NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Memorandum 33-317*

# *Ignition System for the ATS Rocket Motor*

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
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Approved by:

Winston Gin, *Manager*
*Solid Propellant Engineering Section*

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## Contents



## Tables

## Contents (contd)

### Tables (contd)



### Figures

# Contents (contd)

## Figures (contd)

## Abstract

This report documents the design, development, testing, and qualification of an igniter system for the solid-propellant Applications Technology Satellite (ATS) apogee rocket motor. The rocket motor contains 760 lb of propellant with about 898 sq in. of initial burning surface to be ignited. The $L^*$ at ignition is 140. The development phase started with a scale-up of the Syncom I igniter and rapidly progressed to an internally insulated aluminum basket with twelve gas ports and a pyrotechnic charge of 19 ALCLO pellets and two solid-grain ALCLO main grain charges. The igniter interfaces to either a development closure for data acquisition or to a safe-and-arm (S&A) device for flight and qualification testing. Ignition of the pyrotechnic charge is initiated either by a single dual-bridgewire squib for development testing, or two PC-37 squibs when used with the S&A device. The igniter, less closure or S&A, weighs 1 lb.

# Ignition System for the ATS Rocket Motor

## I. Introduction

In January 1963, the Jet Propulsion Laboratory initiated a development program to provide a solid-propellant apogee rocket motor for a second-generation Syncom satellite (Fig. 1). This program, under the management of Goddard Space Flight Center (GSFC), was designated Advanced Syncom. The resultant design is a spin-stabilized, active repeater communications satellite weighing about 750 lb, operating at synchronous altitude (22,300 mi), and capable of handling voice communications, teletype, and monochrome and color television signals.

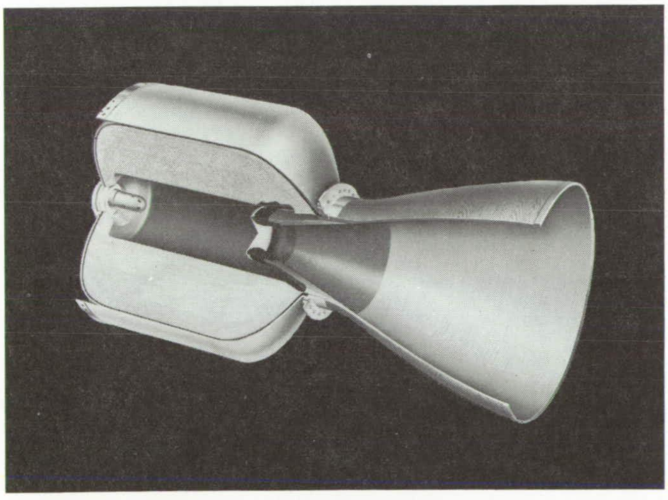


Fig. 1. ATS rocket motor, artist's conception

In January 1964, the Advanced Syncom communication program was redirected to include a number of experimental instruments, in addition to the original communications instruments. This expanded program, the Applications Technology Satellite (ATS) program, will result in a general-purpose satellite capable of operation at medium or synchronous altitude with experimental instruments of meteorology, communications, radiation, navigation, gravity-gradient stabilization, and various engineering experiments. A total of five launches are planned, including two synchronous-altitude spin-stabilized (Fig. 2, Table 1), two synchronous-altitude gravity-gradient-stabilized, and one medium-altitude gravity-gradient-stabilized spacecraft. The medium-altitude gravity-gradient-stabilized spacecraft does not require an apogee motor.

