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INVESTIGATION OF ATLAS SOLID FUEL RETARDING ROCKET DURING ATLAS-CENTAUR SEPARATION TESTS

by Richard W. Heath, Henry Synor,
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SUMMARY

During the course of the Atlas-Centaur separation tests in the Lewis Space Power Chamber recurrent failures were experienced in the firings of the Atlas retarding rockets. In an effort to evaluate the suitability of these rockets for flight use, an investigation into the primary cause for the misfires was instituted and an evaluation of the performance of the rockets was made.

The primary cause of the failures of the rocket to ignite was inconsistent igniter functioning and a too short igniter burning period.

INTRODUCTION

One phase of the Atlas-Centaur separation test series is the gathering of performance information regarding systems and components associated with the separation process. To determine the dependability of the retarding-rocket unit, standard and modified configurations of the rocket engines were run in the Lewis Space Power Chamber and their performances monitored. Various combinations of rockets and igniters were tested to determine the problems involved in their ignition.

APPARATUS

Tests were carried out in the Lewis Space Power Chamber, which can attain a moderate vacuum and maintain it throughout rocket firings because of its large internal volume (approximately 607 000 cu ft). The portion of the chamber in which the tests were conducted is a cylinder 51 feet in diameter and 120 feet long adjoining other cylindrical chambers 90° to it at each end.

The rocket tested (Rocket Power, Inc., P/N 2547-11) has a nominal total impulse of 500 pound-seconds and is 15.25 inches long and 2.75 inches in diameter (fig. 1). It is constructed with two removable end caps, one of which contains the igniter and the other of which is integral with the nozzle. A 0.040-

inch-thick aluminum closure diaphragm is included across the nozzle inlet. The rocket holds 2.1 pounds of polysulfide ammonium perchlorate propellant cast with a star-center cross section, as seen in figure 4(b). The grain burns approximately 0.7 second and produces about 650 pounds of thrust during steady-state operation.

Some of the data were obtained during the Atlas-Centaur separation tests. The eight rockets producing these data were mounted, as shown in figure 2, around the periphery of a full-scale Atlas model hung with its longitudinal axis horizontal. Additional data were obtained from rockets mounted on a small test stand and aimed down an adjoining chamber.

Each rocket tested was modified to accept a fitting in the firing chamber cap at the igniter end. During the early tests, lines were run to strain-gage-type pressure transducers mounted on the Atlas framework (fig. 3). In later tests, the transducers were mounted below the pressure taps and suspended by silicone-oil-filled lines to reduce sensing errors, which could be incurred through the use of long air-filled lines, and to reduce the exposure of the transducers to heated combustion gases.

The igniters fired were manufactured by Ordnance Associates, Inc., (the standard for the Rocket Power, Inc., rocket), by Librascope Division of General Precision, Inc., and by Thiokol Chemical Corp. Of the Ordnance Associates igniters, those from production lots 2-1 and 3-2 were used. The different igniters were loaded with the following constituents at the nominal weights shown in the table:

Ordnance Associates igniters		Librascope igniter	Thiokol igniter
Lot 2-1	Lot 3-2		
0.56 g[a] powdered boron potassium nitrate	0.67 g[a] powdered boron potassium nitrate	1.0 g powdered [b]GPI-F&HP-7	1.0 g boron potassium nitrate pellets
1.99 g[a] solid boron potassium nitrate	1.90 g[a] solid boron potassium nitrate	2.0 g[a] solid boron potassium nitrate	11.34 g [b]TP-E-8035 polysulfide propellant
Approx. 3600 cal total	Approx. 3600 cal total	Approx. 4200 cal total	Approx. 16 100 cal total

[a]Average of random weighings (by others).

[b]Proprietary compound.

OPERATING PROCEDURE

Rockets were fired in the Space Power Chamber at an ambient pressure of approximately 25 pounds per square foot absolute, which corresponds to an altitude of roughly 98 000 feet, and ambient temperature (approximately 70° F). Firings were made or attempted both with and without nozzle closures. The flight-configuration nozzle closure in the rocket consists of a 0.040-inch-thick aluminum burst diaphragm. The closures when used were either of flight configuration or were pierced by a 1/8-inch hole.

During the tests the internal pressures generated in the rockets and the firing voltages and currents were recorded.

RESULTS AND DISCUSSION

Of the 67 units fired, 6 misfires were encountered when Ordnance Associates igniters were used. Examination of the misfired units revealed that the grain was intact, the nozzle diaphragm (which was in accordance with the flight configuration) when used was ruptured and partly extruded into the nozzle, and the igniter was fired with no part of its "propellant" to be found in the rocket (figs. 4 and 5). The characteristic pressure record from a misfired motor is an abrupt pressure rise to approximately 250 to 450 pounds per square inch, after which a rapid decay ensues (fig. 6).

It was noted initially, and supported by subsequent firings, that the igniters in all misfired rocket engines using Ordnance Associates igniters (except for one special test) were from production lot 3-2 (table I). Investigation revealed that the configuration of the igniter (P/N OA-A8) had not been maintained constant; several internal configurations had been used in the igniter with changes made from one lot to the next (fig. 7). The changes from lot 2-1 to 3-2 include (1) the omission of the retaining ring at the igniter exit, (2) a decrease in the depth of the initiator cavity and elimination of a cavity at the exit of the unit, and (3) a repositioning of an acetate disk below the solid sustainer, which created a new cavity containing powdered sustainer.

Pressure traces obtained in the test firings were scrutinized in an effort to discover any apparent inadequacies in the ignition cycle which could be related to the igniter changes. In several instances an abnormally low chamber pressure occurred between the ignition peak of approximately 1500 to 2000 pounds per square inch and the steady-state burning pressure (fig. 8(a)). In order to understand this occurrence, eight rockets having lot 2-1 igniters were fired with a 1/8-inch hole drilled through the nozzle closures so that the chambers were at a near vacuum condition prior to firing. The pressure traces from this test firing, which are shown in figure 8(b), revealed that each engine experienced a pressure falloff similar to that mentioned earlier although not quite as severe. The generation of the falloff, or saddle, in each instance is felt to demonstrate a susceptibility of the igniter to an initial low-pressure condition in the combustion chamber and to give an indication of inadequate performance margin. The pressure falloff probably results from the propellant grain not being sufficiently ignited at the time of igniter burnout and could probably be eliminated with the use of a longer burning igniter. While these tests did serve to uncover a marginal performance characteristic, they did not explain why lot 3-2 igniters produced misfires and lot 2-1 igniters did not under normal conditions.

In an effort to determine how much the margin of performance could be reduced before the engine refused to fire, two rockets were tested with no nozzle closures, one with a lot 3-2 igniter (fig. 9) and one with a 2-1 igniter. Both failed to ignite the rockets at the altitude condition, which confirmed that the limits of reliable operation had been exceeded. Although the ability to ignite the propellant grain successfully under vacuum conditions and with no nozzle closure is a more severe requirement than encountered during flight, it is felt that this test further illustrates the lack of adequate margin in the combination of the Ordnance Associates, Inc., igniter and the Rocket Power, Inc., rocket.

