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J.D.P.

IGNITER DEVELOPMENT FOR THE BLACK BRANT FAMILY OF ROCKET MOTORS

E.P. Morris

CANADIAN ARMAMENT RESEARCH AND DEVELOPMENT ESTABLISHMENT

CENTRE CANADIEN DE RECHERCHES ET PERFECTIONNEMENT DES ARMES

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ABSTRACT

The development of rocket motors for use in the Black Brant family of high-altitude research vehicles has necessitated the development of igniters to provide reliable ignition of the CARDEPLEX ammonium perchlorate-polyurethane propellants. Sea-level ignition systems for the 15KS25000, 23KS20000 and 9KS11000 rocket motors are described. The requirement for the 9KS11000 rocket motor to be used as a second stage for a two-stage Black Brant vehicle presented the problem of ignition under near vacuum conditions. Modifications made to the normal 9KS11000 igniter to provide reliable ignition at altitude are reported, and static firings at a simulated altitude of 95,000 feet are described. The igniters performed satisfactorily in all 59 sea-level launchings of vehicles and in 3 second-stage vehicles.

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1.0 INTRODUCTION

The development of the ammonium perchlorate-polyurethane propellants (CARDEPLEX) for the Black Brant family of rocket motors required the development of suitable ignition systems. To properly ignite a propellant, an igniter must meet the following requirements: 1) provide enough heat flux to bring the propellant to its auto-ignition temperature; 2) increase the pressure in the combustion chamber to a level where the burning process will sustain itself; 3) also provide short, reproducible, ignition delays. The design of the igniter must also be such that damage to the propellant grain and excessive peak pressures are avoided.

CARDE, using a metal oxidant powder, has developed ignition systems that meet these requirements. During the development of Heller anti-tank weapons, SR-371 powder, which is a British composition manufactured by Canadian Arsenals Limited, was used to ignite the propellant of the rockets. In the early days of the development of polyurethane propellants for rocket motors, the SR-371 powder was selected for igniting the grains of 8 inch diameter by 40 inch long rocket motors. The first grains were usually underignited because the loose powder did not provide the sustaining action needed for complete ignition. Later, the SR-371 powder was pressed into pellets and finally enclosed in a mesh wire basket, which was fastened to the body of the igniter located at the head end of the motor. A flash charge in the form of a scroll was used to convey the flame from a pressure squib to the pellet charge through a metal tube. The design provides for the installation of the pressure squib through an opening in the nose cone of the vehicle so as to maintain the rocket motor unarmed until the rocket is ready for firing. This igniter does not require a blow-out diaphragm in the nozzle to assist in the light-up of the grain.

The manufacture of the flash charge and the pellets is described. Information on the igniters for the 15KS25000, 23KS20000 and 9KS11000 rocket motors is given in detail. Finally, the necessary changes and tests made to provide reliable ignition of the 9KS11000 rocket motor as the second stage of a vehicle at a simulated altitude of 95,000 feet are described.

2.0 IGNITER CHARGE MANUFACTURE

2.1 Scroll Flash Charge

The scroll flash charge serves as the flame link between the pressure squib and the pellet charge. Figure 1 illustrates the M-56 Mod 6 pressure squib used for initiation.

The ingredients of the flash charge consist of SR-371 powder, pliobond 30 and a cotton cloth. Their specifications are given in Appendix A. A mixture of 93 per cent of SR-371 powder and seven per cent (dry basis) of pliobond is made into a paste with methyl ethyl ketone as the vehicle. When the paste reaches a suitable consistency, it is brushed onto a strip of light pipe covering cloth (3 x 11 inches). The impregnated cloth is then rolled on a mandrel in three complete revolutions to form a scroll. The final cured dimensions are 0.25 inch internal diameter and 0.45 inch outside diameter, with a weight of approximately one gram per inch of length.

2.2 SR-371 Pellet Manufacture

The SR-371 powder when burned releases heat energy by conduction, convection, radiation and condensation into hot metal drops. As the powder is fast burning, it is not suitable as such to provide long sustaining burning. Its burning rate is reduced by forming it into pellets. One per cent of zinc stearate is added to the powder for lubrication in the Stokes Model F-4 tablet machine, and the well-mixed powder is fed to the machine through an agitated feed shoe. The weight of the pellets is controlled by ajusting the height of the lower punch and by choosing the diameter of the punch used. The tablet-pressing machine is an eccentric cam-type press with force applied from above and below simultaneously. A pressure equalizer is incorporated to control the uniformity of the density of the pellets. A force of 1.25 tons on the machine gives pellets with the following characteristics:

Diameter, in.	-	0.344
Height (with convex faces) in.	-	0.275
Weight, g.	-	0.65
Density, g/cc	-	1.76

3.0 IGNITION SYSTEM FOR THE BLACK BRANT ROCKET MOTORS

3.1 General

To prevent premature expulsion of the burning pellets, these are enclosed in a container consisting of a steel-wire mesh, 4 x 4 mesh, 18 gauge (0.0475 inch), in the form of a basket. The basket is welded to a steel flange which is fastened to the igniter body located at the head end of the rocket motor. Pressure transducer outlets drilled in the body limit the diameter of the basket, and the weight of the pellet charge used for a specific rocket motor determines its length.

The wire mesh is flame-sprayed with Rokide A, an aluminum oxide, to serve as a heat barrier. The thickness of the Rokide sprayed on the wire mesh is 0.020 inch at the flange end of the basket and tapers to 0.008 inch at the tip end, which causes a gradual disintegration of the basket. It was observed that, when the coating of the aluminum oxide was constant throughout the length of the basket, a section of the basket occasionally broke off and was discharged through the nozzle. This caused a partial blockage of the throat area of the nozzle which showed up on the pressure time curve as a small pip and in the exhaust jet as a bright flash. Tapering of the spraying has eliminated most of these effects. The basket was designed to remain completely intact while the pellets are burning. To complete the basket assembly, a latex sleeve is rolled onto the basket and cemented with pliobond rubber at the flange end to provide hermetic sealing during long storage.

3.2 Igniter for the 15KS25000 Rocket Motor of the Black Brant I and II A Vehicles

The 15KS25000 rocket motor is used in the first two of the family of Black Brant vehicles, known as Black Brant I and II A*. The rocket combustion chamber

* The rocket motors for the Black Brant I and II A vehicles differ only in the nozzle expansion cones to suit the two types of vehicle stabilizers.

is 17 inches in diameter by 180 inches long and contains approximately 1750 pounds of CARDEPLEX A5 composite propellant. The composition of the propellant is given in Appendix B. The grain configuration consists of a six-point star-centered grain with a conduit area of 52.62 square inches. Figure 2 shows a cross section of the grain.

To satisfactorily ignite this rocket motor over the propellant temperature range (0°F - 120°F), an ignition charge consisting of 350 grams of SR-371 pellets is enclosed in a 1.62 inch diameter by 10.0 inch long basket (1). The scroll flash charge extends in two sections from the top of the pellets to the pressure squib and is cut to suitable length for location in the flash tube. A schematic diagram of this igniter is presented in Figure 3. Table I gives the results obtained from static firings at different grain temperatures.

