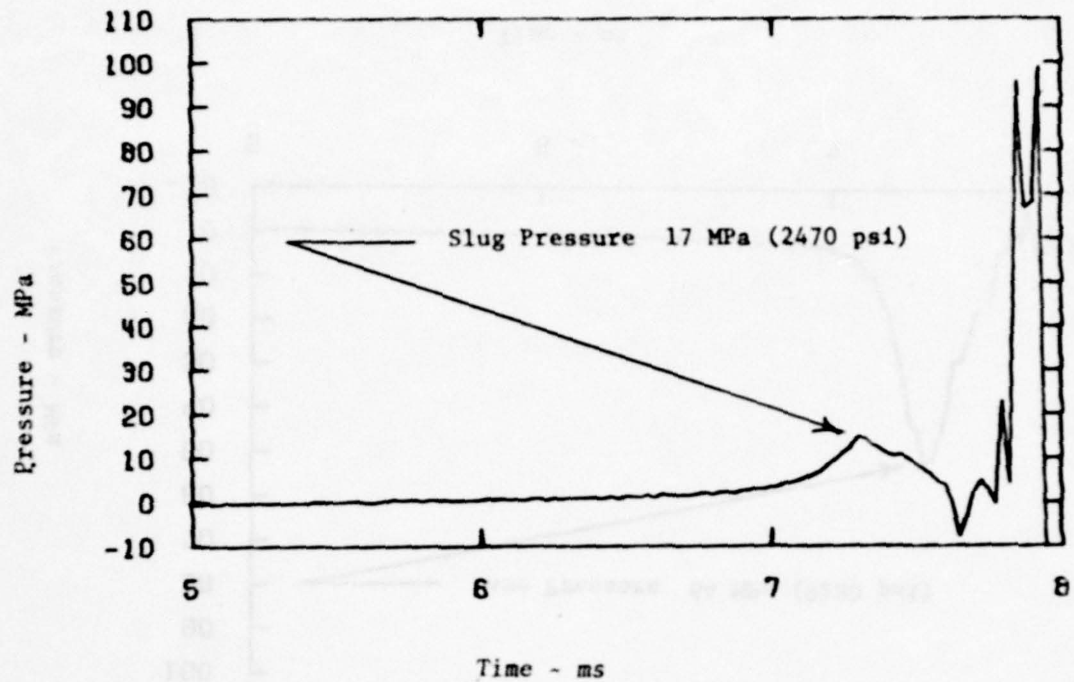


Figure 9. Pressure-Time History for Round 3, Slug Pressure, IF Gage

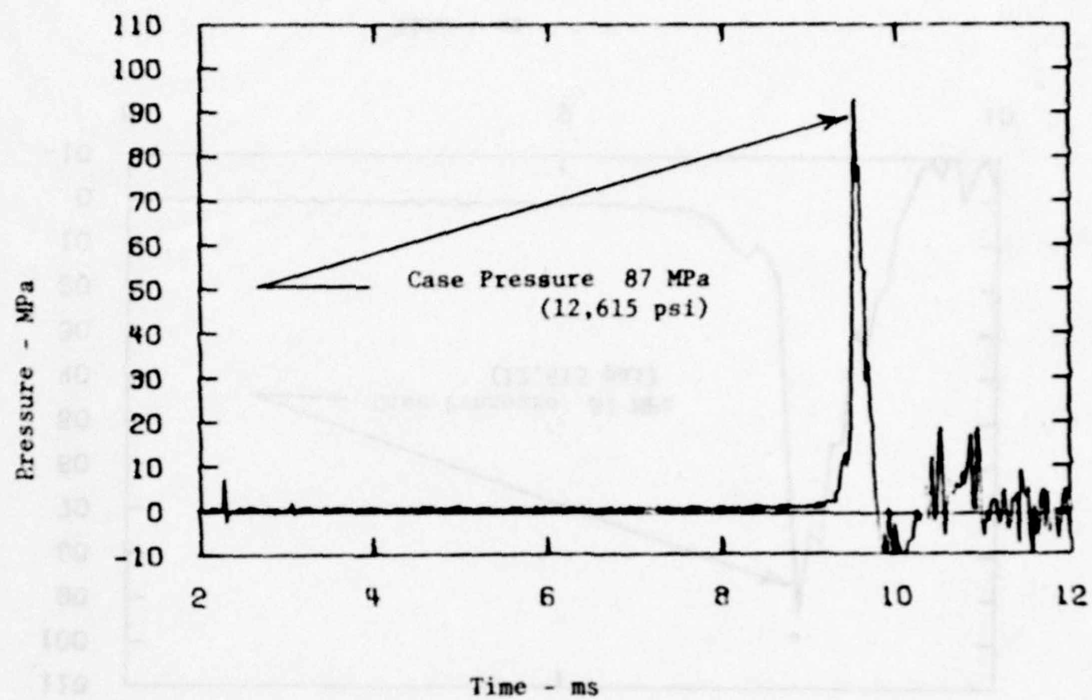