Some tests were conducted by Beckman and Whitley Laboratories to determine what had caused the 3-2 igniters to lose all their margin of performance. Both the lot 3-2 igniters and the lot 2-1 igniters, which had no record of misfires, were fired into Styrofoam blocks to make a record of flame-impingement patterns. Their findings, noted in references 1 and 2, reveal that the lot 2-1 igniters consistently displayed a widely dispersed flame pattern, while the lot 3-2 igniters were inconsistent. The 3-2 units occasionally fired an extremely narrow and concentrated flame front (fig. 10). This characteristic leads to the theory that the lot 3-2 igniters when their discharge pattern is concentrated do not impinge on the grain surface sufficiently and, therefore, may not impart enough heat into the grain to cause ignition. This inconsistency in performance may be inferred to result from the previously described changes in the igniter's geometry. The combination of an initial low performance margin and an inconsistent flame discharge pattern is apparently sufficient to cause occasional ignition failures. Supporting this conclusion are data obtained at Lewis from the firing of two igniters manufactured by Librascope (fig. 11) whose constituents were described earlier. The first igniter firing at sea-level ambient pressure was made into a Styrofoam block, and a narrow impingement pattern was observed (fig. 12). The second firing, at a 98 000-foot-altitude ambient pressure, involved the installation of a Librascope igniter in a Rocket Power, Inc., rocket from which the nozzle closure had been removed. The igniter failed to ignite the rocket propellant, as would be anticipated from the flame pattern.

In order to further substantiate the theories concerning flame direction and igniter burning time outlined, a test was made at a pressure altitude of 98 000 feet with a Thiokol Chemical Corp. igniter (fig. 13), installed in Rocket Power, Inc., rocket having no nozzle closure. This igniter burns for a longer period of time (0.25 sec compared with 0.004 sec for the Ordnance Associates igniter) and directs the flame pattern at the rocket grain. The longer burning time is effected primarily by an increase in the igniter's constituent mass. The increase in the mass, with its resultant increase in heat content and burn time, coupled with the directed flame pattern tended to ensure that the rocket grain would receive sufficient heat to ignite. Successful ignition of the rocket propellant occurred (fig. 14).

CONCLUSIONS

The marginal performance obtained when the Ordnance Associates, Inc., igniter (P/N OA-A8) is used in combination with the Rocket Power, Inc., rocket (P/N 2547-11) makes it undesirable for use in this rocket. The marginality is indicated by the radical change in performance after apparently minor alterations were made in the igniter configuration.

The specific causes for the marginal performance appear to be (1) an inadequate igniter burning time aggravated by (2) inconsistent igniter discharge patterns, which occasionally did not impinge on the rocket propellant grain. Therefore, it is desirable to substitute an igniter which (1) burns till the rocket grain is sufficiently ignited, and (2) directs its flame pattern positively towards the grain surface.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 8, 1965.

REFERENCES

1. Peterson, Norman L.: Ignition Failure Investigation of the RPI P/N 2547-11 Retard Rocket Motor (GD/A P/N 27-04300-1). Doc. No. 7964, Rocket Power, Inc., Oct. 20, 1964.

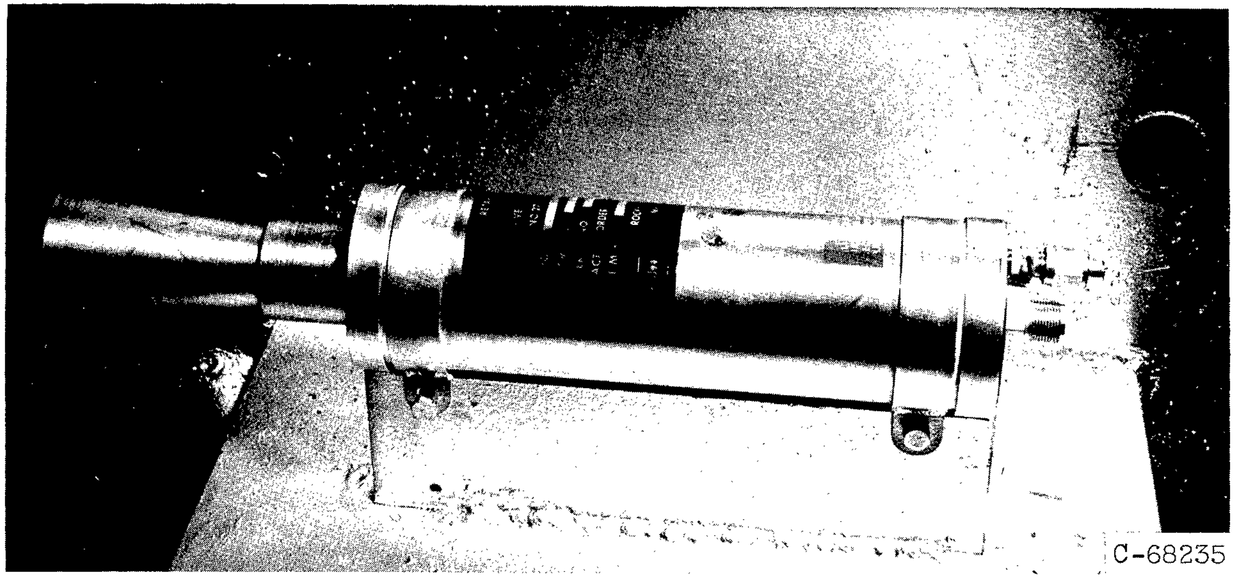
2. Anon.: Test Report to Lockheed Missile and Space Company for Verification of Qualification Testing of RPI P/N 2547-34D Igniter in 2547-14 Rocket Motor (LMSC P/N 1062410-5F). Doc. No. 7927, Rocket Power, Inc., July 24, 1964.

TABLE I. - RETROROCKETS USED IN SPACE POWER CHAMBER FIRING TESTS

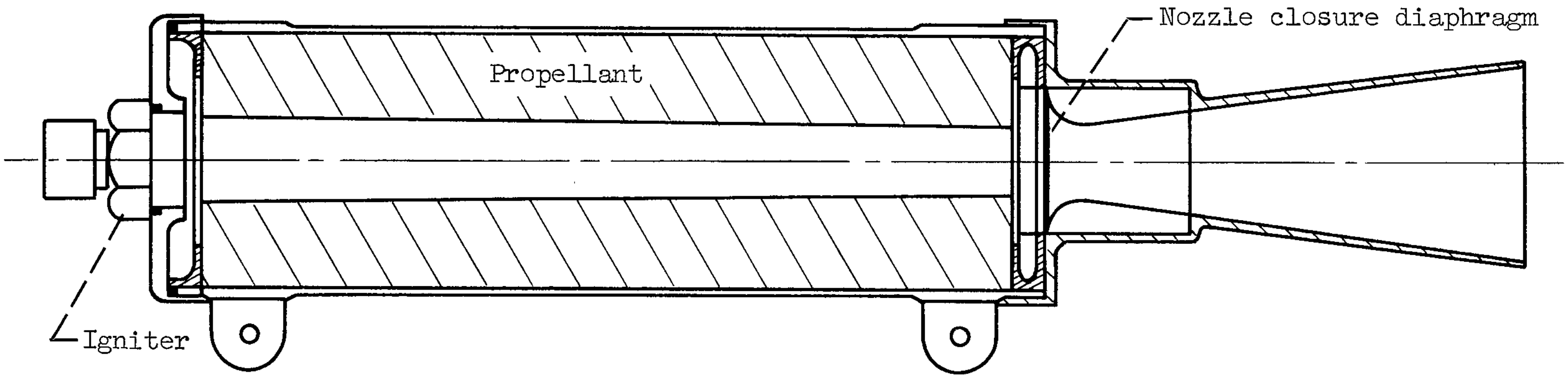
[All rockets used were Rocket Power, Inc. (P/N 2547-11) fired at approximately 25 psfa.]