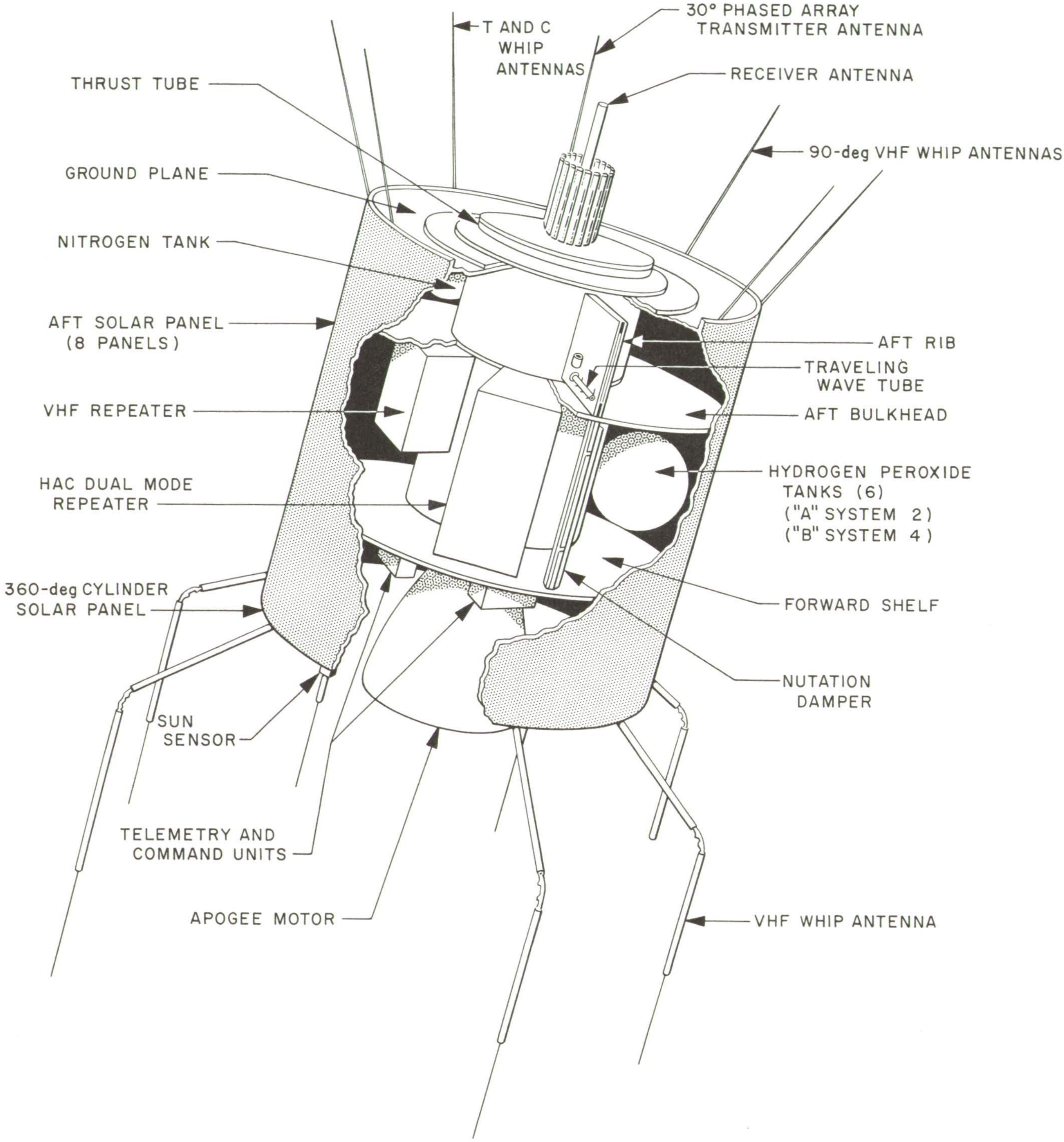



**Fig. 2. Synchronous-altitude spin-stabilized spacecraft**

**Table 1. Parameters of synchronous-altitude spin-stabilized spacecraft**

| | |
|---|---|
| Physical configuration | 56-in.-diameter cylinder |
| Weight | 1625 lb at launch; 670 lb in 24-hr equatorial orbit |
| Apogee motor | Scaled JPL Syncom motor |
| Control systems | 5-lb-thrust $H_2O_2$ system to get on station<br>5 × $10^{-4}$-lb-thrust subliming solid system (inversion)<br>$10^{-5}$-lb-thrust subliming solid system (east-west station-keeping) |
| Electrical power | N-P solar cell array<br>130 w initial<br>Two 6-amp-hr batteries (22 cells each) |
| Telemetry | Four 2.1-w transmitters<br>Two at 136.470 mc<br>Two at 137.350 mc<br>Two encoders; GSFC PCM standard |
| Command | Two receivers<br>Two decoders; GSFC FSK standard |
| Communications | Two triple-mode repeaters<br>4-w TWT power amplifier<br>18-db receiving antenna<br>18-db transmitting antenna<br>6301, 6212 mc ground to spacecraft<br>4195, 4120 mc spacecraft to ground |
| Payloads: | |
| (1) | Ion engine<br>Gravity-gradient stabilization and instrumentation |
| (2) | Gravity-gradient stabilization and instrumentation<br>Ion engine<br>Meteorological experiment |

To place the satellites in synchronous orbit, JPL will furnish a solid-propellant rocket motor (JPL SR-28-3) to provide the final required velocity increment at the apogee of the elliptical transfer orbit. A total of five apogee units will be delivered to the Atlantic Missile Range (AMR) for flight support.

JPL has completed the design, development, and qualification testing at the Arnold Engineering and Development Center (AEDC) at Tullahoma, Tennessee. This report describes the development chronology, design, and qualification of the igniter system for this rocket motor. Figures 3 and 4 show the igniter interface with the motor chamber.[1]

## II. Design and Development

### A. Introduction

The ATS igniter as designed and developed is of the controlled pressure type (shown in exploded and cross-section views in Figs. 5 and 6, respectively). The igniter is assembled as a separate unit and is externally installed into the head-end of the motor. It is secured by a high-strength nut; the igniter closure acts as an integral pressure closure for the head-end motor opening. The ignition material is of an aluminum and potassium perchlorate composition whose hot burning mass impinges on and radiates to the motor propellant surface causing ignition. The aluminum igniter basket is designed to withstand the ignition phase, after which it is consumed and expelled with no effect on secondary motor hardware. The igniter basket assembly (less closure) weighs approximately 1 lb.

### B. Chronological Development

At the inception of the ATS program a scale-up of the flight-proven Syncom igniter was attempted. This previously developed ignition system consisted of a highly perforated fiberglass basket filled with 60 g of ALCLO pellets.[2] A single dual-bridgewire squib initiated the pellets (main charge). The squib body was also designed to function as the head-end closure of the motor (Figs. 7 and 8[3]). The scaled-up ATS igniter (Fig. 9) consisted of a highly perforated steel basket filled with 200 g of randomly packed pellets and was initiated by a squib.[4] Two tests of this ignition system were made, with both baskets rupturing during igniter ignition (Fig. 10). Pressure results were inconsistent from test to test.

[1] The closure shown was the intended flight configuration but safety requirements indicated the use of a safe and arm device (see Appendix A).

[2] This ignition material, which was developed and manufactured by Aerojet-General Corporation, consists of aluminum fuel, potassium perchlorate oxidizer, and suitable additives for binding, stabilizing, and burning rate (see Section IV).

[3] The squib shown in the basket in Fig. 8 is not flight-wired. To insure positive connection and because of spacecraft electrical interface restrictions, the squib was hard-wired as shown by the cabling laid out in Fig. 7.

[4] Holex 1735R squib, manufactured by Holex, Inc., Hollister, California.