Figure 10. Pressure-Time History for Round 4, Case Pressure, IF Gage

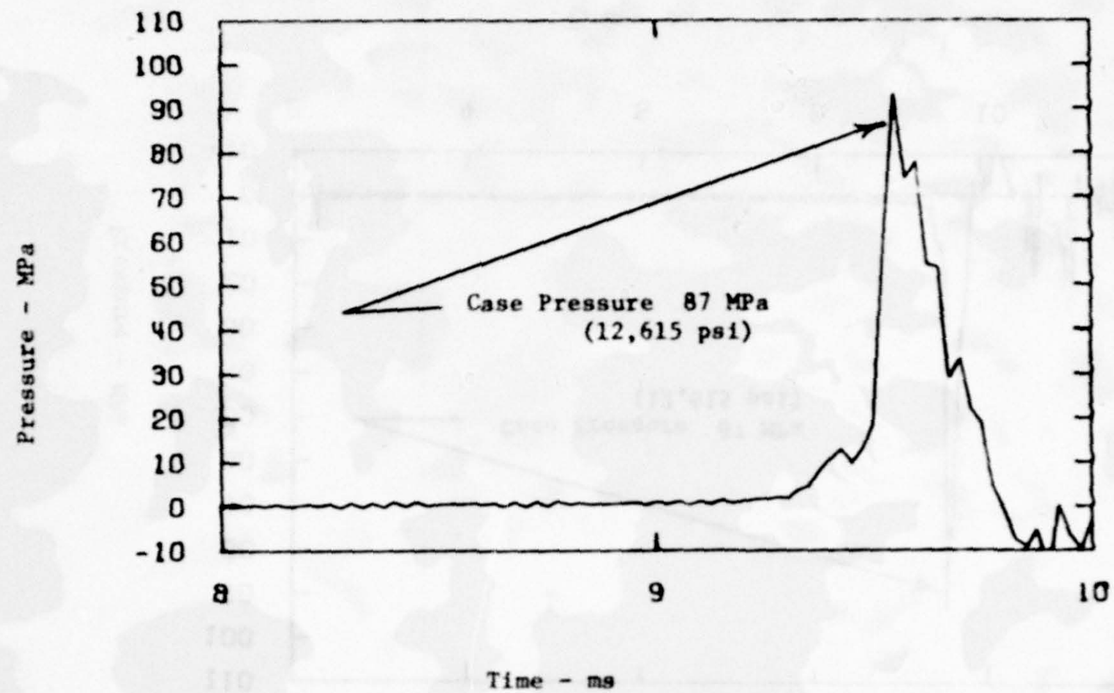


Figure 11. Pressure-Time History for Round 4, Case Pressure, IF Gage, Expanded Time Scale