Test date	Serial number	Production lot	Igniter[a] lot	Harness	Grain fired	Remarks
2-6-64	3101875	M-29	3-2	1	Yes	
	3181883	↓	↓	2	Yes	
	3101880	↓	↓	3	No	
	3101871	↓	↓	4	Yes	
	3101882	↓	↓	5	↓	
	3101881	↓	↓	6	↓	
	3101879	↓	↓	7	↓	
2-19-64	3111895	M-30	3-2	1	No	
	3111894	↓	↓	2	Yes	
	3111893	↓	↓	3	↓	
	3111892	↓	↓	4	↓	
	3101867	M-29	↓	5	↓	
	3101868	↓	↓	6	↓	
	3101869	↓	↓	7	↓	
	3101870	↓	↓	9	No	No closure
2-27-64	2071069	M-10-14	2-2	1	Yes	
	2101149	M-13-17	2-2	2	↓	
	2030815	M-6	2-1	3	↓	
	2030814	M-6	↓	4	↓	
	2030816	M-6	↓	5	↓	
	2061057	M-9-13	↓	6	↓	
	2101151	M-13-17	↓	7	↓	
	2101175	M-13-18	↓	9	No	No closure
3-5-64	3111896	M-30	2-2	1	Yes	1/8-inch hole in closure
	3111900	↓	2-1	2	↓	↓
	3111897	↓	2-1	3	↓	↓
	3111891	↓	2-2	4	↓	↓
	3111903	↓	2-2	5	↓	↓
	3111902	↓	2-1	6	↓	↓
	3111899	↓	2-2	7	↓	↓
	3111901	↓	2-1	8	↓	↓
3-16-64	3111898	M-30	2-1	9	Yes	1/8-inch hole in closure
4-8-64	3081750	M-24	3-2	1	Yes	
	3081771	↓	↓	2	↓	
	3081760	↓	↓	3	↓	
	3081761	↓	↓	4	↓	
	3081757	↓	↓	5	↓	
	3081772	↓	↓	6	↓	
	3081759	↓	↓	7	↓	
	3081768	↓	↓	8	↓	
4-24-64	3081763	M-24	3-2	1	Yes	
	2101146	M-13-17	2-3	2	↓	
	2101158	M-13-17	3-2	3	↓	
	3061776	M-22	3-2	4	↓	
	2101157	M-13-17	2-3	5	↓	
	3101872	M-29	3-2	6	No	
	3111887	M-30	3-2	7	Yes	
	3081751	M-24	3-2	8	Yes	
5-7-64	3101879	M-29	3-2	1	No	
	3101878	↓	↓	2	Yes	
	3101877	↓	↓	3	↓	
	3101876	↓	↓	4	↓	
	3081765	M-24	↓	5	↓	
	3081770	M-24	↓	7	↓	
	2081105	M-11-15	↓	8	↓	
	2081106	M-11-15	Librascope	9	No	No closure
5-21-64	2030786	M-6	3-2	1	Yes	
	3067775	M-22	3-2	2	↓	
	3111889	M-30	↓	3	↓	
	3111890	M-30	↓	4	↓	
	2040876	M-7	↓	5	↓	
	2071070	M-10-14	↓	6	↓	
	2040890	M-7	↓	7	↓	
	2040877	M-7	↓	8	↓	
6-3-64	2101148	M-13-17	2-3	2	Yes	Grain dried
	2101160	M-13-18	3-2	9	Yes	Grain dried
	2101159	M-13-18	Thiokol	10	Yes	No closure

[a]All Ordnance Associates igniters (P/N OA-A8) except as indicated.



(a) Overall view.



(b) Cross section.

Figure 1. - Rocket tested: P/N 2547-11, Rocket Power, Inc.

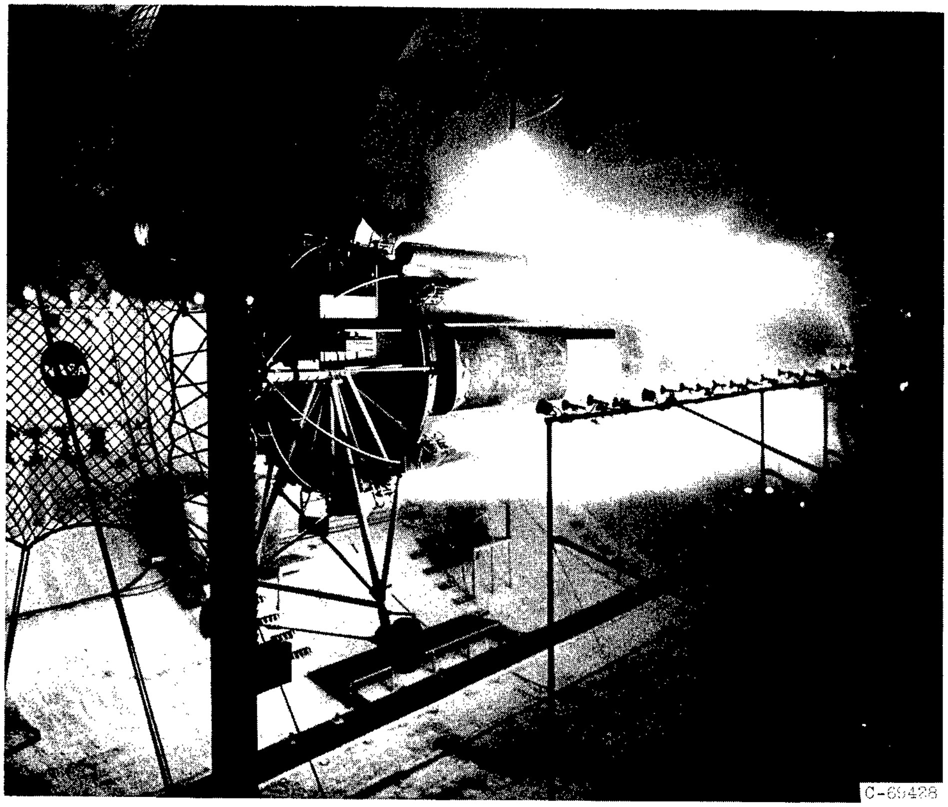


Figure 2. - Atlas model erected in Space Power Chamber.