TABLE I

Developmental Firings of the 15KS25000 Rocket Motor

Motor No.	Grain Temperature (°F)	Ignition Delay (Milliseconds)	Ignition Peak Pressure (psi)	Pressure t_b (psi)
17180/060	120	228	1242	1034
030	72	195	1031	889
037	70	215	1022	925
038	67	225	998	855
046	70	242	989	847
101	2	231	923	778
093	2	216	915	773
062	1	249	900	816
094	0	237	935	770

Ignition delays are measured from the time the electrical energy is applied to the squib until the pressure rises to 100 psi in the combustion chamber. The average ignition delay is 228 milliseconds and is almost constant over the temperature range. The difference in the ignition pressure and the average pressure over time of burning, t_b, is also constant, except at 120°F where it is slightly higher.

3.3 Igniter for the 23KS20000 Rocket Motor for the Black Brant II B Vehicle

The basic differences between the 15KS25000 and the 23KS20000 rocket motor are the propellant formulation and grain configuration. Both changes have contributed to an increase in the propellant charge from 1750 to 2075 pounds while essentially the same combustion chamber is used. Modifications were made to the chamber to permit the core insertion and removal from the head end of the rocket motor. The propellant formulation is designated as CARDEPLEX F10 and is described in appendix B. The grain configuration is cast in the form of a tapered three-leaf clover. The conduit area in the vicinity of the igniter is 31.88 square inches.

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For the 23KS20000 motor, the 200 grams of pellet charge loaded in a basket 2.02 inches in diameter and 4.37 inches long was calculated by multiplying the 350 grams, used for the 15KS25000 rocket motor, by the ratio of the respective conduit areas (2). The cross section of the propellant charge is shown in Figure 2. The schematic diagram of the 23KS20000 rocket motor igniter assembly is shown in Figure 4. Table II gives the relevant results for this rocket motor.

TABLE II

Developmental Firings of the 23KS20000 Rocket Motor

Motor No.	Grain Temperature (°F)	Ignition Delay (Milliseconds)	Ignition Peak Pressure (psi)	Pressure t_b (psi)
17180/112	116	136	1324	984
115	102	146	1247	921
110	60	155	1189	848
109	60	157	1197	816
108	60	191	1232	953
107	33	168	1064	765
114	15	205	1054	706
111	0	215	1053	663
106	0	187	1073	805

The average ignition delay over the temperature range is 173.3 milliseconds compared to 228 in the case of the 15KS25000 rocket motor. The results indicate that for this type of propellant the ignition delay decreases as the grain temperature increases. The over-pressurization varies from 268 to 390 psi.

3.4 Igniter for the 9KS11000 Rocket Motor for the Black Brant III Vehicle

3.4.1 Ignition at Sea Level

The third member of the family of Black Brant rocket motors is designated as 9KS11000. The igniter and the propellant were developed at CARDE as a sounding rocket by Canadian Bristol Aerojet Limited and the Government of Canada. The rocket motor is 10 inches in diameter and 125 inches long; it contains 435 pounds of A12 propellant cast in the form of a six-point star-centered grain, and has a conduit area of 15.56 square inches. A 115-gram SR-371 pellet charge is loaded in a basket 1.32 inches in diameter and 5.20 inches long (3). A diagram of the igniter assembly is shown in Figure 5. More than 40 rocket motors were statically fired at various temperatures; Table III shows the results obtained from a representative group. It is observed that the ignition delay for the 9KS11000 motor is almost flat across the temperature range, but the ignition peak pressure shows a few hundred psi increase at 120°F. The greatest over-pressurization also occurs at this temperature.

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TABLE III

Developmental Firings of the 9KS11000 Rocket Motor

Motor No.	Grain Temp. (°F)	Ignition Delay (Milliseconds)	Ignition Peak Pressure (psi)	Pressure t_b (psi)	Over Pressurization (psi)
10125/27	128	178	1440	1083	351
13	120	168	1520	1102	418
14	120	129	1662	1247	415
11	60	182	1358	862	496
12	60	188	1348	1011	337
21	37	169	1395	1222	173
33	35	160	1344	1053	291
40	10	142	1221	970	251
15	0	141	1346	1253	93
17	0	163	1292	1044	248
22	-12	238	1182	1008	174
57	-12	193	1271	1085	186
60	-20	173	1377	1223	154

Six motors cast with maximum quality control of the ingredients and manufacture were fired as performance reproducibility rounds. Table IV shows that reproducible ignition delays were obtained and that the ignition peak pressures and average pressures, P_{t_b}, were also in agreement. Over-pressurization varies from 226 to 268 psi, which may be considered normal.

TABLE IV

Performance Reproducibility Series of 9KS11000 Rocket Motor

Motor No.	Grain Temperature (°F)	Ignition Delay (Milliseconds)	Ignition Peak Pressure (psi)	Pressure t_b (psi)
10125/48	68	166	1259	1020
49	71	171	1229	1003
50	66	180	1270	1008
51	72	162	1294	1026
52	71	175	1247	997
53	67	173	1250	1000

3.4.2 Ignition of the 9KS11000 Rocket Motor at a Simulated Altitude of 95,000 Feet

The 9KS11000 rocket motor was chosen as the second stage for the Black Brant IV vehicle. In this role it should ignite reliably at altitudes up to 60,000 feet. Some modifications were required in the standard igniter for the 9KS11000 motor. As power to the squib was to be supplied internally from the vehicle nose cone, a flash tube was no longer required and a special connector mounted directly on the igniter body was designed to hold two M-56 Mod 6 squibs. To increase the ignition reliability, two firing circuits with two independent power supplies were located in the nose cone. The flash charge was located in the center of the pellet charge extending from the bottom of the basket into the squib connector. The full length of scroll flash charge in the basket is essential for the ignition of the pellets under vacuum conditions. Details of the igniter assembly are shown in Figure 6. The standard basket was increased in length to 6.31 inches to cater for the volume taken up by the flash charge.

Ignition tests under vacuum were carried out with the rocket motor as shown in Figure 7. To have the same initial grain configuration and to minimize heating of the vacuum chamber, a 10 by 125 inch heavy-walled casing was prepared with a thick inert liner; this gave a reduced combustion chamber, holding about twenty-five per cent of the standard propellant weight (4). An aluminum tube with a diameter corresponding to a 0.33 inch thick propellant web was centered in the heavy-walled casing and a high aluminum content polyurethane filler was cast around it. The filler provided a good heat sink for the combustion chamber, which could be refurbished and used in additional ignition tests. The aft end flange of the heavy-walled motor fitted inside a 50 cubic foot chamber, as illustrated in Figure 8. The motor was coupled to the tank by a rubber sleeve fastened to both flanges with clamps. A water-spray system was used to protect the tank from overheating at the aft end. Figure 9 shows the complete assembly of the motor and tank mounted in the firing bay.

A heavy reinforced cover was employed to withstand the high vacuum, but it was damaged on the first test because the chain hinge was not strong enough. For subsequent tests a simple expendable cover was designed. It consisted of a 24ST aluminum plate 36 inches in diameter and 0.25 inch thick which, under 10 mm of mercury, had a deflection of only one inch at the centre. The 10 mm of mercury vacuum achieved on each test corresponding to an altitude of 95,000 feet gave a safety margin for the expected grain light-up at the specified altitude of 60,000 feet. Five tests were carried out; the results obtained are presented in Table V.