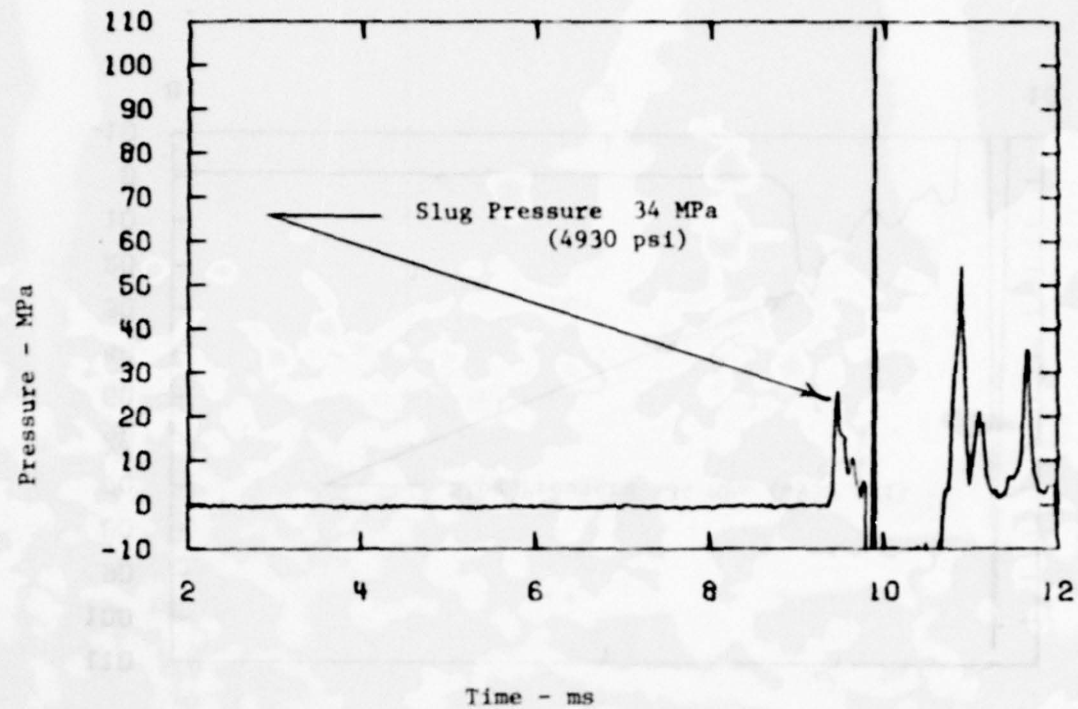


Figure 12. Pressure-Time History for Round 4, Slug Pressure, IF Gage

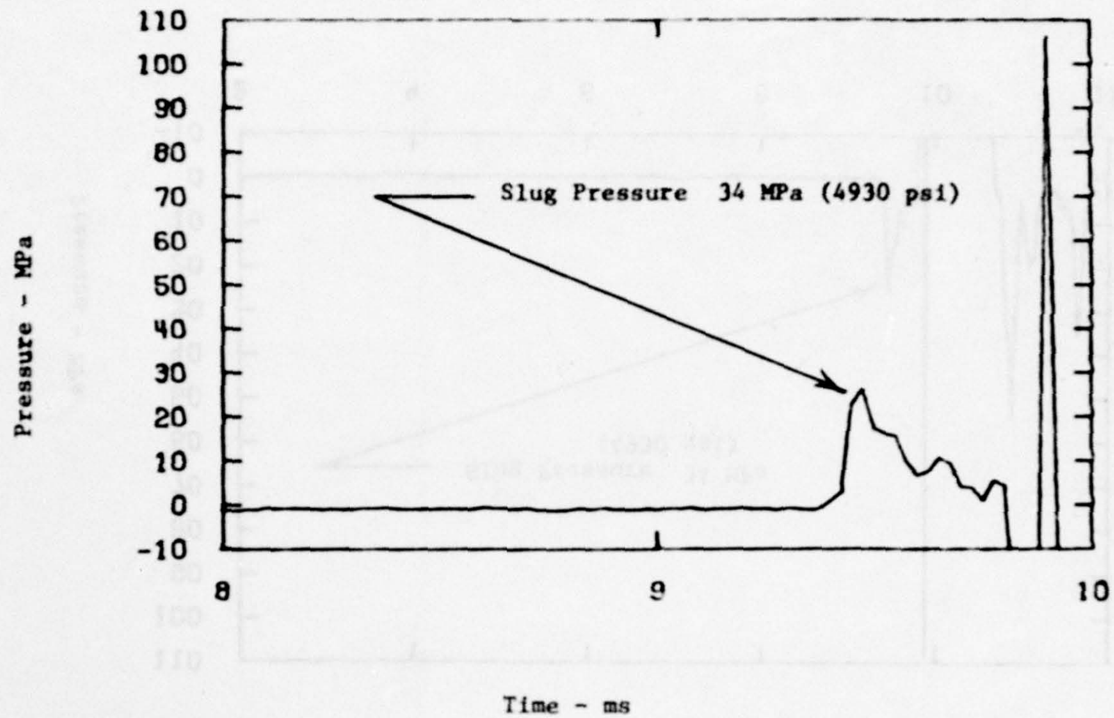


Figure 13. Pressure-Time History for Round 4, Slug Pressure, IF Gage, Expanded Time Scale