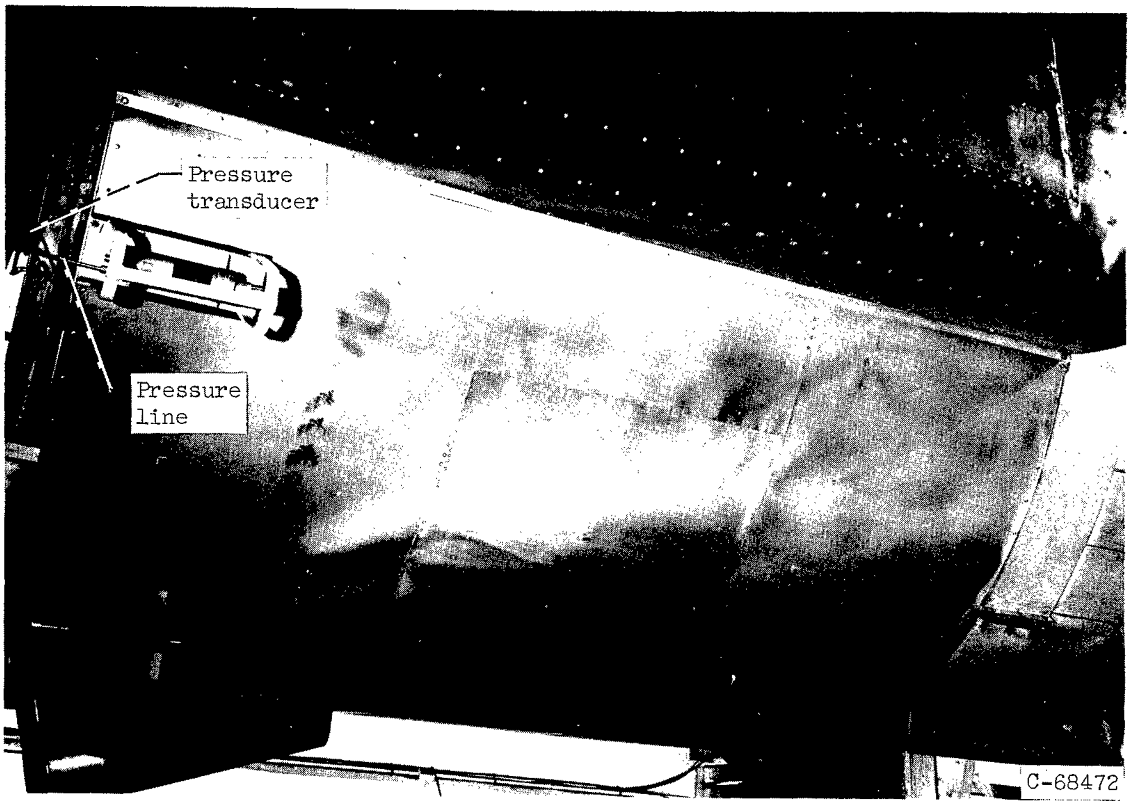
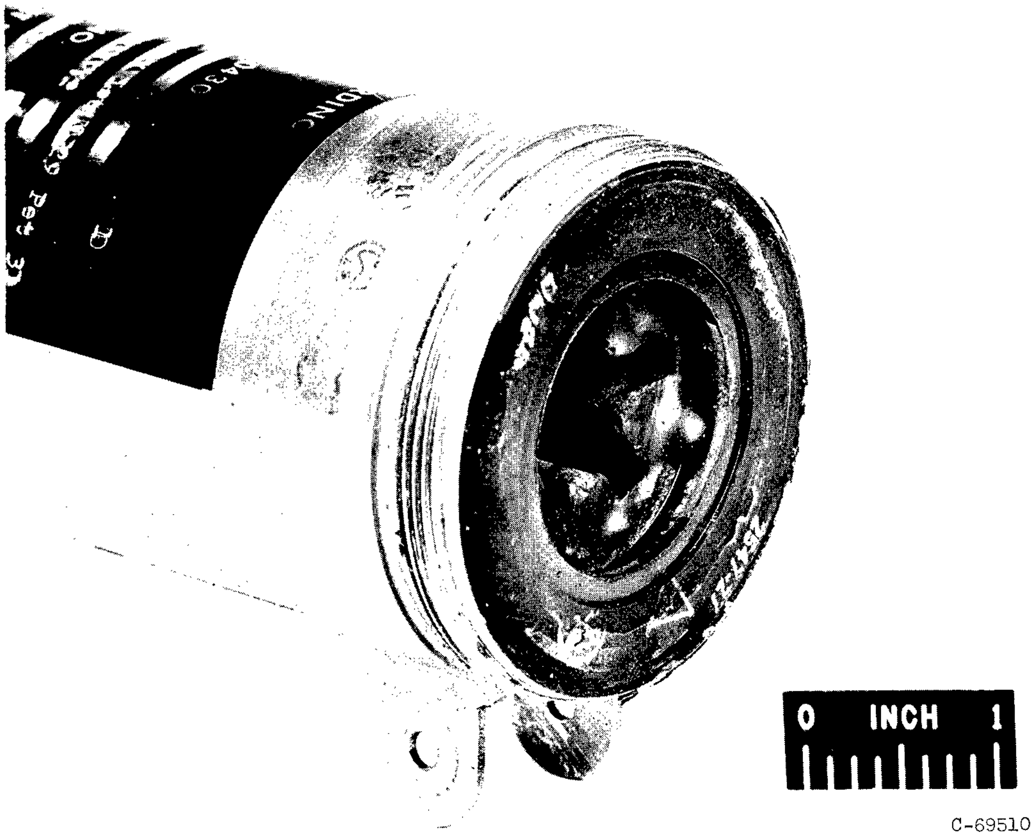
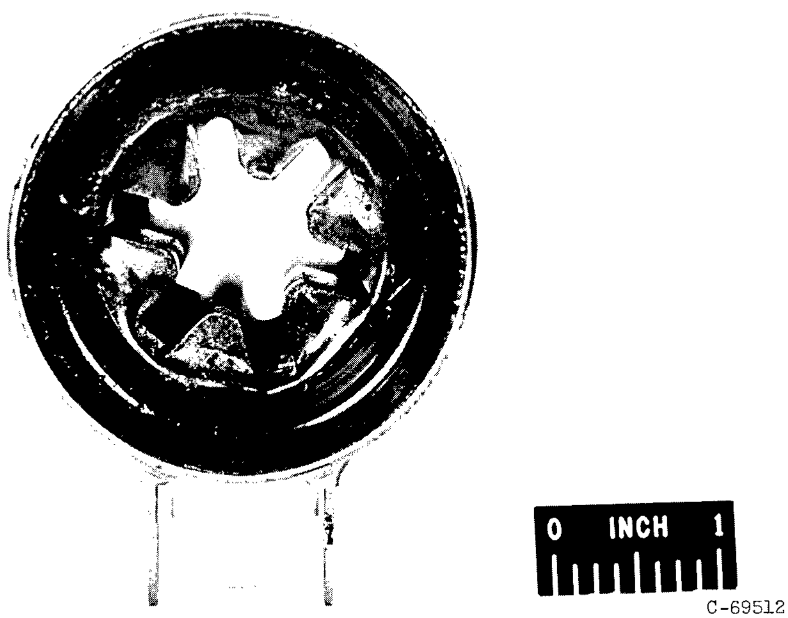


Figure 3. - Rocket and pressure sensing apparatus mounted on Atlas model.



(a) Viewed from nozzle end.

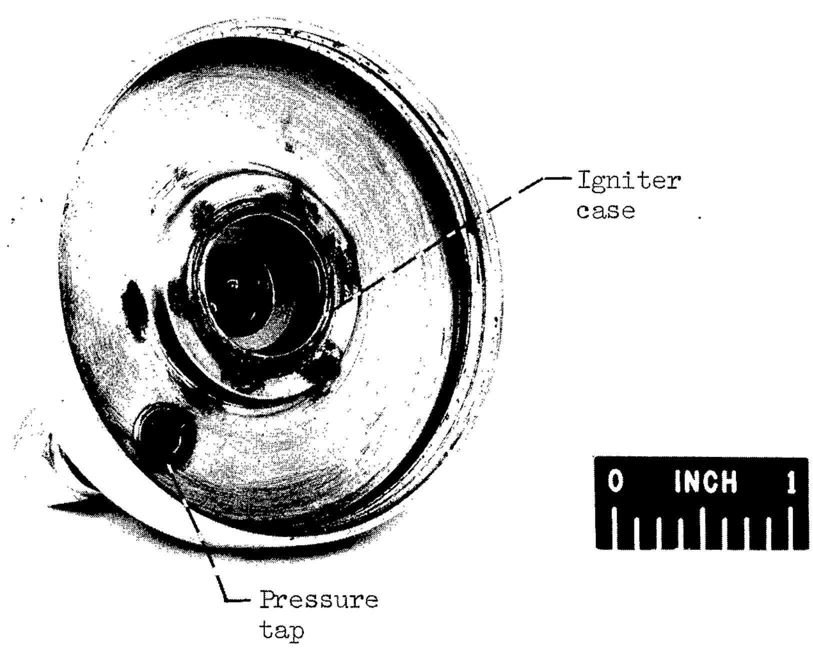


(b) Viewed from igniter end.