TABLE V

Vacuum Ignition Tests with the 9KS11000 Rocket Motor

Fitted with Altitude Igniter

Motor No.	Grain Temperature (°F)	Ignition Delay (Milliseconds)	Ignition Peak Pressure (psi)
10125/54	70	306	1415
69	70	324	1400
55	40	302	1415
56	25	311	1354
67	22	384	1398

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A marked increase in both the ignition peak pressure and the delay is observed. The higher peak pressure is due to the longer period required to produce combustible gaseous products at very low pressures. Figure 10 illustrates the pressure-time curve obtained from the ignition of a 0.33-inch web star-centered A12 propellant under 10 mm of mercury. The burning under full pressure lasted about one-half of a second and then dropped off during normal tail-off.

The first BB IV vehicle was fired at Churchill Research Range on the 24th of June 1964. The first stage performed properly, but shortly after ignition of the second stage the nose cone broke off; the motor continued, however, and was tracked by radar to an estimated altitude of 300 miles. The second BB IV vehicle was fired on the 2nd of July 1964, but damage to the nose cone, apparently caused by rough separation, prevented the firing of the second-stage squibs. Modifications to the vehicle are being carried out by Canadian Bristol Aerojet Limited.

4.0 IGNITER PERFORMANCE

4.1 Static Firings

All static firings employing the prototype Black Brant igniters have shown satisfactory ignitions over propellant grain temperature of -20°F to 120°F.

4.2 Launchings

The igniters for the Black Brant rocket motors have performed satisfactorily in all 59 launchings conducted to date.

5.0 CONCLUSION

The successful development of igniters for the 15KS25000, 23KS20000 and 9KS11000 rocket motors has been achieved. Numerous static tests and 59 successful sea-level launchings have confirmed the proper functioning of the igniters.

The modifications made to the 9KS11000 rocket motor igniter to ensure the reliability of ignition at near vacuum conditions were satisfactory. This was proved in the successful ignition of the second stage of the Black Brant IV Vehicle in June 1964 and January 1965.

6.0 ACKNOWLEDGEMENTS

The advice and guidance from Mr. C.D. Martin, my Section Head, in the design and development of the igniters described in this report, is gratefully acknowledged. Thanks are also extended to Mr. H.K. Clark who suggested the aluminum plate closure for the vacuum tank. The development of the rocket motor for the vacuum ignition tests was made by Process Engineering Section.

7.0 REFERENCES

(1) Rojeska, H. "15KS25000 Black Brant Rocket Engine - Operation and Handling Instructions Issue No. 2". CARDE Tech. Note 1528/63. UNCLASSIFIED.

(2) Rojeska, H. "23KS20000 Black Brant Rocket Engine - Operation and Handling Instructions Issue No. 1". CARDE Tech. Note 1629/64. UNCLASSIFIED.

(3) Rojeska, H. "9KS11000 Black Brant Rocket Engine - Ground Handling and Operation Instructions Issue No. 1". CARDE Tech. Note 1480/62. UNCLASSIFIED.

(4) Duchesne, G. Process Engineering Section, Propulsion Wing, CARDE. "Personal Communication".

APPENDIX A

SCROLL FLASH CHARGE CONSTITUENTS

1. SR-371 Powder Composition

Specification C.S.	2450
Potassium Nitrate, Grade 1	50%
Magnesium, Grade 5	42%
Acaroid Resin, Red, Grade 2	8%

2. Pliobond Rubber

Specification MIL - A13883 Type 1
Pliobond 30
Adhesive Synthetic Rubber Supplied by
Goodyear Tire & Rubber Company

3. Base Cloth

Cotton, Light, Pipe Covering

APPENDIX B

CARDEPLEX PROPELLANT FORMULATIONS

Formulation Code	A5	A12	F10
Polyurethane Fuel % by wt.	25	25	27
Ammonium Perchlorate (150 Microns) % by wt.	70	70	55
Aluminum - % by wt.			
SAX3 (40 Microns, 6% Mg)	5		
SA24		5	
SA26 (23 Microns)			17
Copper Chromite - % by wt.			1