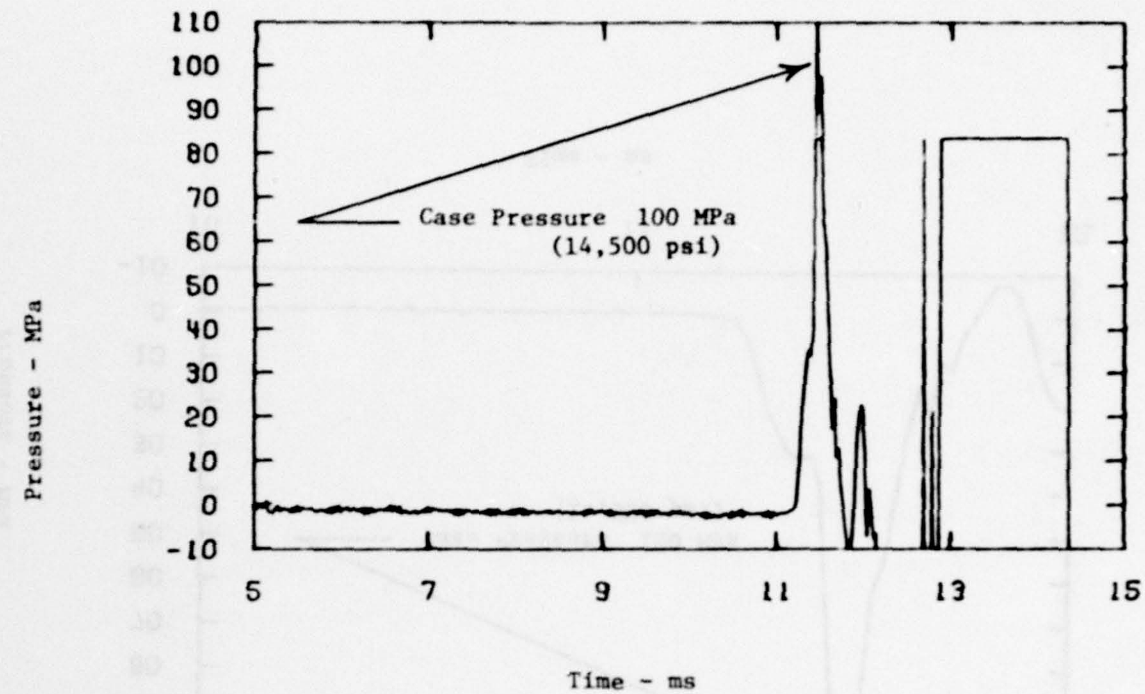


Figure 14. Pressure-Time History for Round 5, Case Pressure, IF Gage

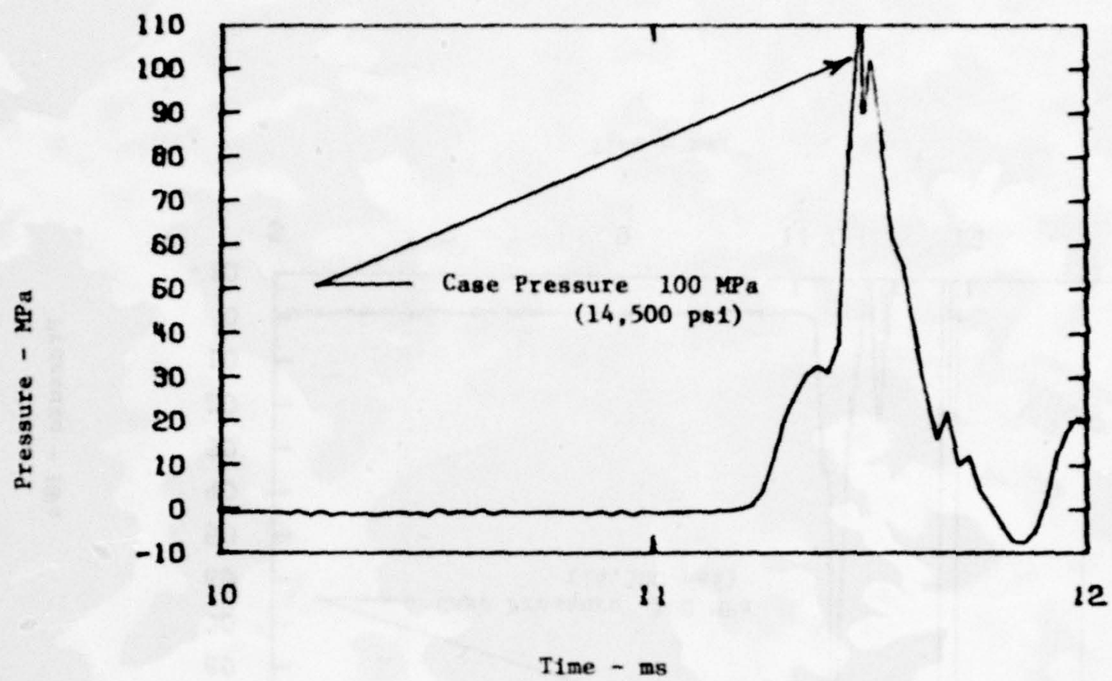


Figure 15. Pressure-Time History for Round 5, Case Pressure, IF Gage, Expanded Time Scale