Figure 4. - Grain of misfired rocket.

C-68326

(a) Nozzle showing ruptured diaphragm.



C-69511

(b) End cap showing expended igniter.

Figure 5. - Misfired rocket.

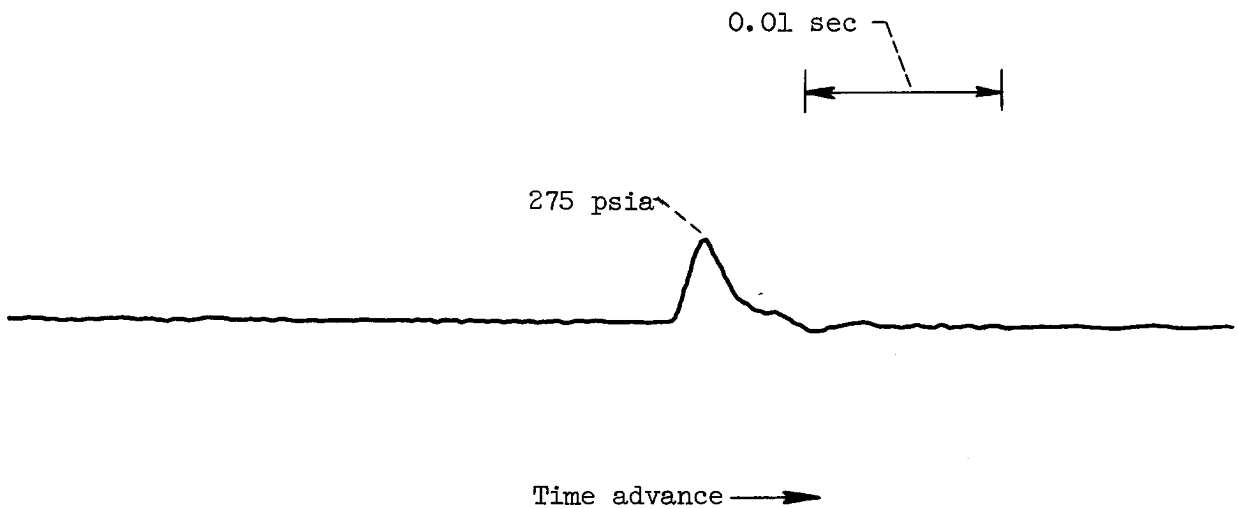
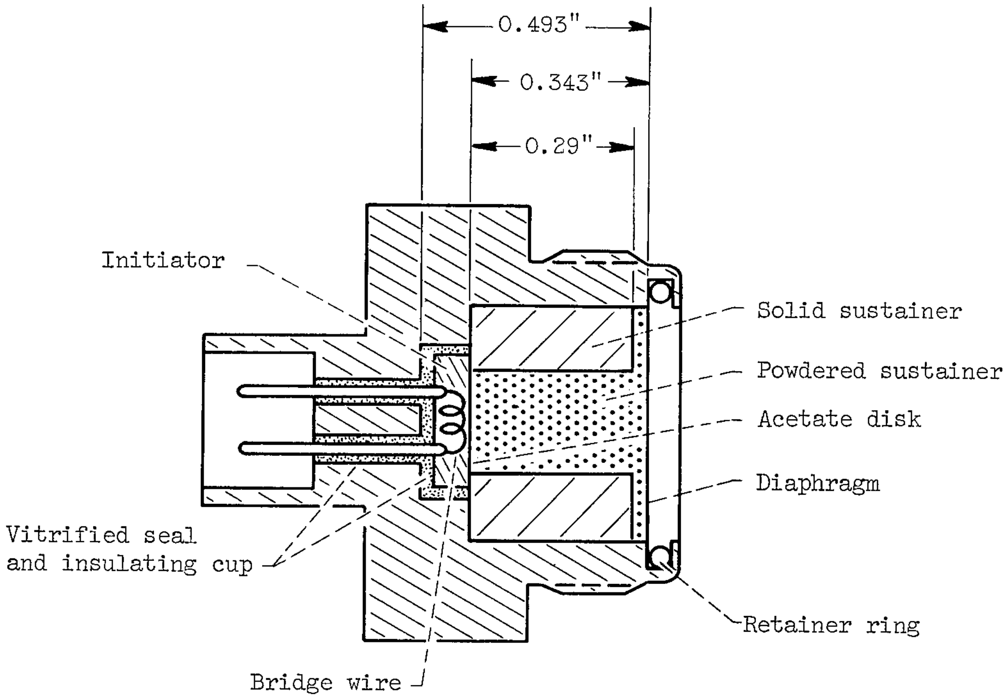
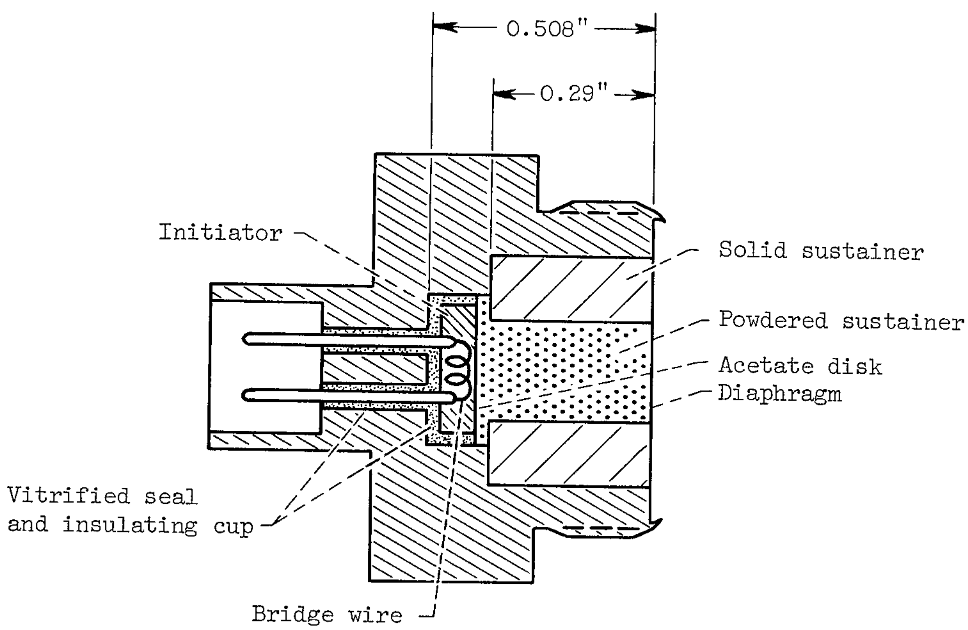


Figure 6. - Typical pressure trace of misfired rocket.