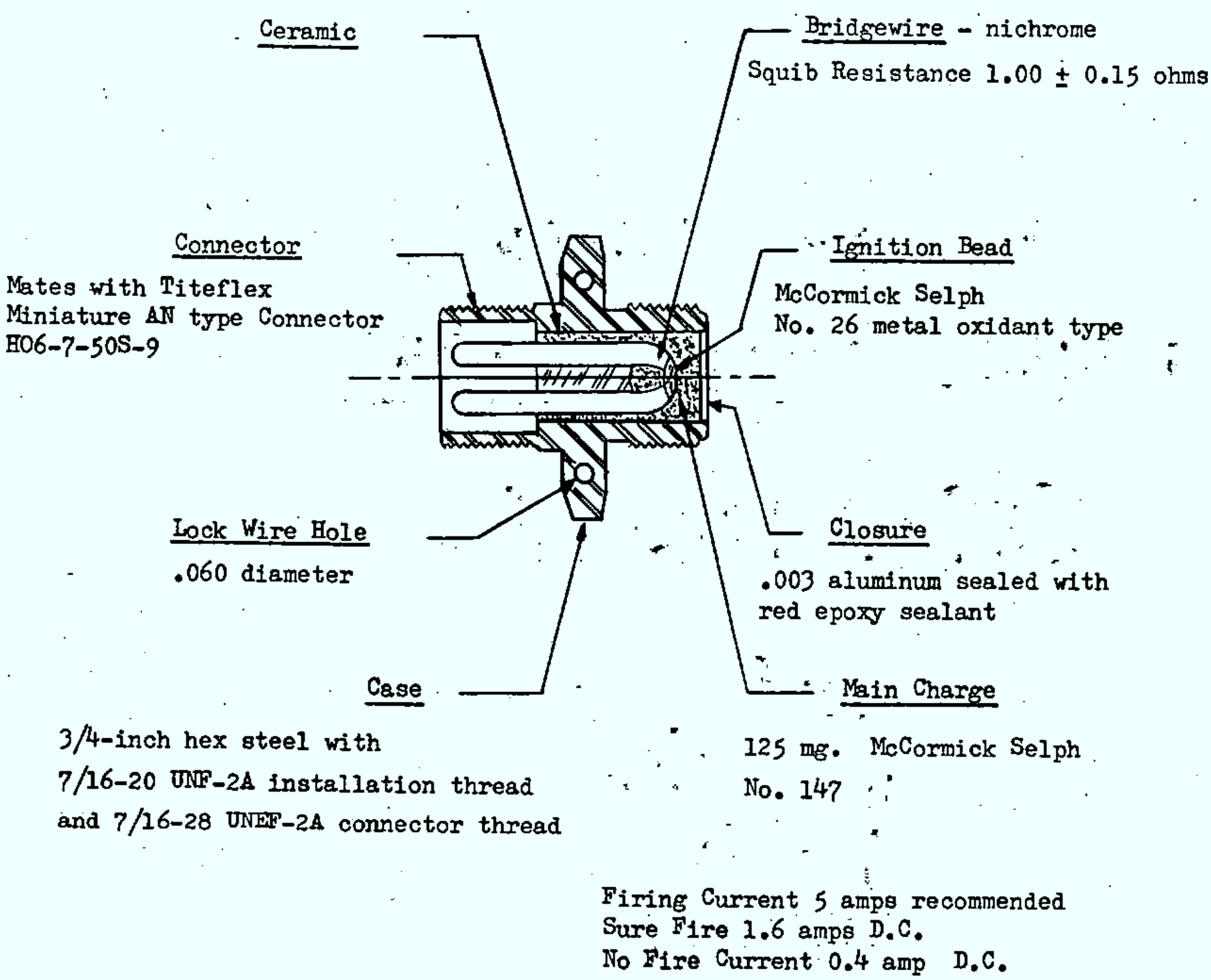

FIGURE 1 - M-56 Mod 6 Pressure Squib

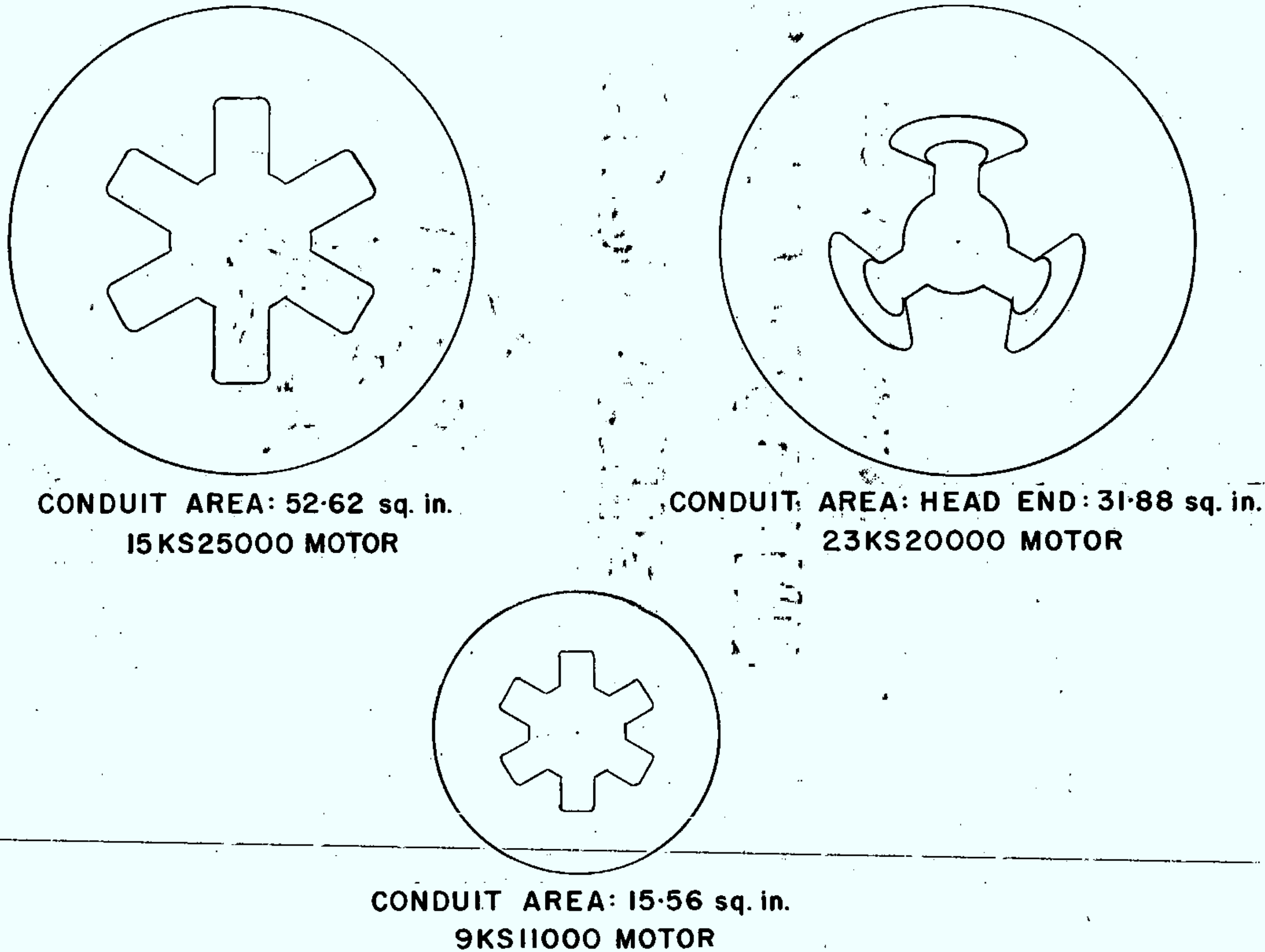

FIGURE 2 - Grain Configurations for CARDE Motors for the Black Brant Vehicles