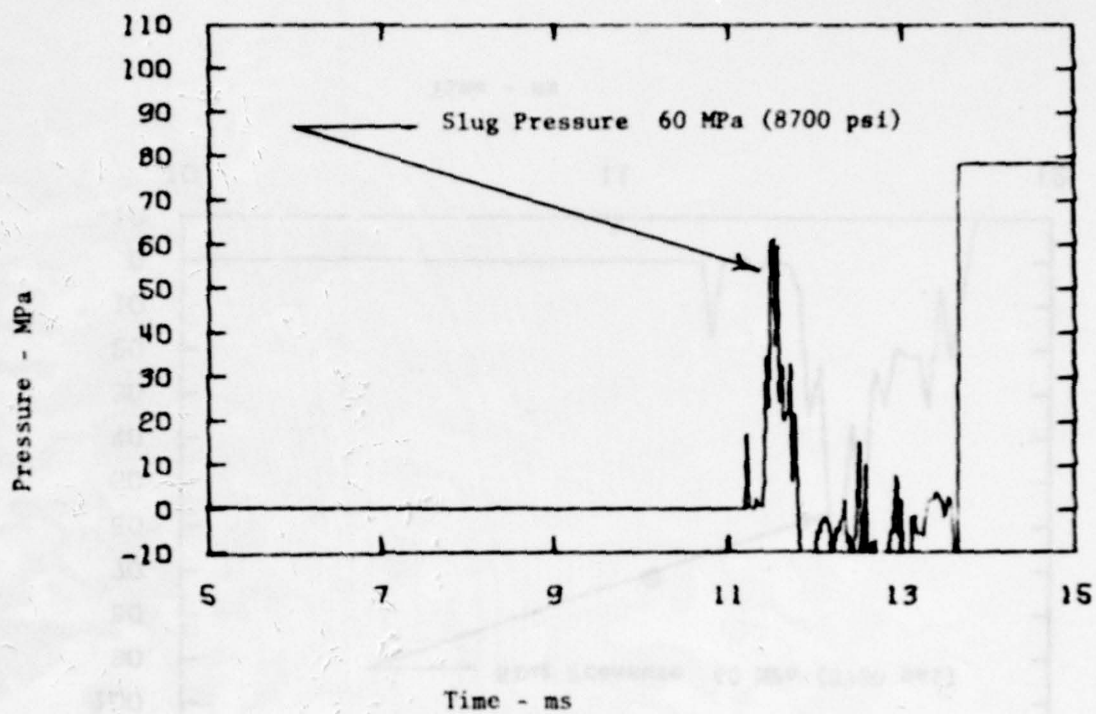


Figure 16. Pressure-time History for Round 5, Slug Pressure, IF Gage

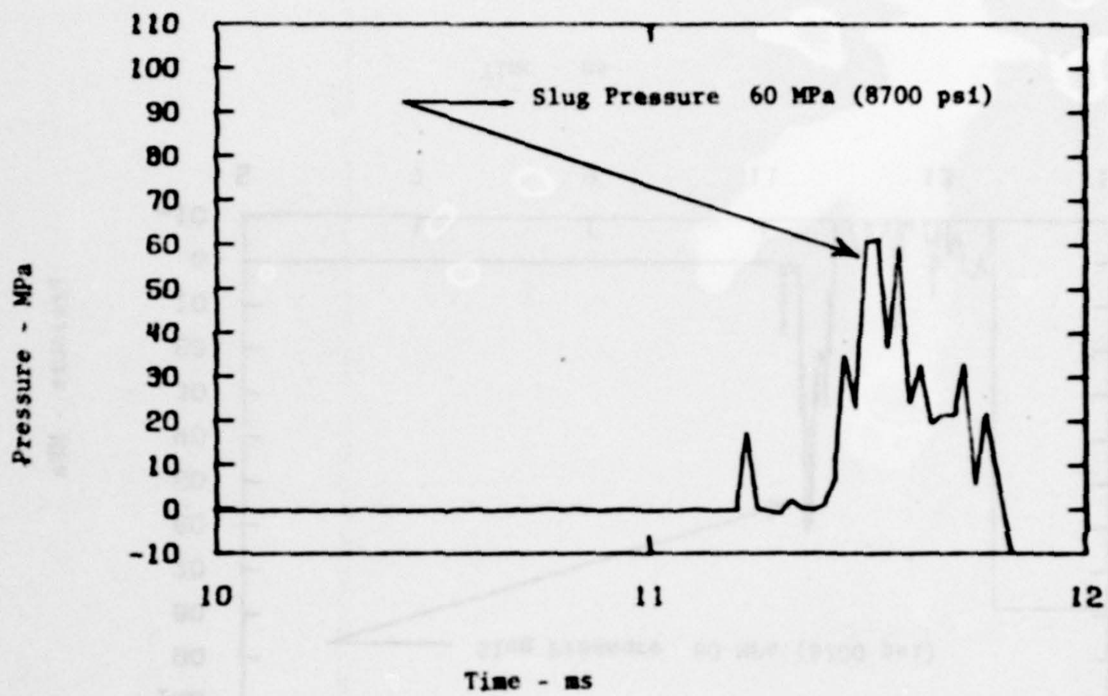


Figure 17. Pressure-Time History for Round 5, Slug Pressure, IF Gage, Expanded Time Scale