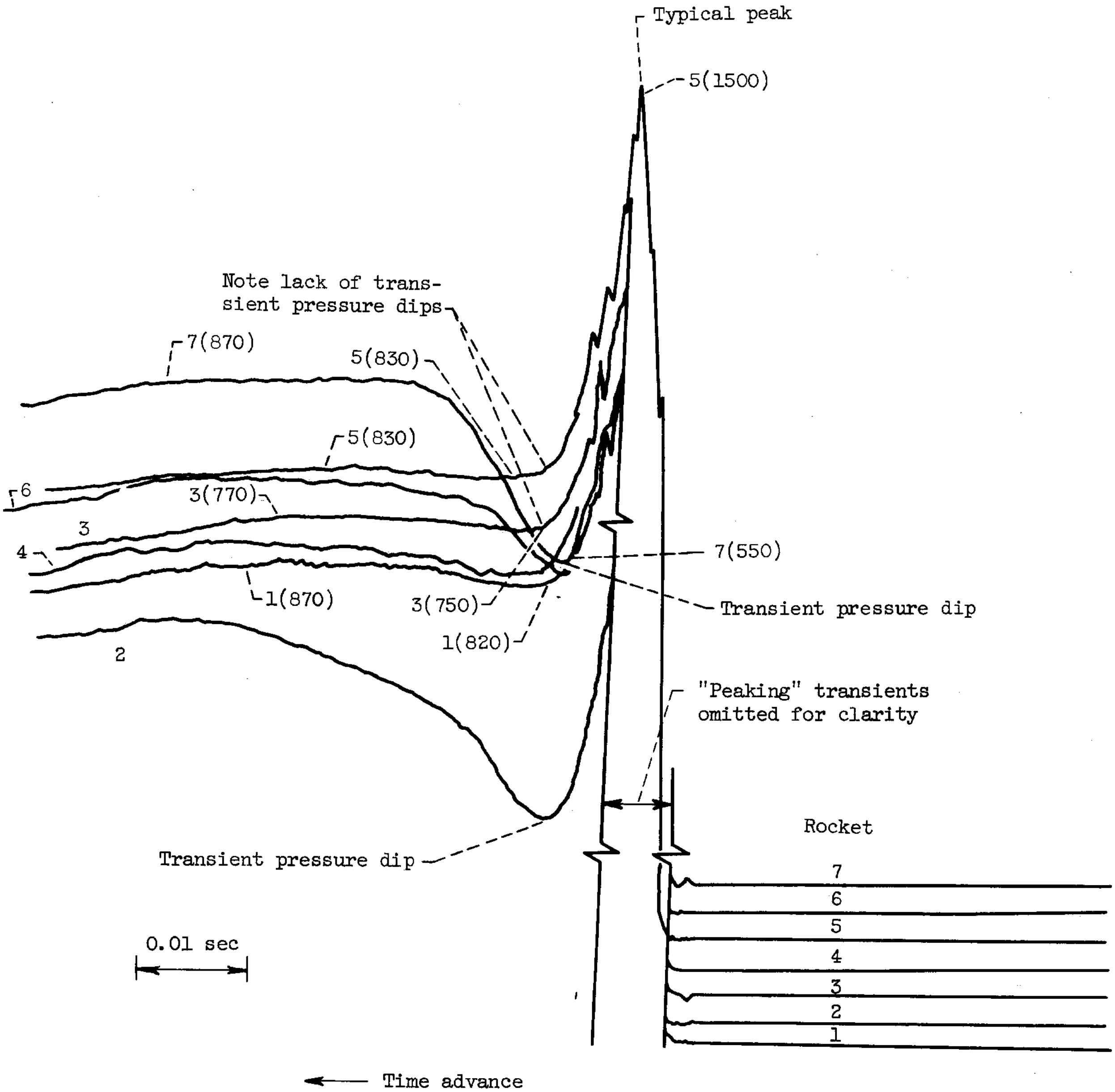


(a) Production lot 2-1.



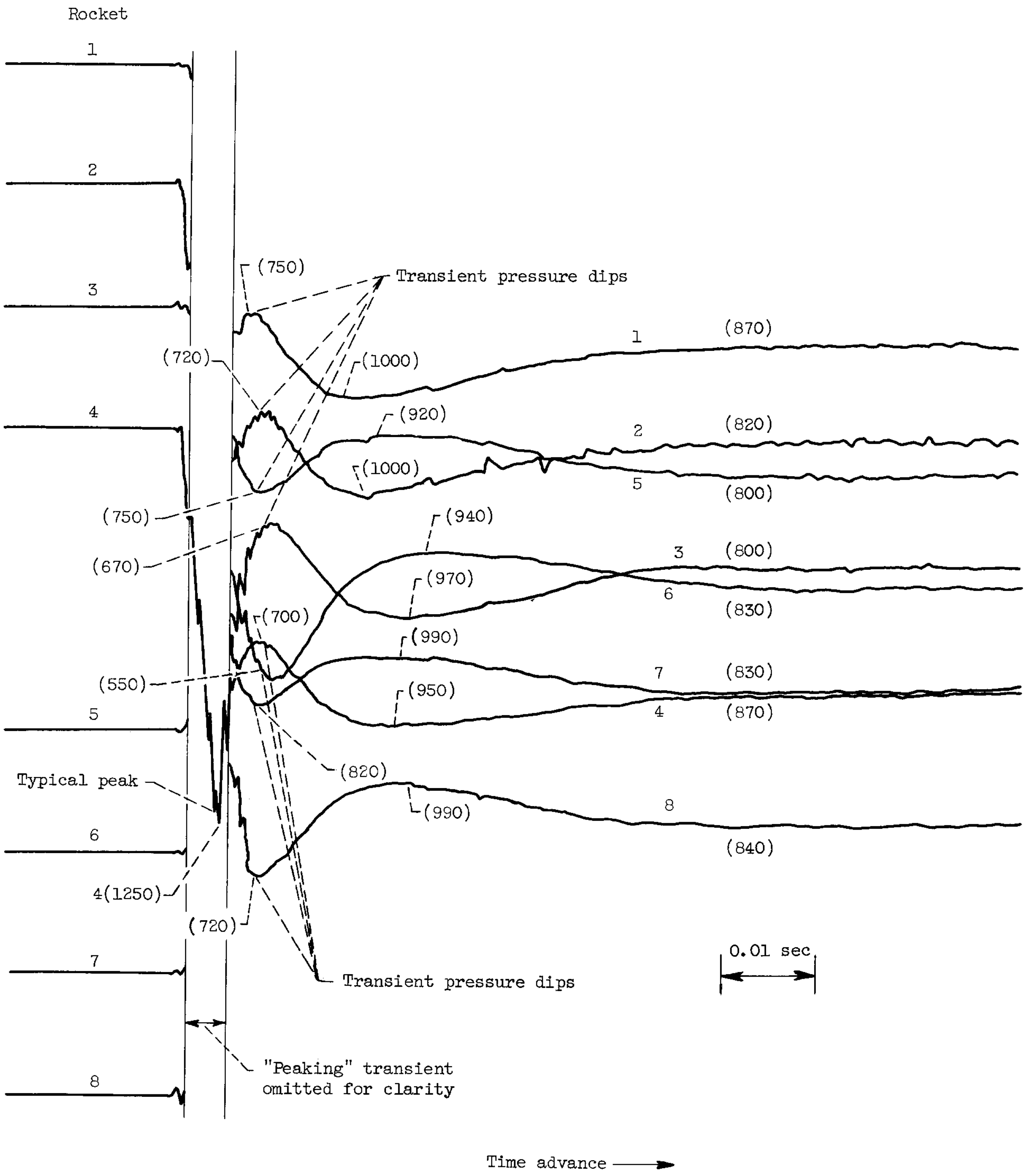
(b) Production lot 3-2.

Figure 7. - Igniter configuration; P/N OA-A8, Ordnance Associates, Inc.



(a) Random failures.

Figure 8. - Pressure records of incipient rocket failures. Numbers in parentheses are peak pressures and pressure dips in psia.



(b) Consistent failures.