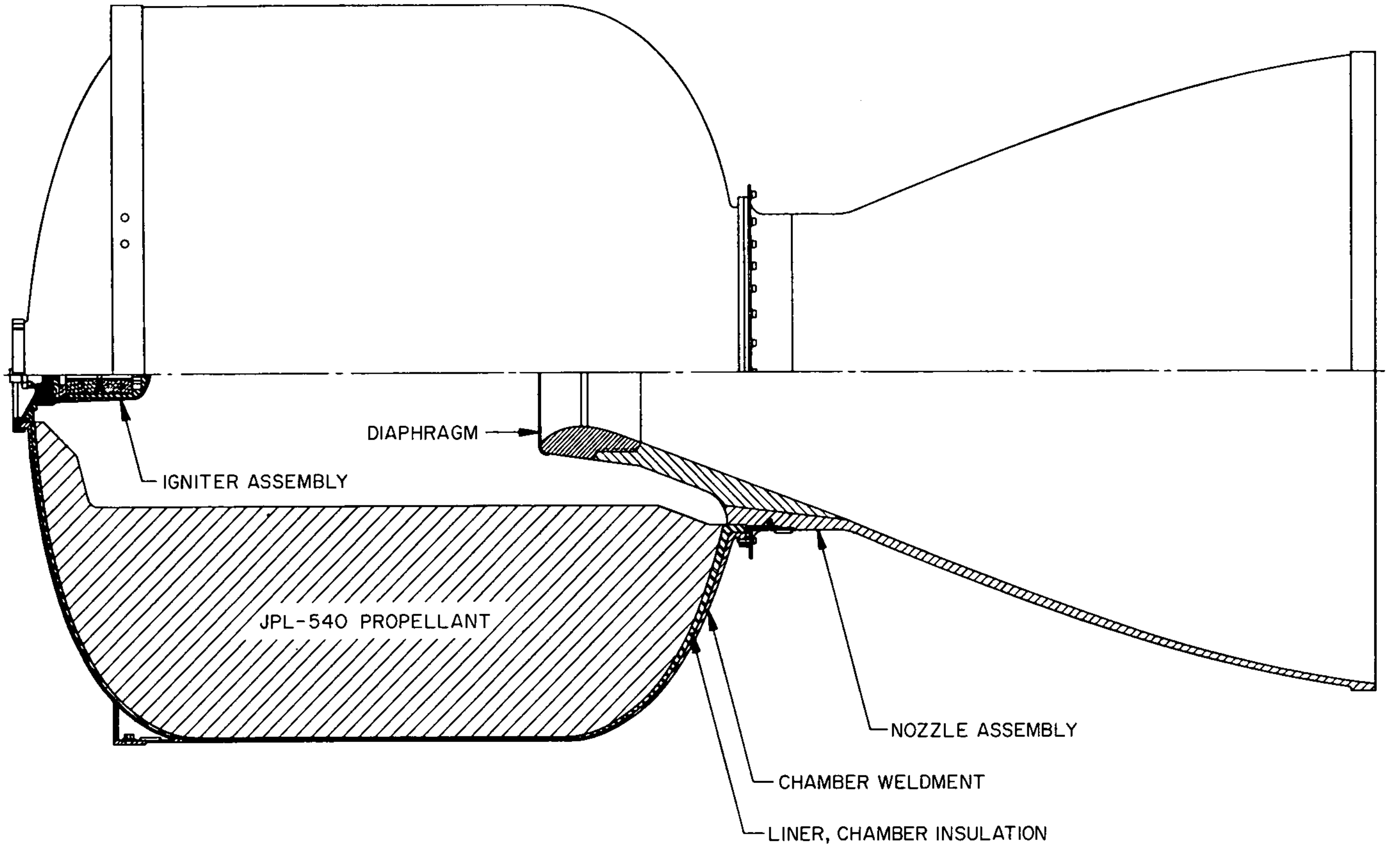



**Fig. 3. Apogee motor assembly**

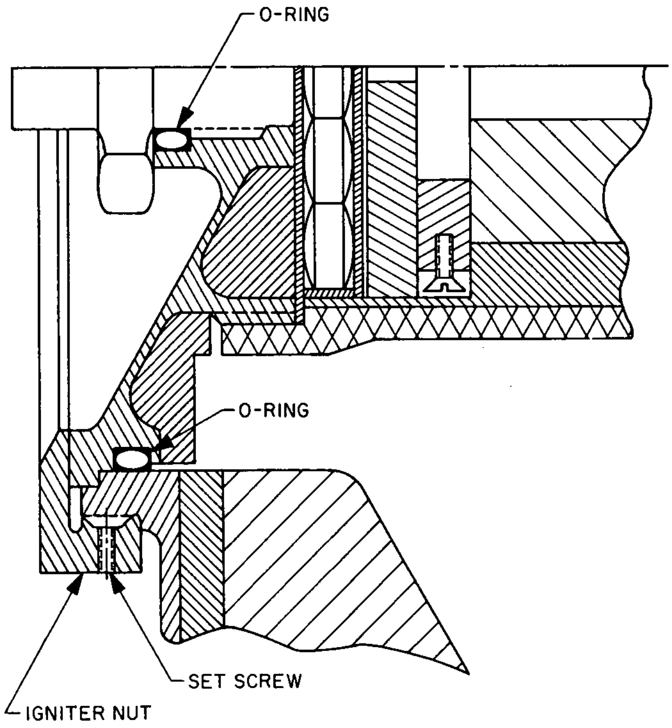



**Fig. 4. Igniter interface**

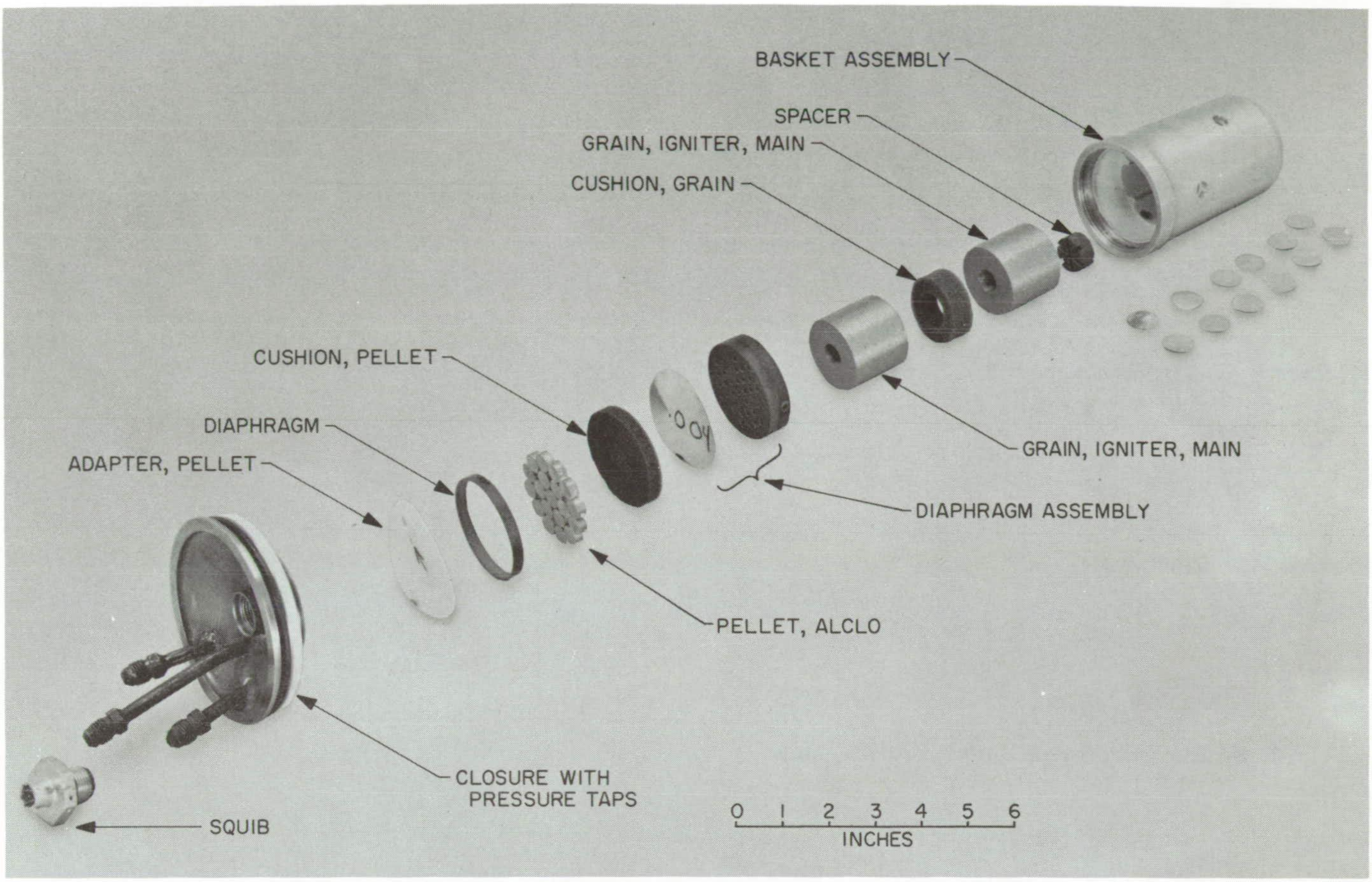



**Fig. 5. Exploded view of ATS igniter with development closure**

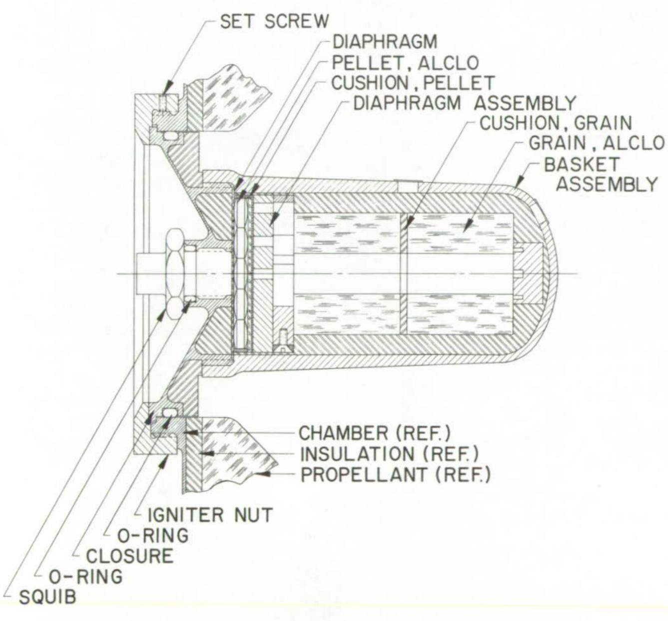



**Fig. 6. ATS igniter, cutaway view**

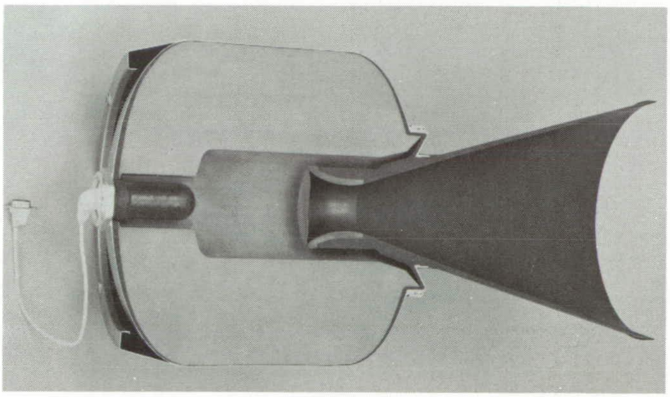


**Fig. 7. Syncom I, cutaway view**

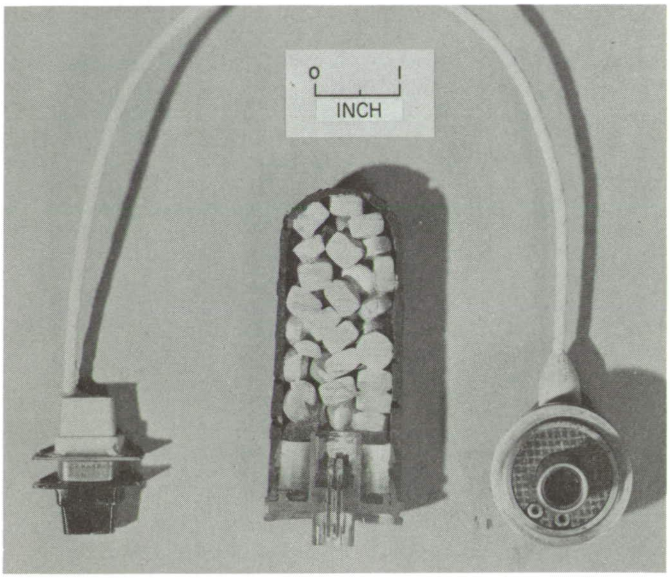



Fig. 8. Syncom I flight-type igniter, cutaway view

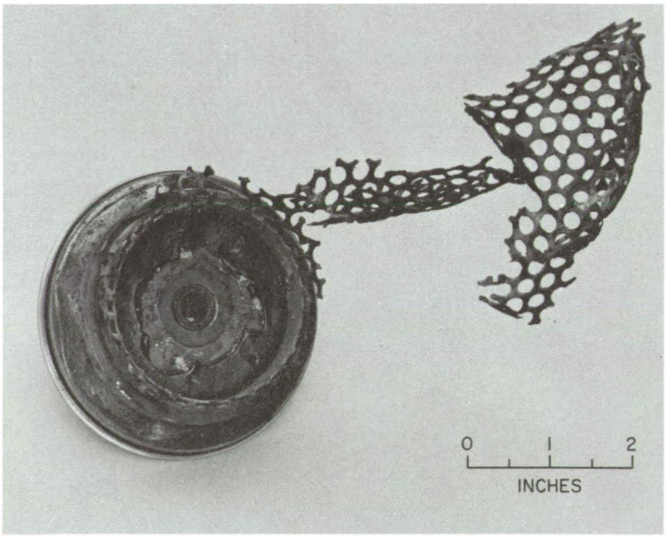



Fig. 10. Scaled-up Syncom igniter, post-fire


Fig. 9. Components of scaled-up Syncom igniter

A contract was let to develop a Polaris-type grain (controlled pressure) igniter.[5] This igniter (Fig. 11) was to be of a heavy hardware type, with a minimum of test to prove the pyrotechnic system only. A modification of the igniter was developed at JPL (Figs. 12 and 13) by replacing the primary grain with 19 pellets and increasing the number of gas ports in the main grain chamber from 6 to 12. The additional six holes were spaced 120 deg apart in two planes along the cylindrical section. Figure 14 shows post-fire condition of the modified Aerojet igniter.

By the time of the firing of the first heavy-wall motor (A-2), enough tests had been run to fix the pyrotechnic charge of two main grains and 19 ALCLO 0-052 pellets as the primary charge. Additional tests using ignition test motors (see Section III-E) and/or isolated igniters were continued to optimize basket material thickness, number and size of gas ports, burst diaphragm thickness, and number and size of diaphragm gas ports. Internal and external insulations were also part of the continued testing.

[5]Manufactured by Aerojet-General Corp., Von Karman Center, Azusa, California.