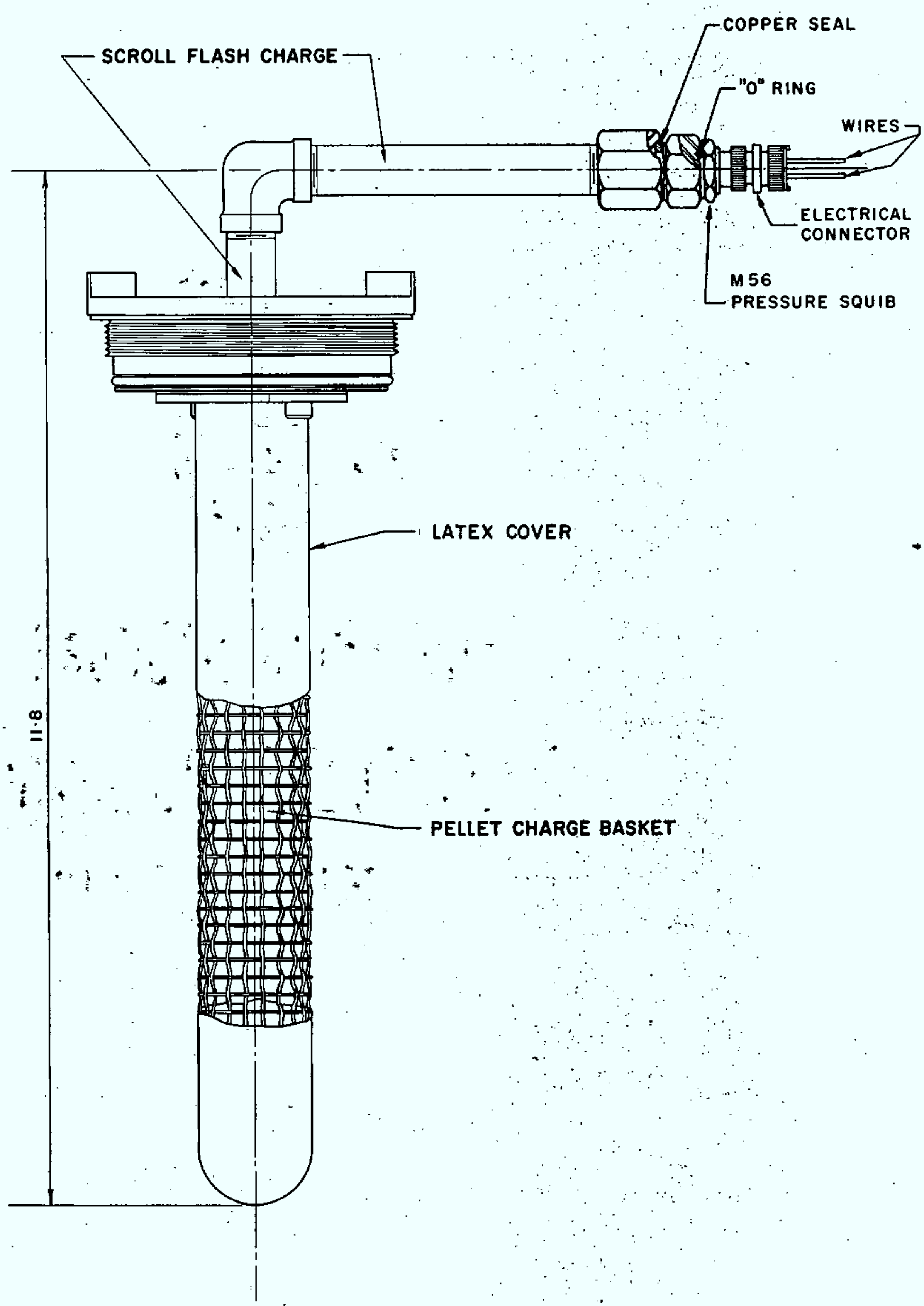

FIGURE 3 - Schematic of 15KS25000 Rocket Motor Igniter

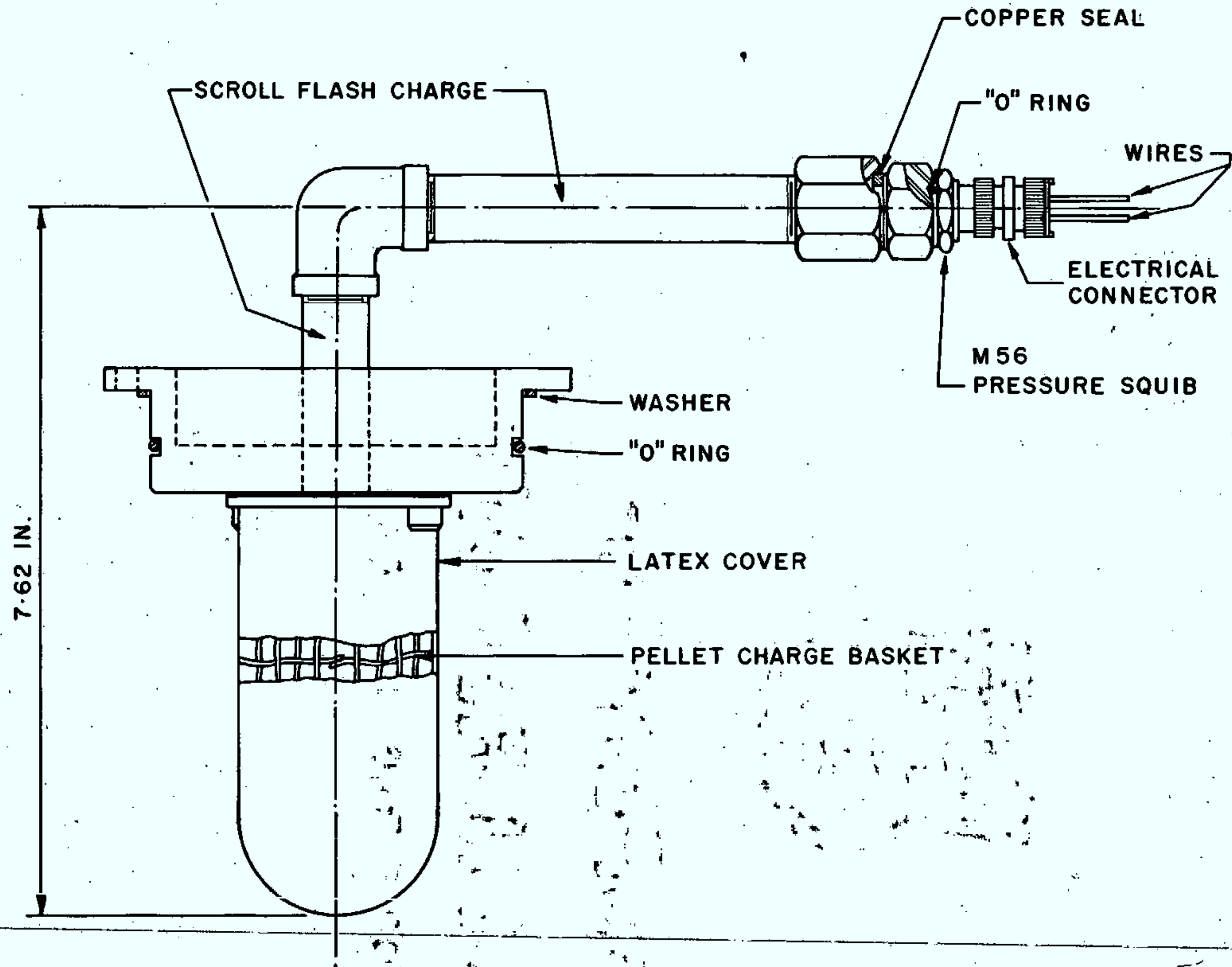

FIGURE 4 - Schematic of 23KS25000 Rocket Motor Igniter