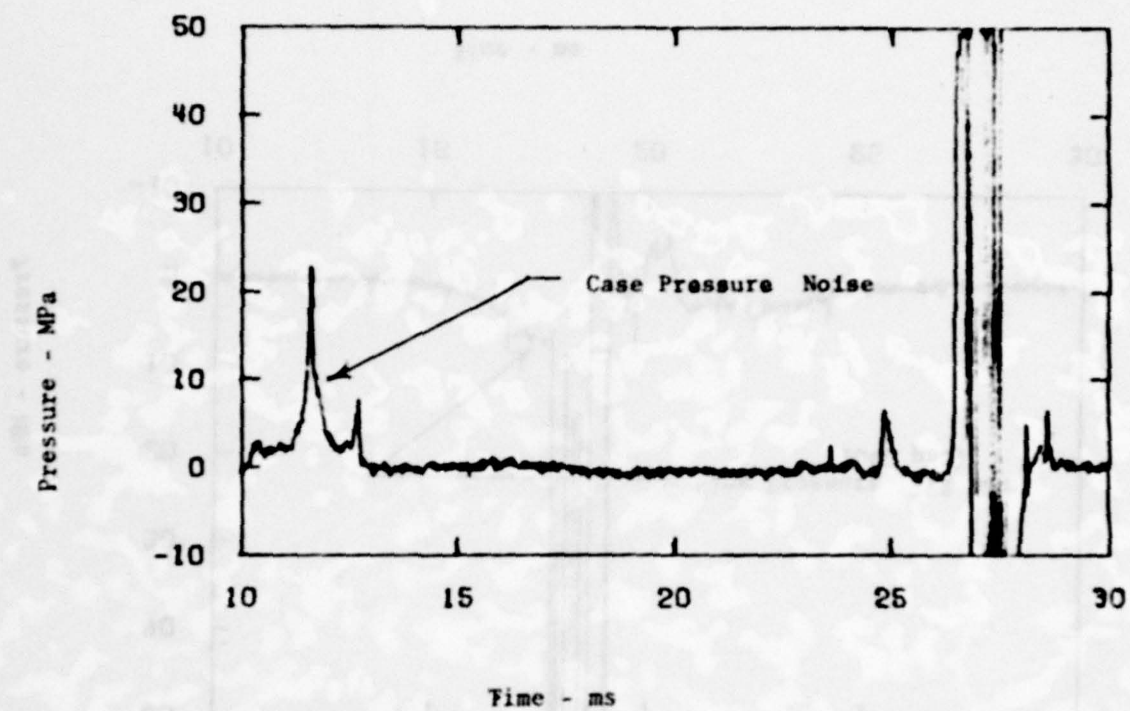


Figure 18. Pressure-Time History for Round 6, Case Pressure, IF Gage

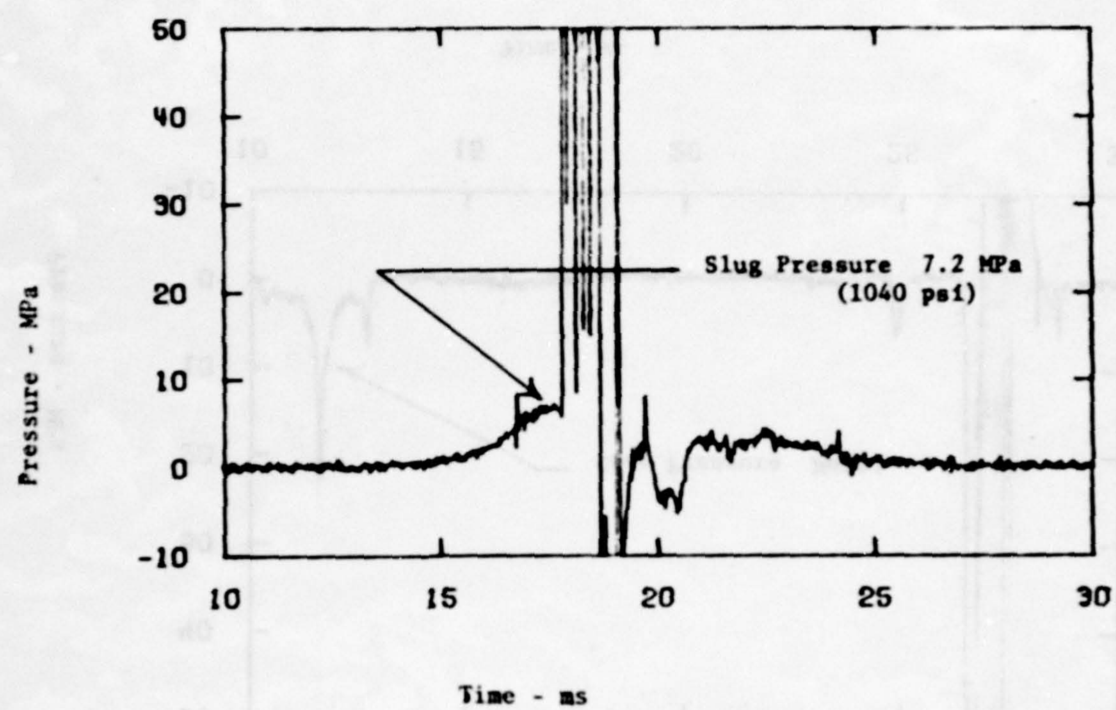


Figure 19. Pressure-Time History for Round 6, Slug Pressure, IF Gage

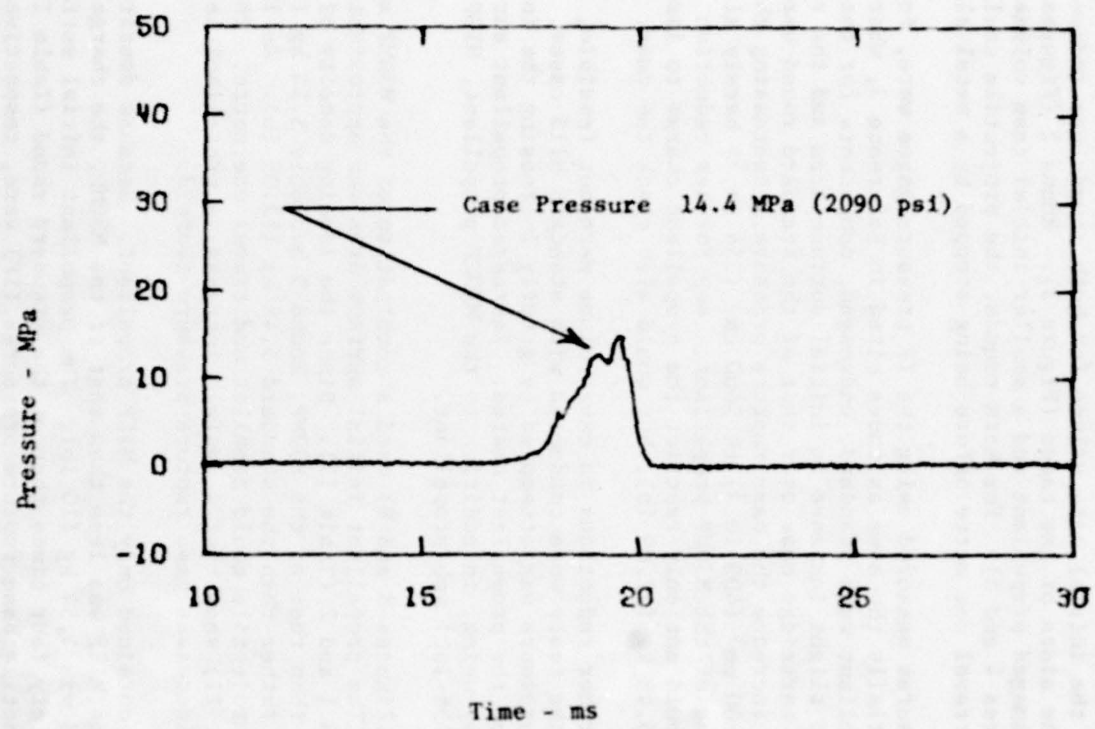


Figure 20. Pressure-Time History for Round 6, Case Pressure, Kistler Gage

Rounds 1 and 2 used both standard (undamaged) and nonstandard (damaged) M30MP, 1.143-mm (0.045-in.) web propellant. Damaged propellant grains were those that had been broken, split, crushed, or cut into pieces by personnel at the BRL. In addition to increasing the initial surface area, the initial case volume for both rounds was reduced by crushing in the sides of the cases (Figure 3). Round 2 (Figures 6 and 7) had more damaged propellant and a smaller initial case volume than Round 1 (Figures 4 and 5). For both rounds, the projectile could debullet and travel one metre before being stopped by a metal plate.

The pressures measured using the IF pressure gages were, for both rounds, essentially the same as those cited in Reference 3, wherein the case and propellant were standard, undamaged, components for the 105-mm Gun, M68. The slight increase in initial surface area and the reduced volume of the cartridge case over that of the standard round were not sufficient to increase the case rupture pressure. Decreasing the case volume from 6600 cm^3 (403 $in.^3$) to 5800 cm^3 (354 $in.^3$) barely allowed for the loading of the M30MP propellant. Any further reduction in case volume would not only restrict the propellant charge to less than the standard 5.48 kg (12.09 lb), but would also crack the case.

Since further reductions in case volume were not feasible, the remainder of the tests were conducted with standard M115 cases. Increased case rupture pressure was attempted by greatly increasing the initial surface area of the propellant charge. Increased propellant surface area was obtained by using, in addition to the M30MP propellant, M1SP, 0.396-mm (0.0156-in.) web propellant.