Figure 8. - Concluded.

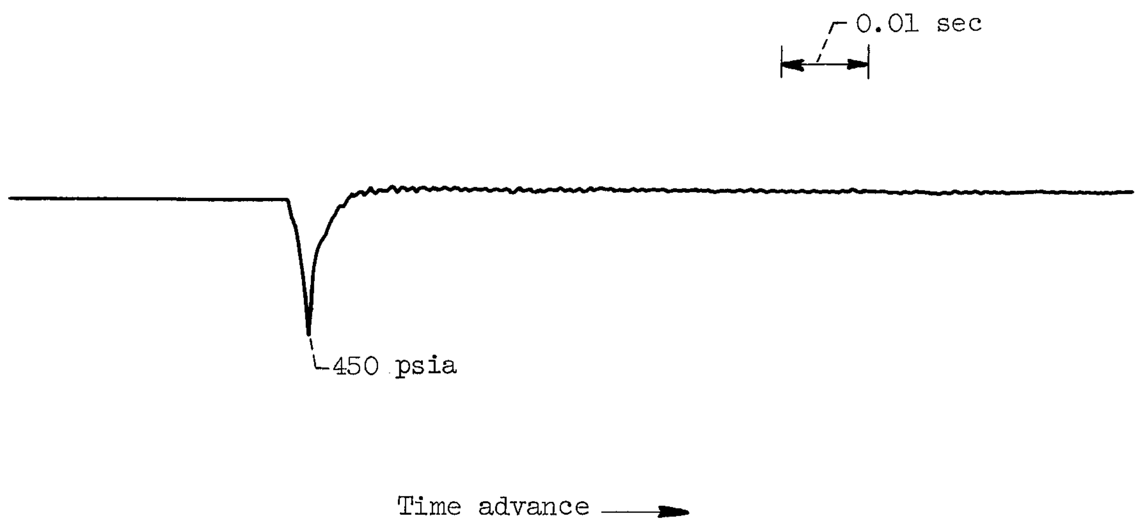
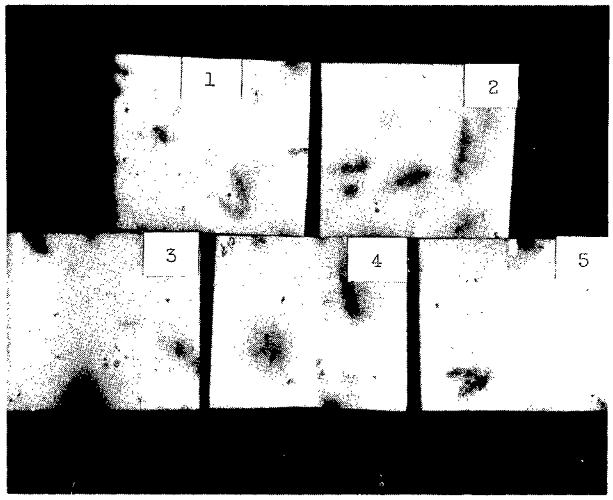
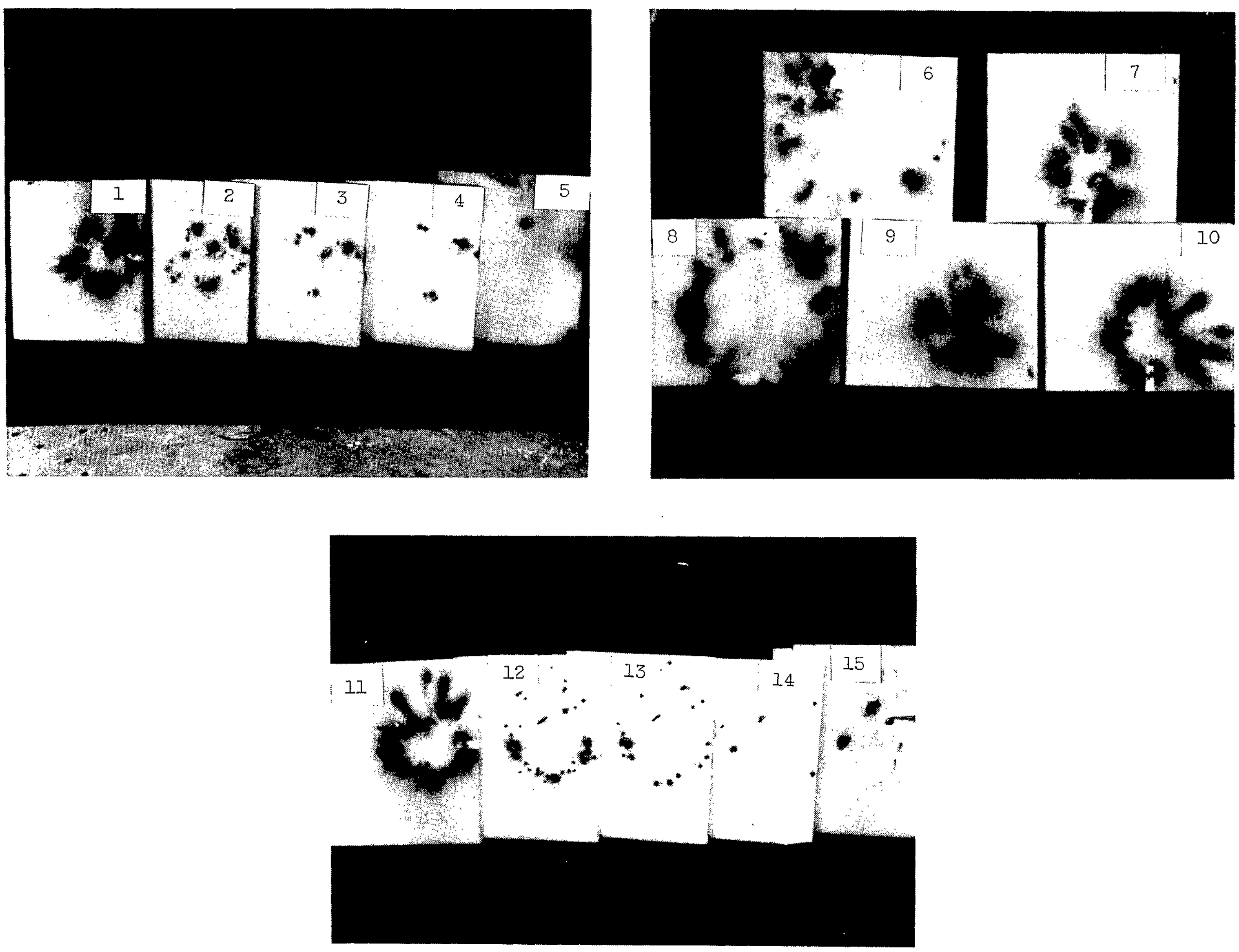


Figure 9. - Pressure record of lot 3-2 igniter fired into live rocket with no closure diaphragm.

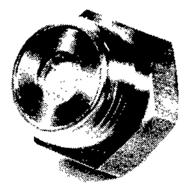


(a) Lot 2-1 igniters. Note widely dispersed patterns.

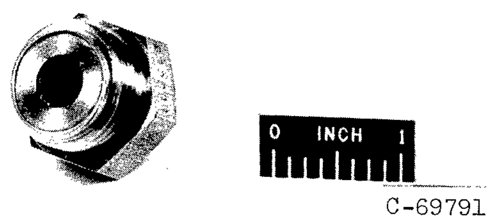


(b) Lot 3-2 igniters. Note narrowly dispersed patterns in 1, 7, 9, and 11 and widely dispersed patterns in 4, 5, 6, 8, and 14.