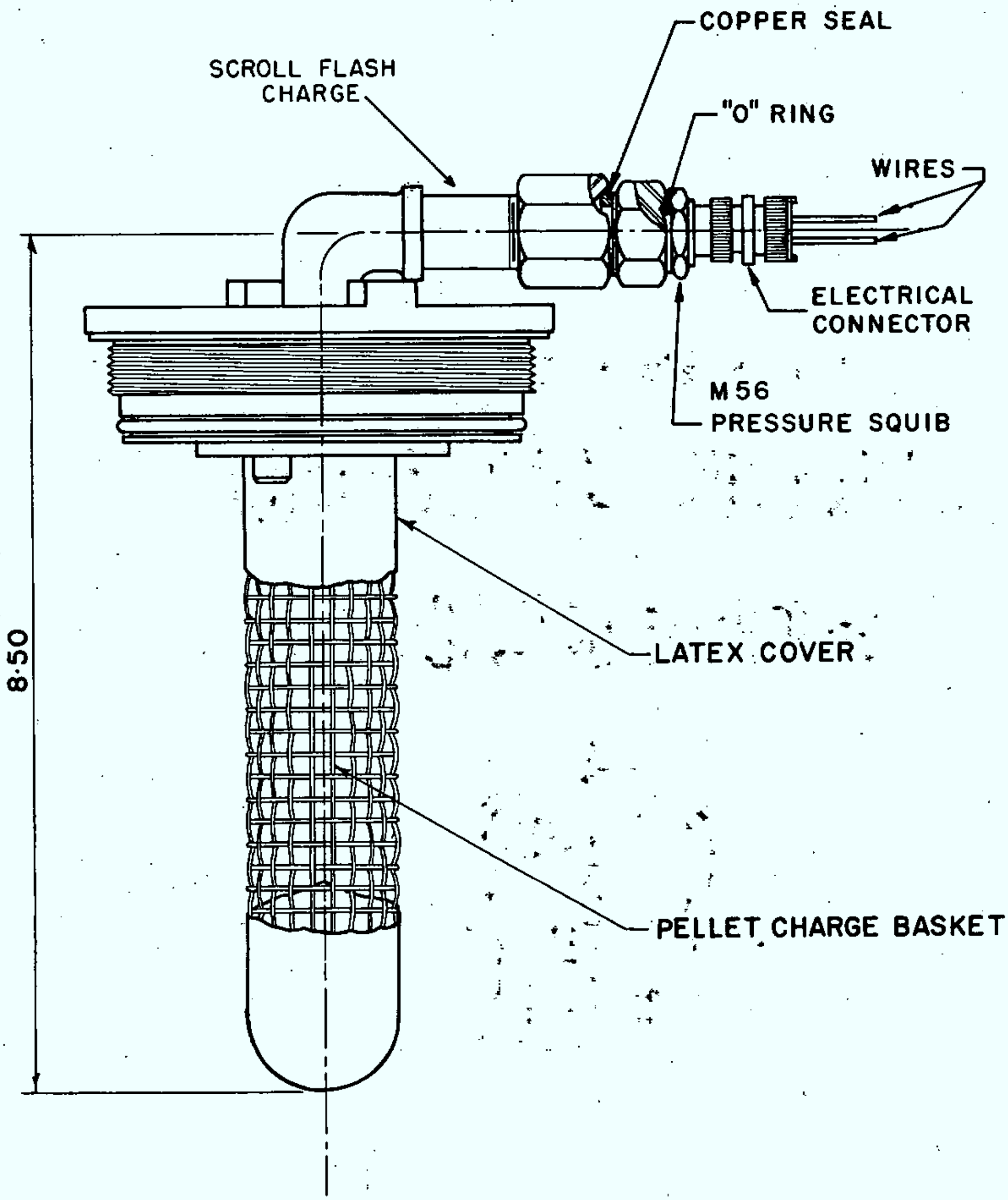

FIGURE 5 - Schematic of 9KS11000 Rocket Motor Igniter

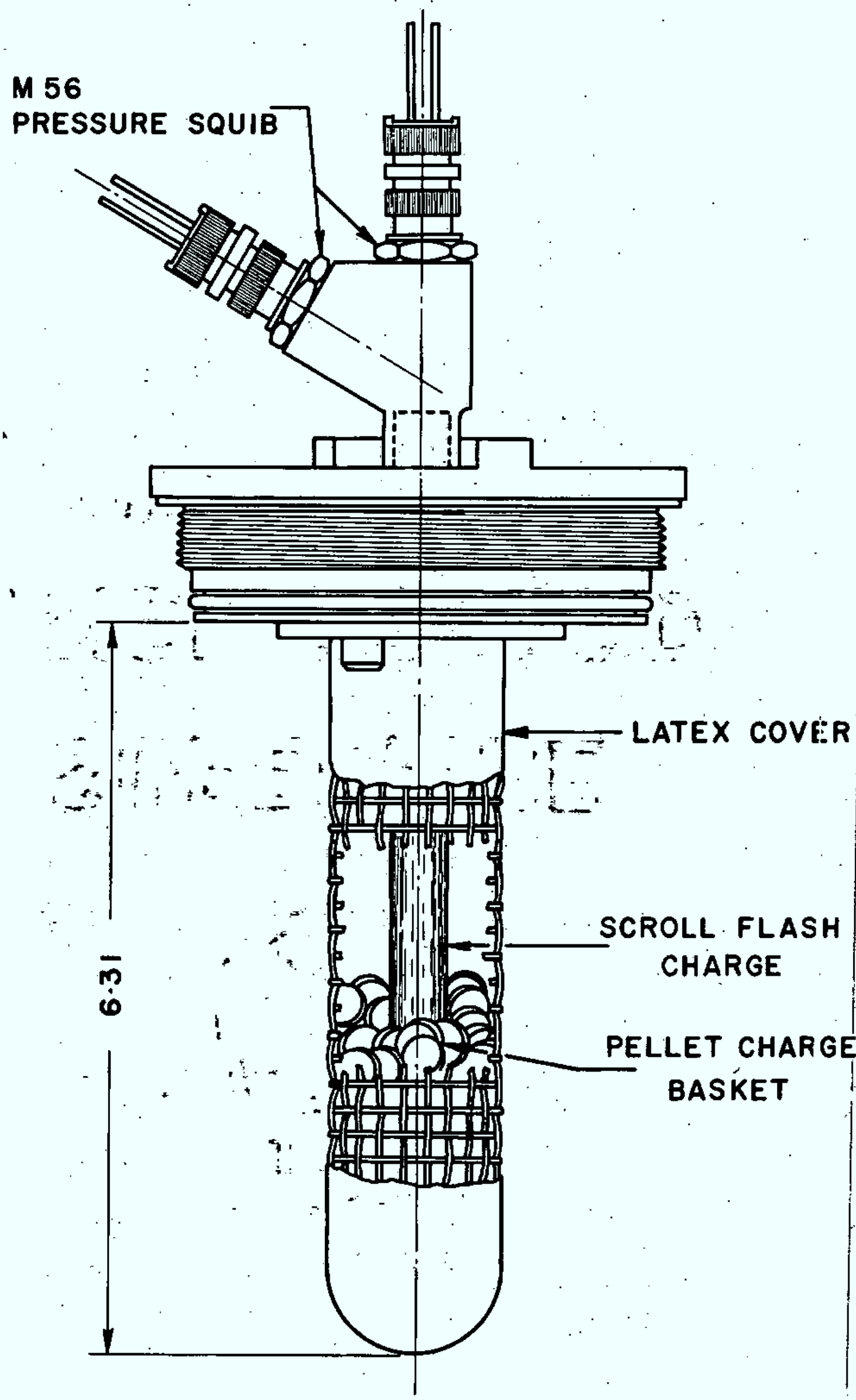

FIGURE 6 - Schematic of Vacuum Igniter for Black Brant IV (9KS11000 Motor)