Round 3 (Figures 8 and 9) used a combination of the M30MP and M1SP propellants. The propellant initial surface area was approximately twice that of Rounds 1 and 2 (Table II). Since the loading density of the M1SP was less than that of the M30MP, Round 3 had only 5.13 kg (11.3 lb) of propellant rather than the standard 5.48 kg (12.09 lb). As in Rounds 1 and 2, the projectile could debullet and travel one metre. The test results (Table II) show that a twofold increase in propellant initial surface area increases case rupture pressure twofold.

Round 4 contained only the M1SP propellant. Because density of loading for the M1SP was less than that of the M30MP, the charge weight for this round was 4.54 kg (10 lb). The propellant initial surface area was approximately four times that of the standard round (Table II). Case and projectile base rupture pressures (IF) were, respectively, three and four times larger than those cited in Reference 3. Because of the rapid rise time of the pressure, the frequency response of the internal ferrule gage system was approached, causing oscillations and overshoot of the gage (Figures 10 through 13). The actual case rupture pressure is within the range cited in Table II.

Round 5 used the same M1SP propellant as Round 4. To see if an external constraint would increase rupture pressure above that of

Round 4, a readily-available, loose-fitting, 0.63-cm (0.25-in.) thick, 14-cm (5.50-in.) diameter, plexiglass sleeve was placed over Round 5. The front ends of the sleeve and projectile were constrained by a metal plate which supported the sleeve and prevented it from touching the surface of the case and projectile. The plate also prevented the projectile from debulleting. Because of the oscillatory response of the IF gage for Round 4, a Kistler 601 pressure gage, having a much higher frequency response than the IF gage, was also used to measure case rupture pressure.

The results for Round 5 are cited in Tables I and II and Figures 14 through 17. Both case and projectile base rupture pressures were higher than those for Round 4. An instrumentation malfunction caused the loss of the Kistler pressure data. The use of the plexiglass sleeve and/or the inability of the projectile to debullet apparently increased the rupture pressure slightly.

For Rounds 1 through 5, the propellant temperature was approximately 21°C (70°F). By substantially increasing the propellant temperature before ignition (a probable event for secondary reactions in the ammunition box tests), the case rupture pressure might be expected to be larger than that of Round 5. Ideally, the propellant temperature should be slowly increased to a value just below cook-off before the propellant is set off with the primer[6]. This elaborate test was not possible in the time frame available for these firings.

Rather, in an attempt to heat the propellant rapidly in the case before ignition took place, Round 6, which used only M1SP propellant, was set off by atmospherically burning 5.4 kg (12 lb) of M30MP propellant under the fully-instrumented round. The propellant was placed into a trough 60 cm (23.6 in.) deep. The trough was so positioned that the top of the propellant bed was 2 cm (0.8 in.) below and in line with the case. Rapid ignition of most of the loose, granular propellant was accomplished by pouring a few grams of A1 black powder over the M30MP grains. The black powder was, in turn, ignited by a squib embedded in the powder using the same capacitor discharge system that ignited the primers in previous rounds. The projectile in the test was free to debullet.

The results were not as expected. Pressures for Round 6 are shown in Table II and Figures 18 through 20. The IF case pressure gage malfunctioned. Both the IF slug gage and the Kistler case gage indicated low case pressures.

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6. *Robert B. Frey, Giordano Melani, Jerry E. Waddell, Boyd C. Taylor, and Carl R. Ruth, "Pressure Measurements in Highly Confined, M456 Cartridge Cases after Primer and Cook-Off Ignition", Ballistic Research Laboratory Memorandum Report No. 2764, June 1977, AD# B020522L.*

Apparently, local ignition of propellant at the sidewall of the case occurred before any substantial heating of the interior grains. The projectile-case interface apparently opened when the uncrimping pressure was reached, thus minimizing pressure buildup in the case. Attesting to the low pressures, the case split open rather than bursting into many small pieces.

IV. CONCLUSIONS

In all tests with unconfined rounds, maximum case rupture pressures never approached the 207 MPa (30,000 psi) level cited in the early MTD ammunition box tests. The maximum rupture pressures recorded for the internal ferrule and copper crusher gages were, respectively, 100 MPa (14,500 psi) and 133.1 MPa (19,300 psi). Apparently, confinement of the rounds in the ammunition box is a critical criterion for inducing the conditions necessary to produce pressures over 207 MPa (30,000 psi).

For all tests, the copper crusher gage pressures were higher than their electronic gage counterparts. Since only copper crusher gages were used in the cartridge cases for the MTD tests, the pressures cited therein may have been high and partially caused by other effects (deceleration, damage, etc).

ACKNOWLEDGMENTS

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