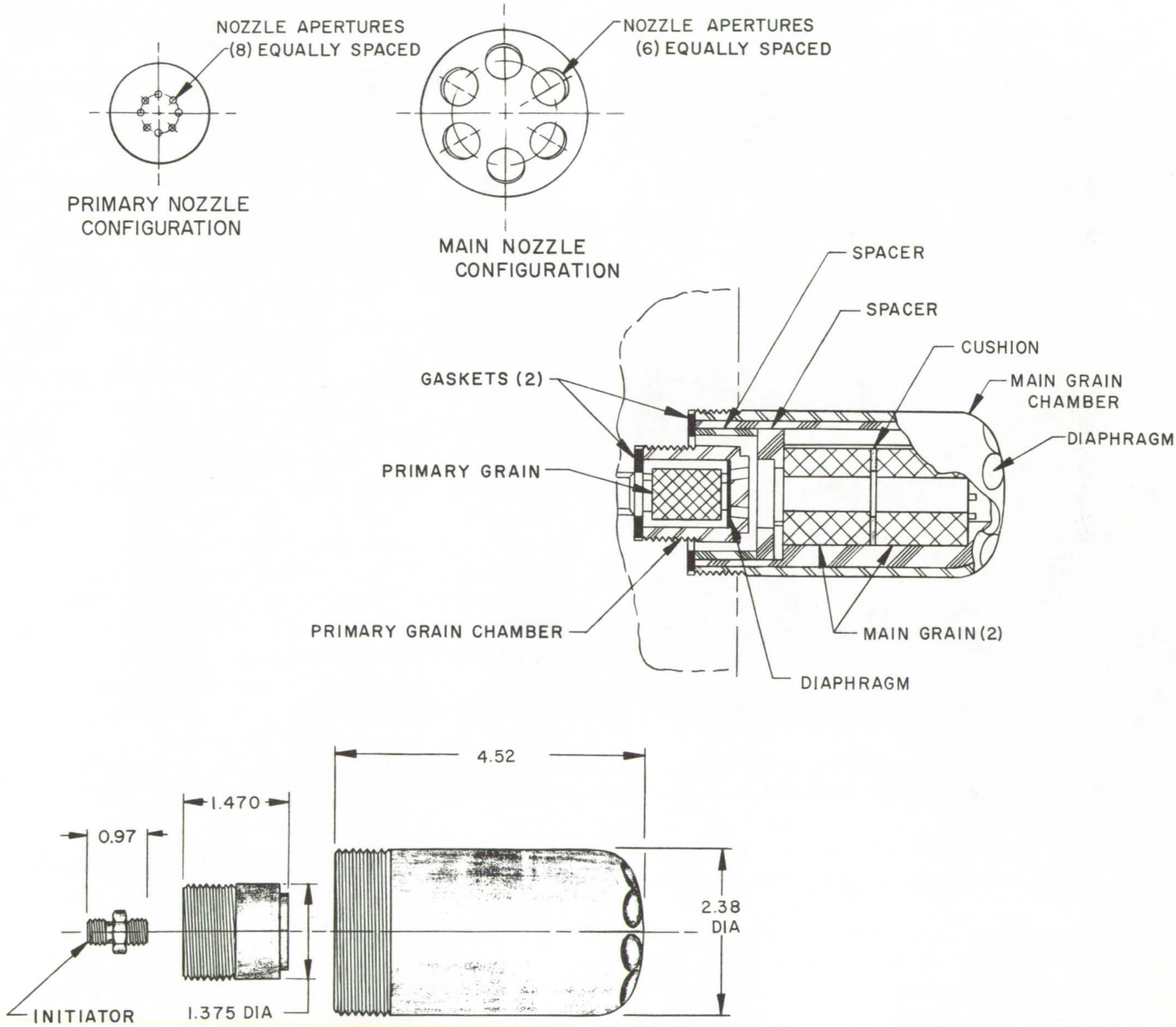



Fig. 11. Aerojet ATS igniter design proposal

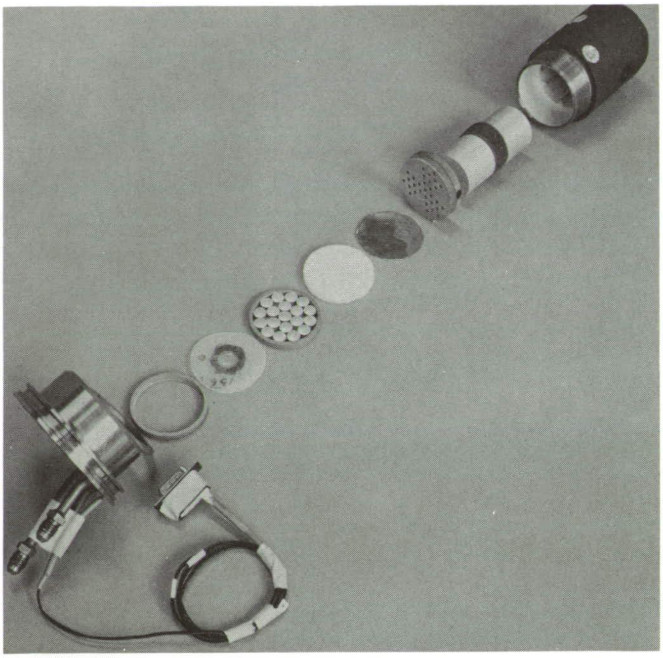


**Fig. 12. Modified Aerojet igniter (steel basket), exploded view**

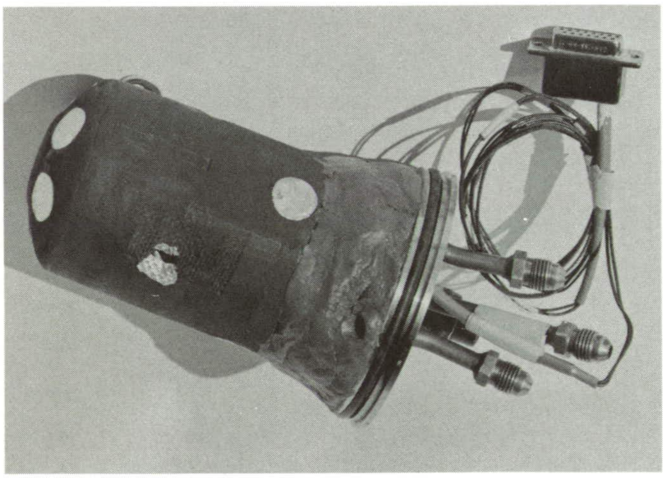


**Fig. 13. Modified Aerojet igniter (fiberglass basket), assembled**

The basket materials tested were of steel, fiberglass, nitrocellulose, magnesium, and aluminum (Fig. 15).[6]

Because of the satisfactory results and thorough testing and qualification of the Syncom I squib, a similar squib was decided on for use in the ATS development

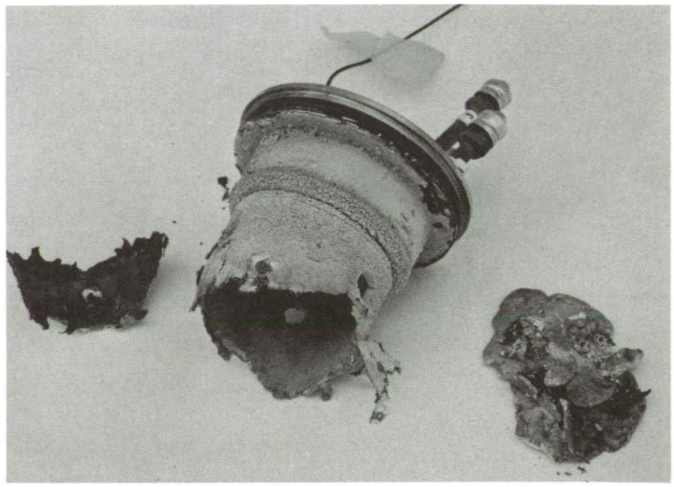


**Fig. 14. Modified Aerojet igniter (fiberglass), post-fire**

phase. The internal configuration of the squib would be the same as that of the Syncom igniter, but the body would be designed so as to adapt to a threaded closure squib port. Later modifications of the squib were made to the bridgewire attachments and resistor heat sinks to improve the reliability of the system. Figure 16 shows the improved version.[7]

### C. Design Details of Present Igniter

The ATS igniter, as finally designed and proven (Figs. 5 and 6) is of the controlled pressure type. The pyrotechnic element consists of a squib that ignites 19 pellets (primary charge). The pellets burn, build up to a desired pressure, burst a soft aluminum diaphragm, and ignite two large ALCLO main grains (87 g/grain). The flame temperature of the ignition material is about 8000°F. For a total igniter burn time of 85 to 110 msec, an internal basket peak pressure in a range from 1800–3000 psi (depending on the temperature conditioning of the igniter assembly) and an internal motor peak pressure in the range of 212–273 psi are produced.[8] For igniter data summary, see Table 2; for definitions of parameters, see Fig. 17.

The basket, which is made of 6061-T6 aluminum, has tapered walls running in thickness from 0.4 in. at the back to 0.1 in. at the dome. The basket is internally

[6]The failures of the nitrocellulose and fiberglass baskets (Fig. 15) occurred during shock loading.

[7]For more complete specifications see JPL drawing 3901527B.

[8]Chamber pressure during ignition is a function of the igniter pressure.