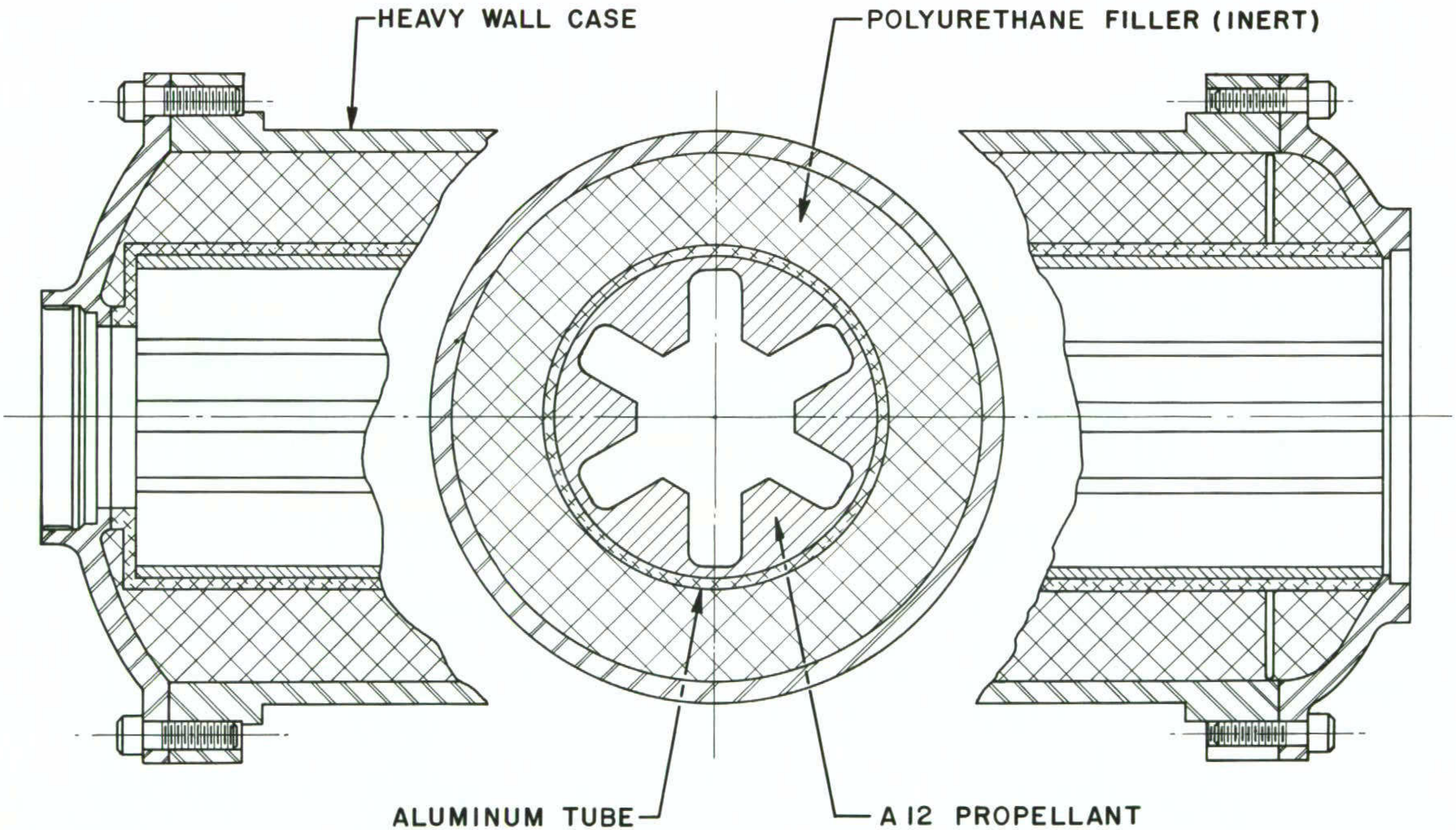

FIGURE 7 - Rocket Motor for Vacuum Igniter Tests

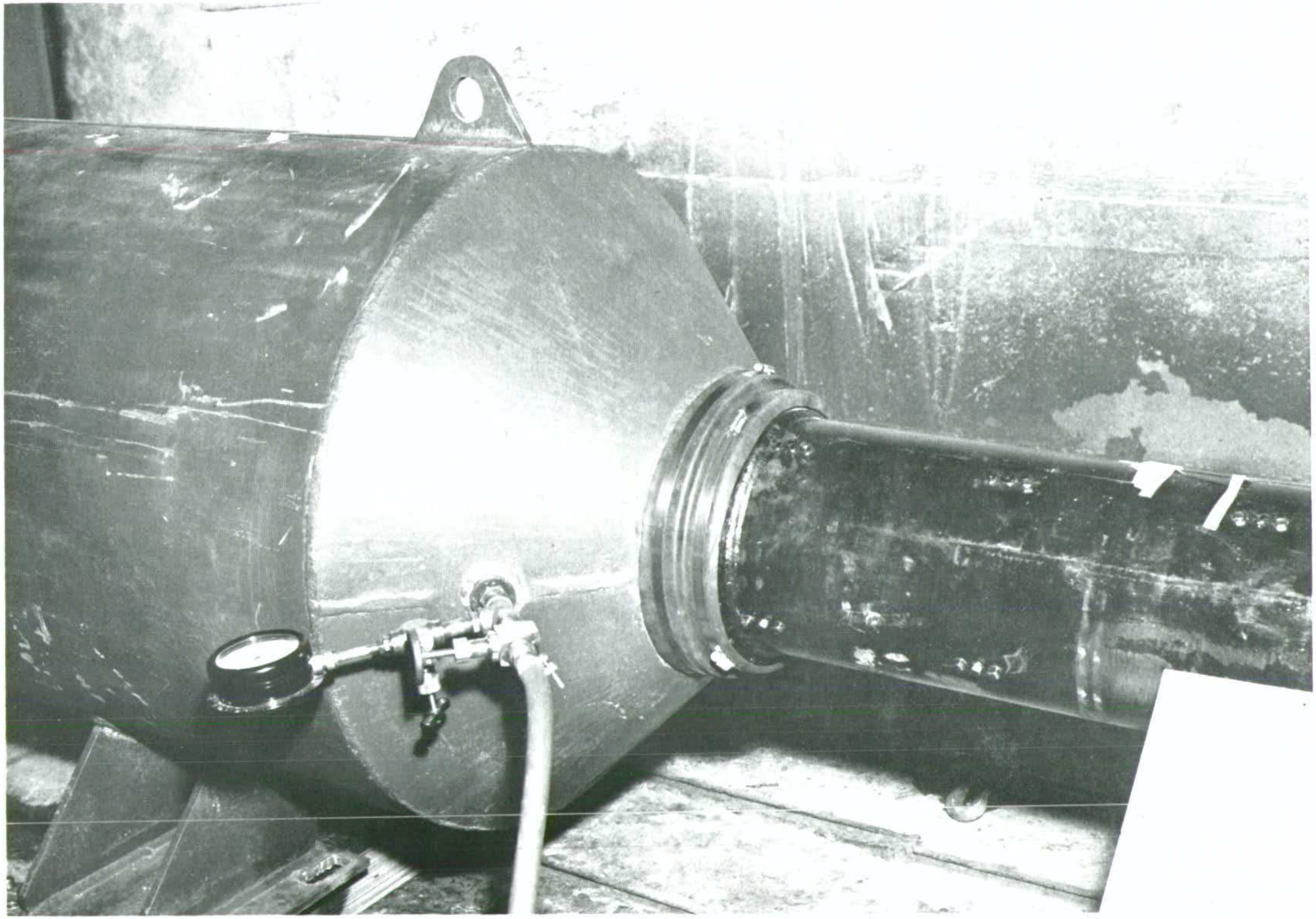

FIGURE 8 - Vacuum Chamber Coupling to Heavy-Wall Motor

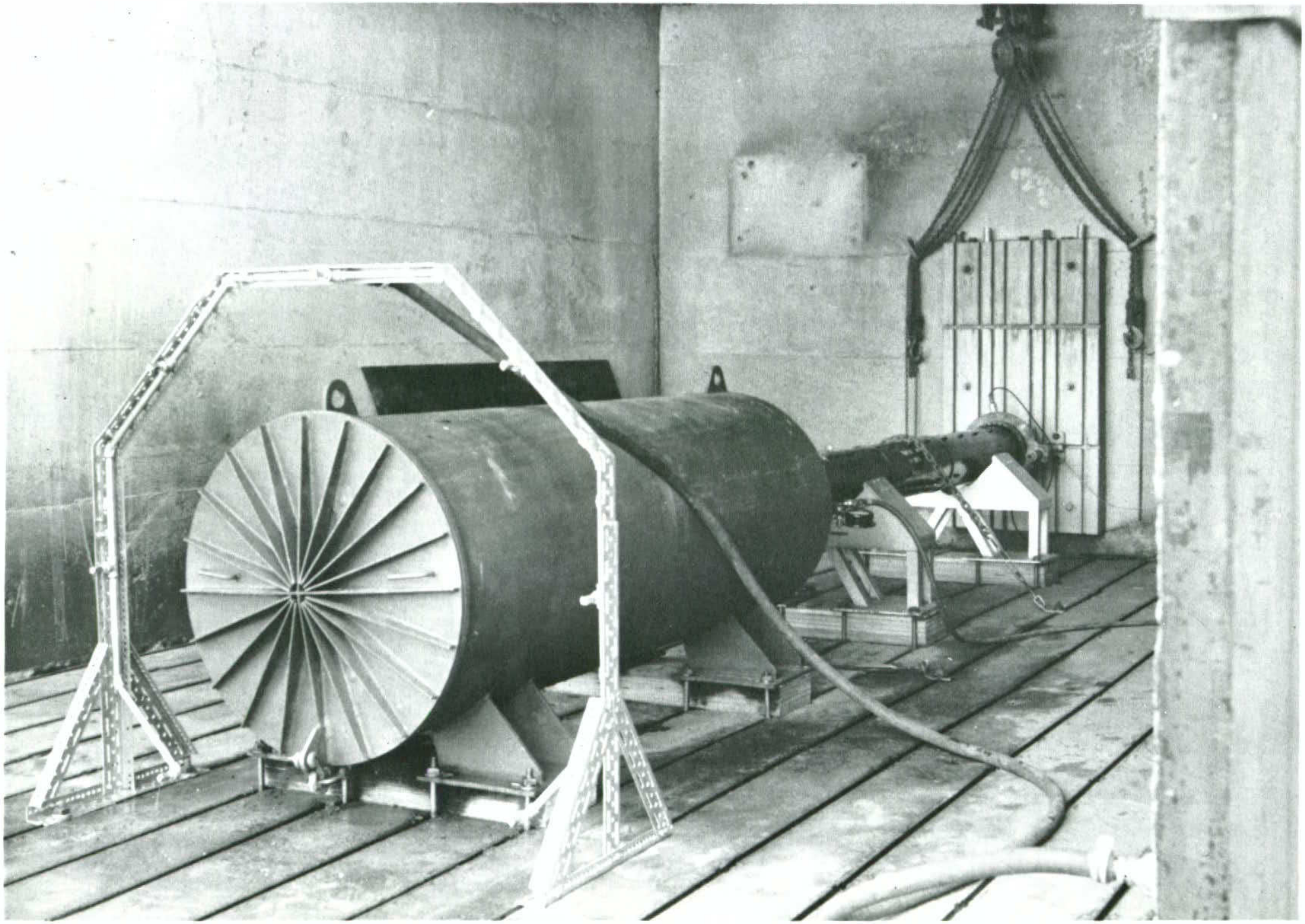