Figure 10. - Flame impingement patterns.



(a) Before.



(b) After.

Figure 11. - Librascope igniters before and after detonation.

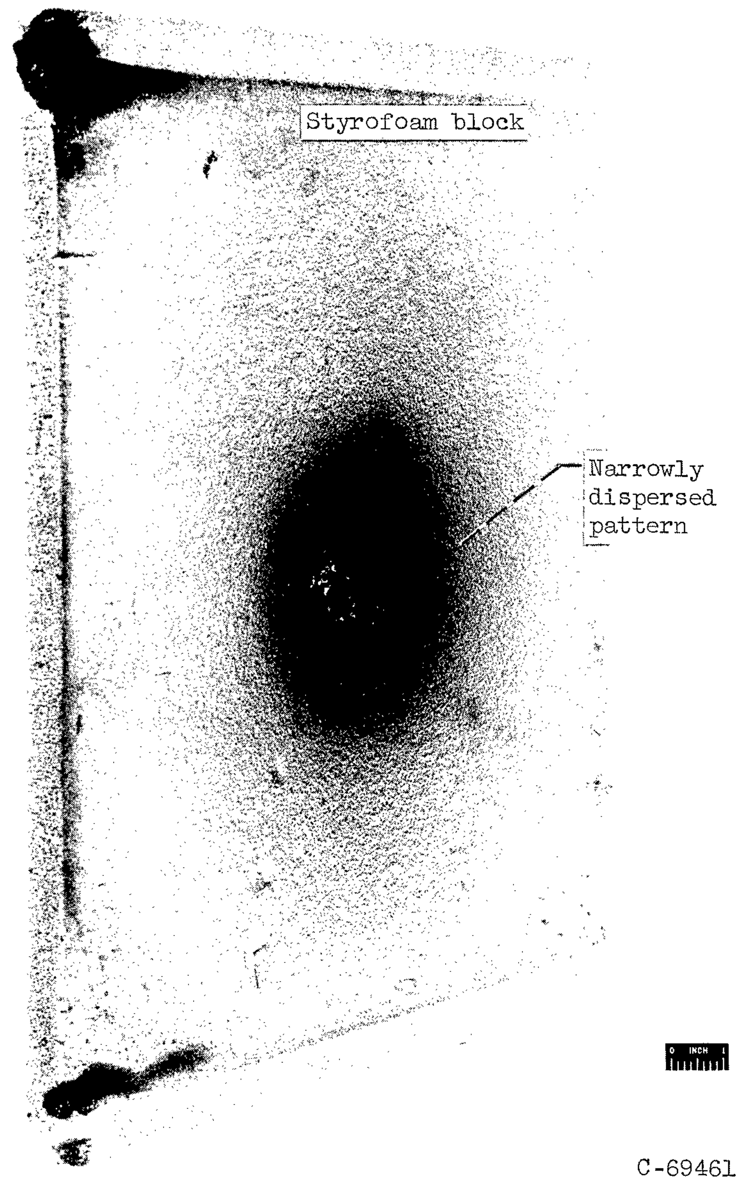
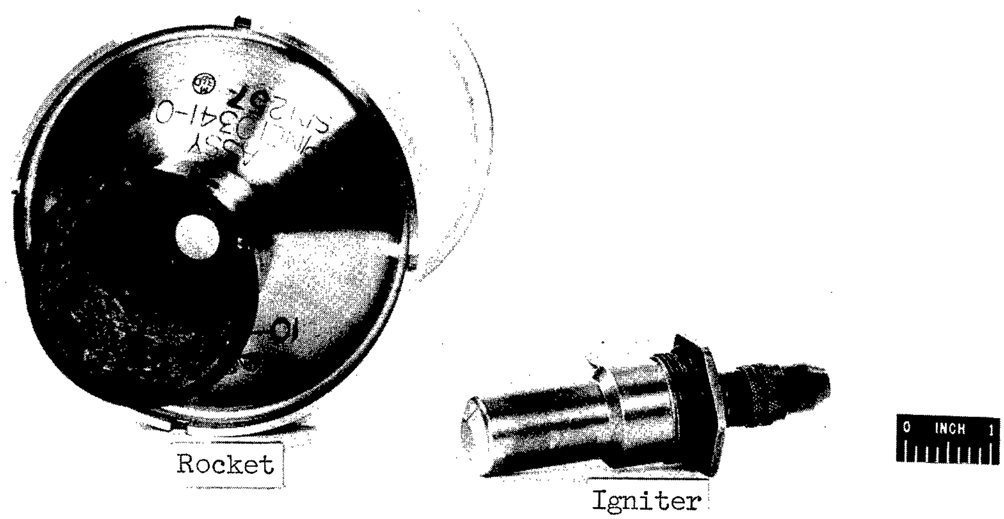


Figure 12. - Flame impingement pattern of Librascope igniter.



C-69608

Figure 13. - Thiokol igniter TE 350 with rocket 2.41 KS 513 for which it was designed.

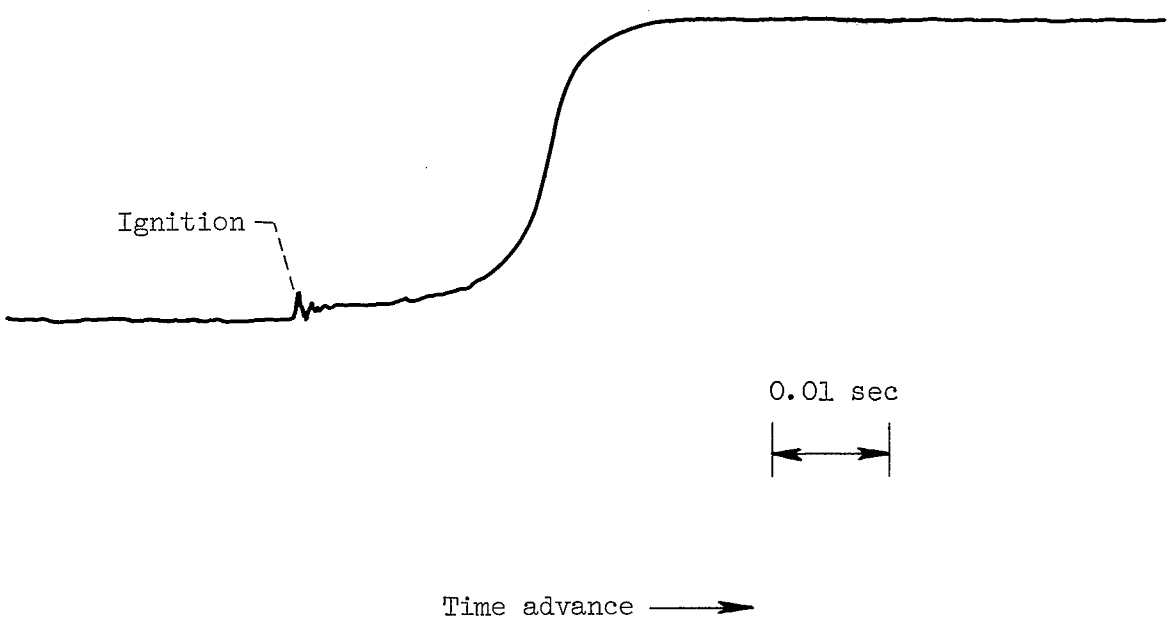


Figure 14. - Internal pressure record of Rocket Power, Inc., rocket ignited by Thiokol Chemical Corp. Pyrogen igniter.

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