**Fig. 15. Post-shock-loading test**

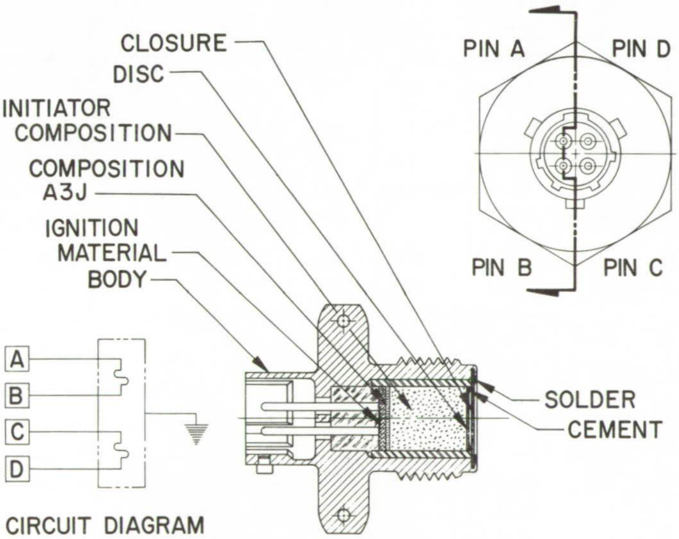



**Fig. 16. ATS squib**

insulated with a silica-fiber-filled polyurethane[9] insulation in such a manner as to hold and cushion the main grains. The diaphragm assembly (which separates the primary charge from the main grain, as shown in Fig. 6) is made of laminated plastic and has 31 gas ports of 0.125-in. diameter. A soft aluminum diaphragm of 0.004-in. thickness provides the desired pressure buildup of the igniter pellets. A polyethylene diaphragm holds the pellets in place and acts as a seal (O-ring type) for the basket-to-closure interface. A closure with three pressure taps (Fig. 5) was designed and used during the development phase; it is made of heat-treated stainless steel and insulated to be protected from propellant burning. The flight-type closure, with squibs, will be a part of the S&A device (see Appendix A).

The igniter is assembled in two configurations (see Appendix B): development test and flight use. The primary difference is in the use of an S&A device for flights as opposed to an igniter closure with pressure taps for development testing.

Both the S&A device and the development closure are held in place by a roll pin. Figures 18 and 19 show some of the dimensions of the igniter basket and development closure.

## III. Igniter Testing and Qualification

### A. Introduction

A complete series of tests has been run on the igniter as an isolated unit to test the various subcomponents as well as the unit's ability to withstand the ignition phase.

[9]Polytherm 20-SA80, manufactured by American Poly-Therm Co., Sacramento, California.

**Table 2. Igniter summary, development phase[a, b]**

| Development test | Test date | Temperature, °F | Vacuum start | $t_{D_i}$ msec | $P_{I_i}$ psia | $t_{I_i}$ msec | $P_{I_m}$ psia | $t_{I_m}$ msec | $t_{\Delta}$ msec | $t_{M_i}$ msec |
|---|---|---|---|---|---|---|---|---|---|---|
| A-2 | 8/15/63 | 60 | Yes | 14 | 1741 | 50 | 243 | 60 | 10 | 36 |
| A-3 | 9/24/63 | 60 | Yes | 8 | 2275 | 39 | 272 | 50 | 11 | 31 |
| A-4 | 10/1/63 | 60 | Yes | 13 | 2235 | 24 | 247 | 38 | 14 | 11 |
| A-5 | 11/7/63 | 60 | Yes | 12 | 2015 | 40 | 246 | 54 | 14 | 28 |
| C-1 | 2/26/64 | 60 | Yes | 11 | 1997 | 52 | 255 | 63 | 11 | 41 |
| C-2 | 3/5/64 | 60 | Yes | 11 | 1620 | 50 | 173 | 60 | 10 | 39 |
| C-3 | 6/4/64 | 60 | Yes | 21 | 1828 | 59 | 249 | 71 | 12 | 38 |
| C-3A | 6/12/64 | 60 | Yes | 27 | 2289 | 48 | 270 | 63 | 15 | 21 |
| C-6 | 7/9/65 | 60 | No | 2 | 1950 | 22 | 269 | 29 | 7 | 20 |
| G-5 | 11/24/64 | 60 | No | 10 | 1930 | 33 | 225 | 42 | 9 | 33 |
| C-4 | 7/15/64 | 10 | Yes | 17 | 1853 | 34 | 228 | 45 | 11 | 17 |
| H-1 | 11/4/64 | 10 | Yes | 2.5 | 2005 | 20.5 | 224 | 40.5 | 20 | 18 |
| G-2 | 12/16/64 | 10 | No | 2.3 | 1527 | 21.5 | 212 | 32 | 10.5 | 19 |
| G-7 | 8/6/65 | 10 | No | 2.5 | 1650 | 14 | 217 | 23 | 9 | 12 |
| G-9T | 1/4/66 | 10 | No | 2 | 1592 | 17 | 234 | 30 | 13 | 15 |
| G-8T | 11/9/65 | 110 | No | 1 | 2863 | 12 | 296 | 22 | 10 | 11 |
| C-5 | 7/23/64 | 110 | Yes | 4 | 3292 | 21 | 273 | 29 | 8 | 17 |
| C-7 | 8/10/65 | 110 | No | 2 | 3000 | 12.5 | 320 | 16.5 | 4 | 10.5 |
| G-1 | 12/16/64 | 110 | | | (no oscillograph data) | | | | | |
| G-6 | 7/16/65 | 110 | No | 5 | 3485 | 16 | 276 | 23 | 7 | 11 |
| E-1 | 7/16/64 | 60 | Yes | 18 | 1524 | 58.5 | 239 | 69 | 9.5 | 40 |
| E-2 | 10/13/64 | 60 | Yes | 14 | 1832 | 37.5 | 233 | 49.2 | 11.7 | 23.7 |
| E-3T | 6/2/66 | 75 | Yes | | (spacecraft test—no pressure measurements) | | | | | |
| G-3 | 5/28/65 | 75 | Yes | 13 | 1626 | 33 | 241 | 44 | 9 | 20 |
| G-4 | 5/26/65 | 75 | Yes | 15 | 1826 | 32 | 233 | 45 | 11 | 16 |
| | | | (single igniter test) | | | | | | | |
| SYC-266 | 7/8/65 | 60 | No | 2 | 1850 | 16 | | | | 14 |
| SYC-276 | 7/29/65 | 110 | No | 2 | 2525 | 24 | | | | 22 |
| SYC-281 | 1/10/66 | 110 | No | 1 | 2075 | 23 | (pellet chamber) | | | |
| | | | | | 1875 | | (basket chamber) | | | |

[a]See Fig. 17 for ignition events index.

[b]The data here listed constitute a complete summary of all motor firings to February 1966. The single-igniter tests include three special test runs to check a prototype of the S&A device as well as to study high-speed movies of the flame spreading characteristics. SYC-281 has two peak pressures. A special test was run to compare pressures throughout the igniter system.