FIGURE 9 - Static Testing of Vacuum Ignition

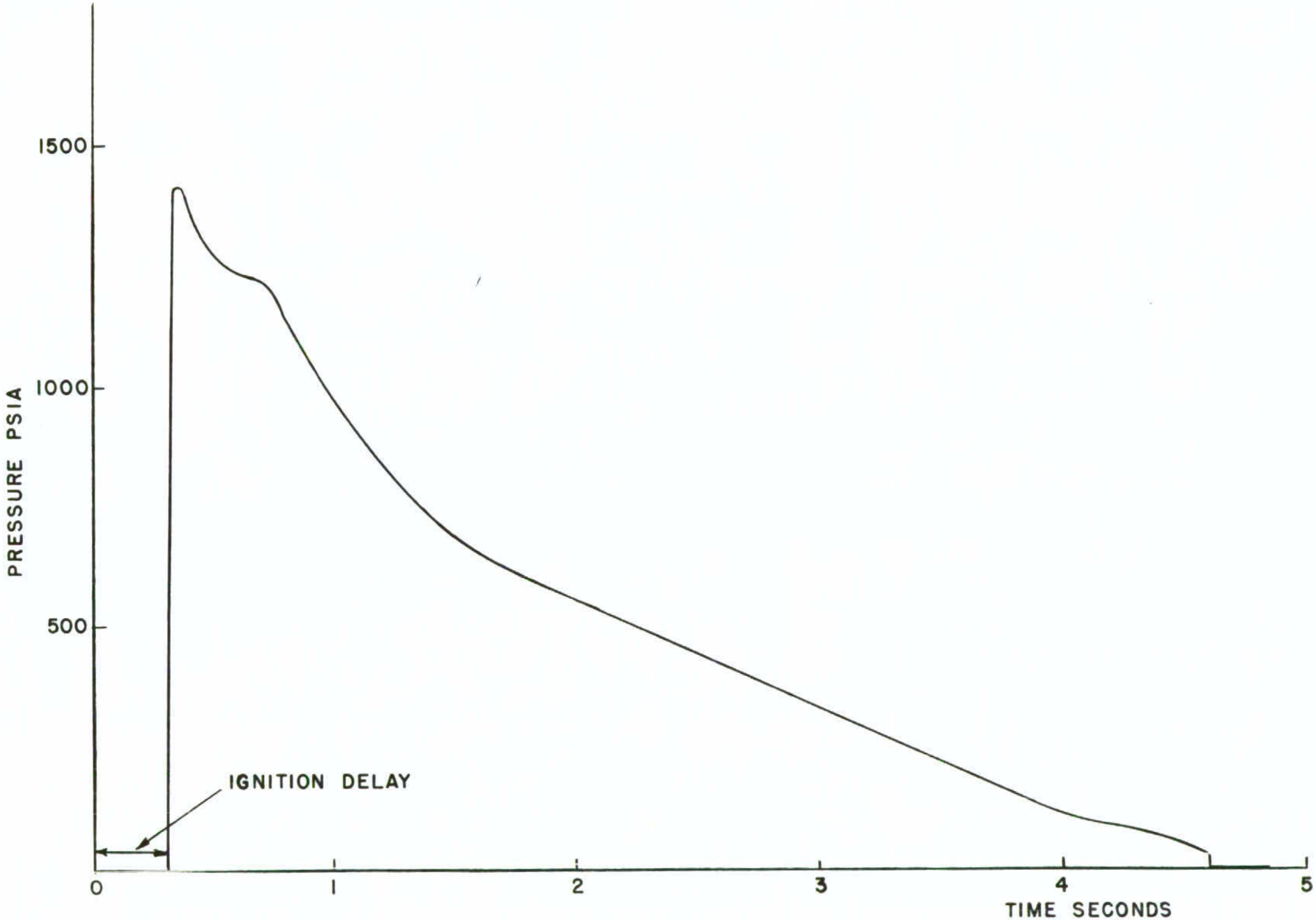

FIGURE 10 - Pressure-Time Curve from Vacuum Ignition Test for 9KS11000 Rocket Motor

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