$P_{I_i}$ = peak pressure of igniter basket during ignition

$P_{I_m}$ = peak pressure of motor chamber during ignition

$t_0$ = zero time, or time at which current is applied to squib

$t_{D_i}$ = the delay time from $t_0$ until the first indication of squib pressure is seen

$t_{I_i}$ = the time from $t_0$ till peak igniter pressure is seen

$t_{I_m}$ = the time from $t_0$ till peak chamber ignition pressure is seen; this is not the same as peak run pressure

$t_\Delta$ = the time difference between peak igniter basket pressure and peak chamber ignition pressure

$t_{M_i}$ = the time from initial squib pressure till peak igniter basket pressure; the total igniter reaction time

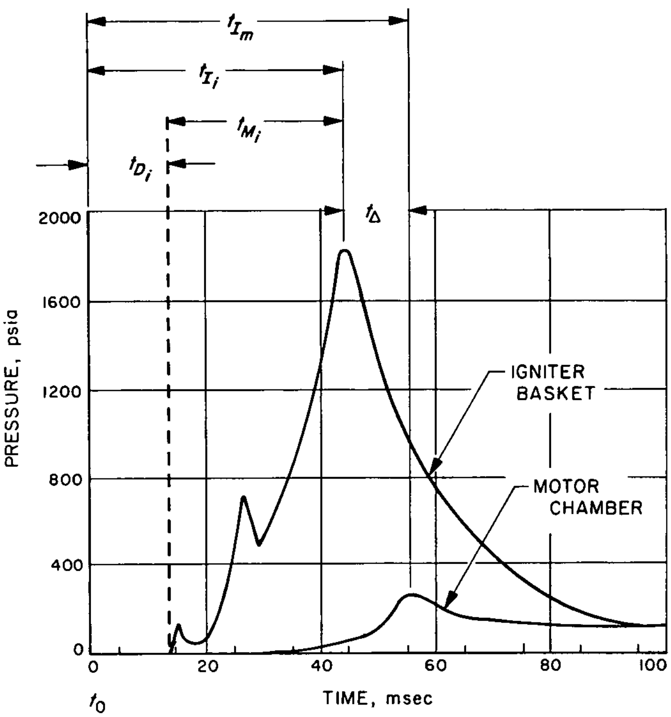



**Fig. 17. ATS apogee motor ignition parameters**

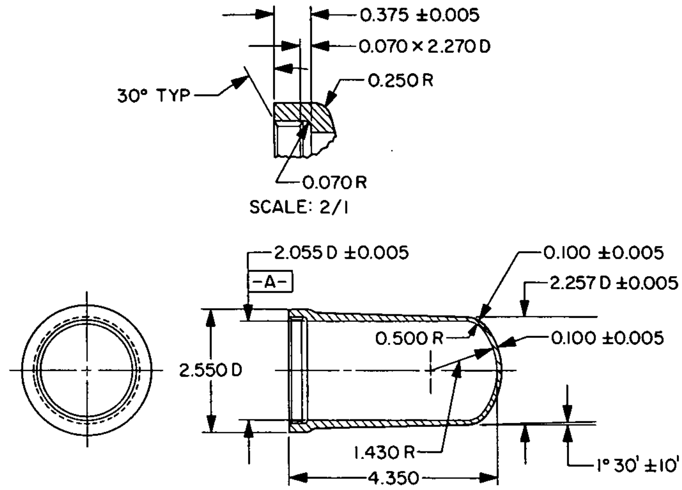



**Fig. 18. ATS igniter basket**

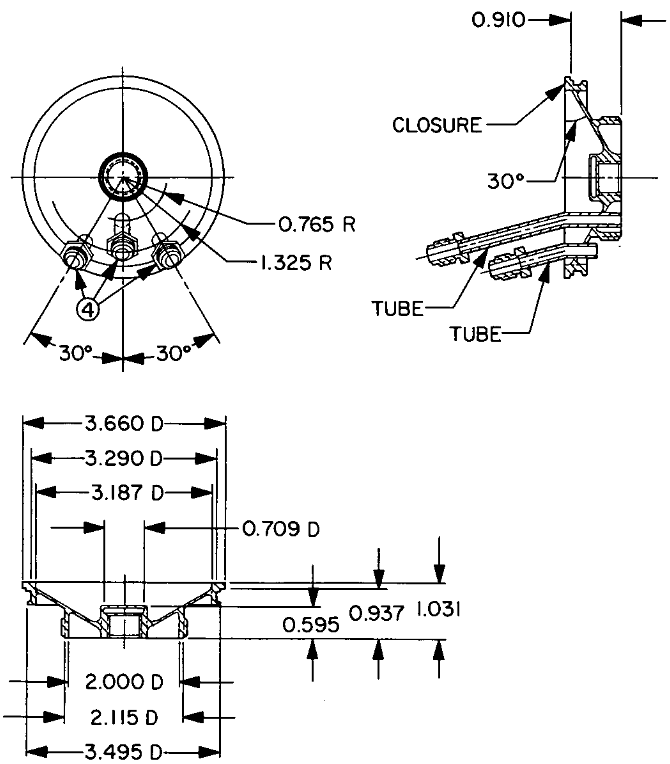



**Fig. 19. ATS igniter closure, with pressure taps**

Hydroburst tests were performed on unported baskets to check the difference in various tapered-wall thicknesses. Shock tests on baskets with gas ports were run to check possible yield from the ignition phase. Fiberglass and nitrocellulose baskets failed during these tests, whereas the 6061-T6 aluminum baskets showed little or no yielding after repeated testing with shock pressures in the range of 1800 to 2900 psia. Single igniter firings with a full pyrotechnic load were tested to examine the ability of the igniter basket to withstand the burning of the pellets and main grains.

High-speed movies were taken to examine the flame spreading characteristics. Post-fire inspection showed the igniter gas ports eroded to about 25% of their original size. Four igniters were subjected to temperature cycling with no noticeable effect on physical characteristics or performance. Three igniters were put through vibration testing and two igniters were centrifuged with no deleterious effects. Two igniters have been through all three environmental tests (centrifuge, vibration, and temperature cycling), inspected, and fired with no adverse effect

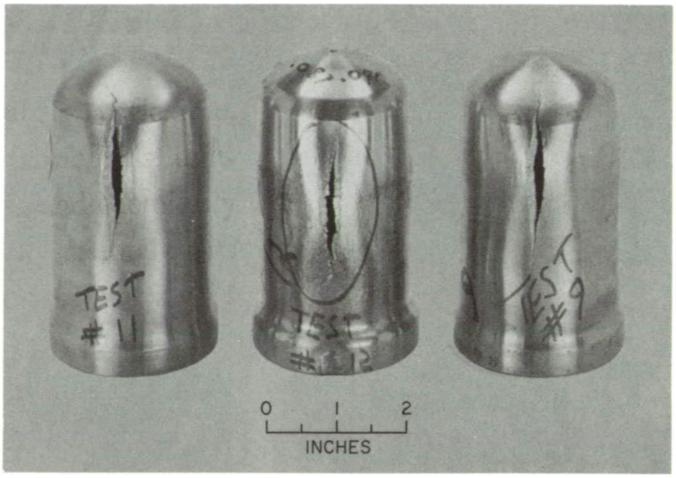



Fig. 20. Igniter basket hydroburst tests

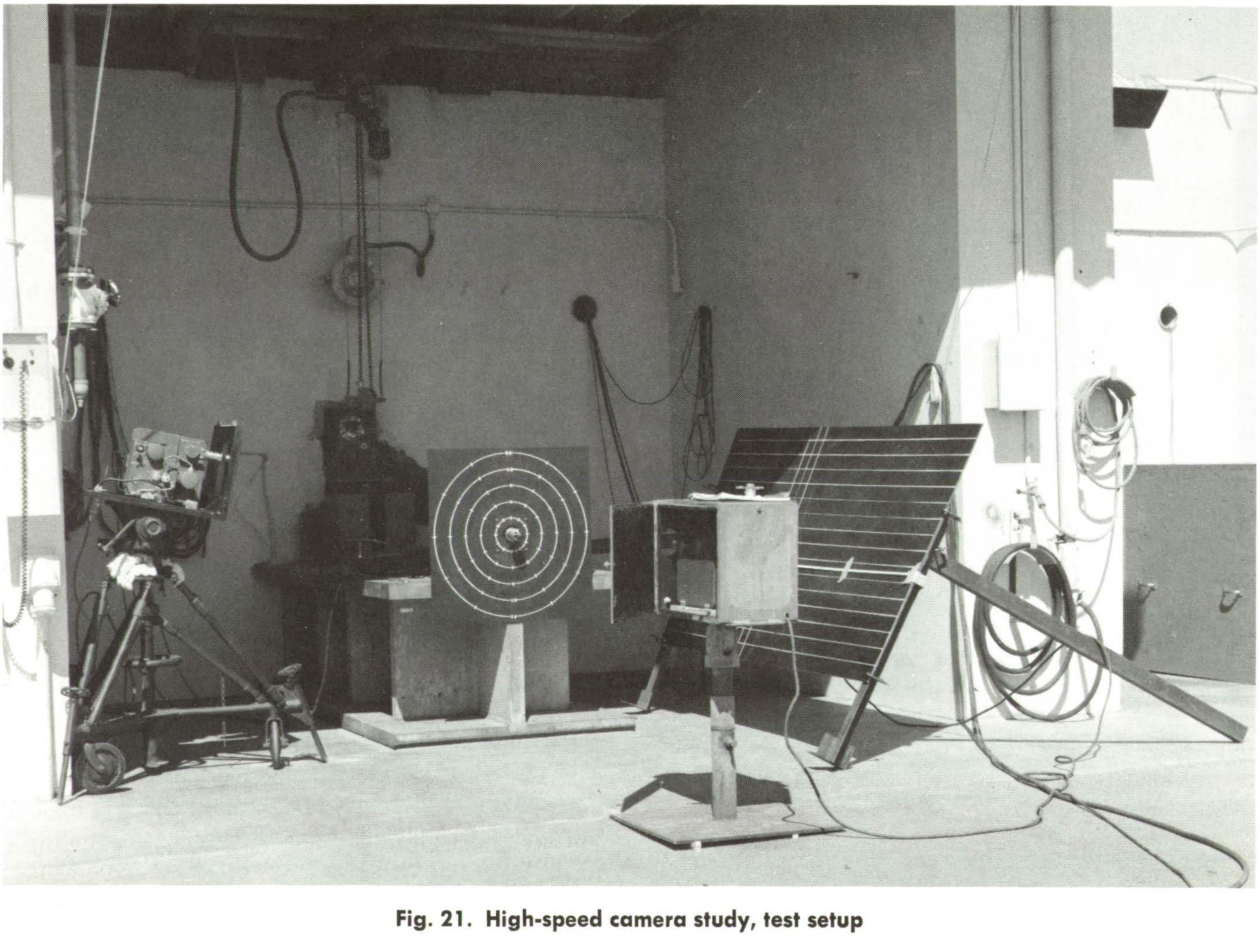


Fig. 21. High-speed camera study, test setup

on performance. Hydrotests were run on the igniter closure to check for yield, buckling, and failure. The closure was found to have a margin of safety of 1.45 on buckling and 4.2 on failure (burst).

### B. Igniter Basket Hydroburst Tests

Using a special setup, hydroburst tests were run on baskets of various thicknesses of aluminum. (Previous testing of other materials had eliminated them from consideration.) Figure 20 shows three baskets from tests 11, 12, and 9. The basket from test 12 was of the thin-wall design. Tests 11 and 9 were of the proposed final design of a tapered-wall thickness. The burst pressures for the tests were 5920 psi for test 11, 5050 psi for test 12, and 5850 psi for test 9.

### C. Igniter Basket Shock Test

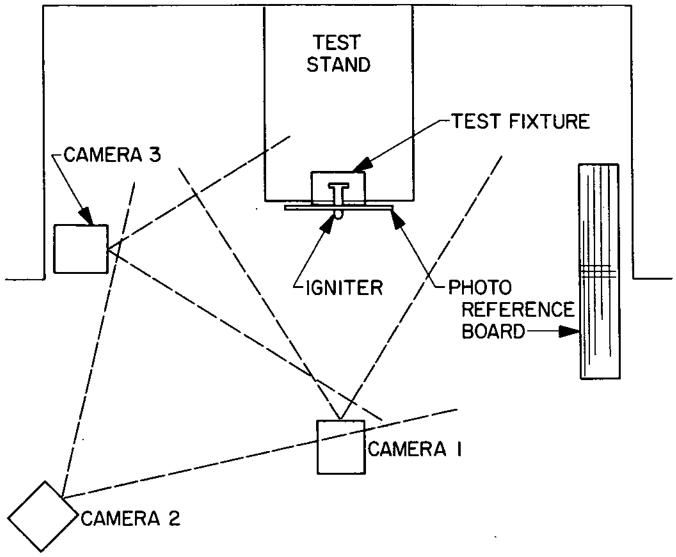
The purpose of this series of tests was to confirm the ability of the basket to withstand the pyrotechnics ignition and the resultant high pressure (1500 to 3000 psi) without fragmenting and causing the igniter to expel the ALCLO grains before motor ignition occurred. A system was designed such that shock loads in a range of 1500 to 3000 psi could be obtained to simulate the outgassing effects on the basket. Figure 15 shows the results of this test on both fiberglass and nitrocellulose baskets when subjected to 2500-psi shock loads. The normal transit time for peak loads during this test was about 4 to 6 msec.

Because of the problem of the burst diaphragm fragmenting when it ruptured and causing considerable damage to the internal insulation of the baskets, this procedure was not performed on all hardware. A series of tests was run, however, on a selected set of flight-type baskets. Some of these baskets received as many as eleven consecutive shock loads with no material damage or yielding except to the internal insulation, which was expected.

### D. Igniter Pyrotechnics and Flame Spreading Characteristics

Two igniters were fired for flame spreading studies. Figure 21 shows the test setup. Three high-speed cameras were used and positioned as shown in Fig. 22.

No determination was made as to flame spreading rate; rather, it was desired to determine how the flame propagated from the gas ports and with respect to the forward ports to the cylindrical ports as a function of time. Maximum intensity occurred at about 28 to 30 millisec (Fig. 22), which is within the observed range of times for




CAMERA:
1. FAIRCHILD AT 2500 frames/sec
2. MILLIKEN AT 500 frames/sec
3. FAIRCHILD AT 2600 frames/sec

**Fig. 22. High-speed camera study, camera positions**

maximum peak pressures listed in Table 2. Figure 23 gives a general three-quarter view from camera No. 2. Figure 24 gives a front view from camera No. 1, and Fig. 25 gives a side (normal) view from camera No. 3. Figure 26 gives a cross-sectional view with respect to the igniter and the initial propellant grain diameter to give an idea of how the flame would propagate down the motor, completely filling the motor with ignition flame. Because of the gas ports on the cylindrical portion of the igniter, no aspiration is experienced at the forward end of the motor chamber. This of course allows a full and even ignition of all of the initial propellant grain. High-speed film studies were made to evaluate safety procedures (Appendix C).

### E. Ignition Test Motors

In order to test the ability of the igniter system to ignite the propellant grain, an ignition test motor (ITM) was designed. This motor (Fig. 27) simulates the actual initial grain configuration in the full-size motor but contains only about 40 lb of propellant, thus facilitating handling and decreasing cost by eliminating the necessity of firing full-scale motors during igniter design optimization. The grain surface of the ITM, although simulating the initial burning surface of the full-scale motor, has a fuel-rich, as-cast surface. This type of propellant grain surface is considered more difficult to

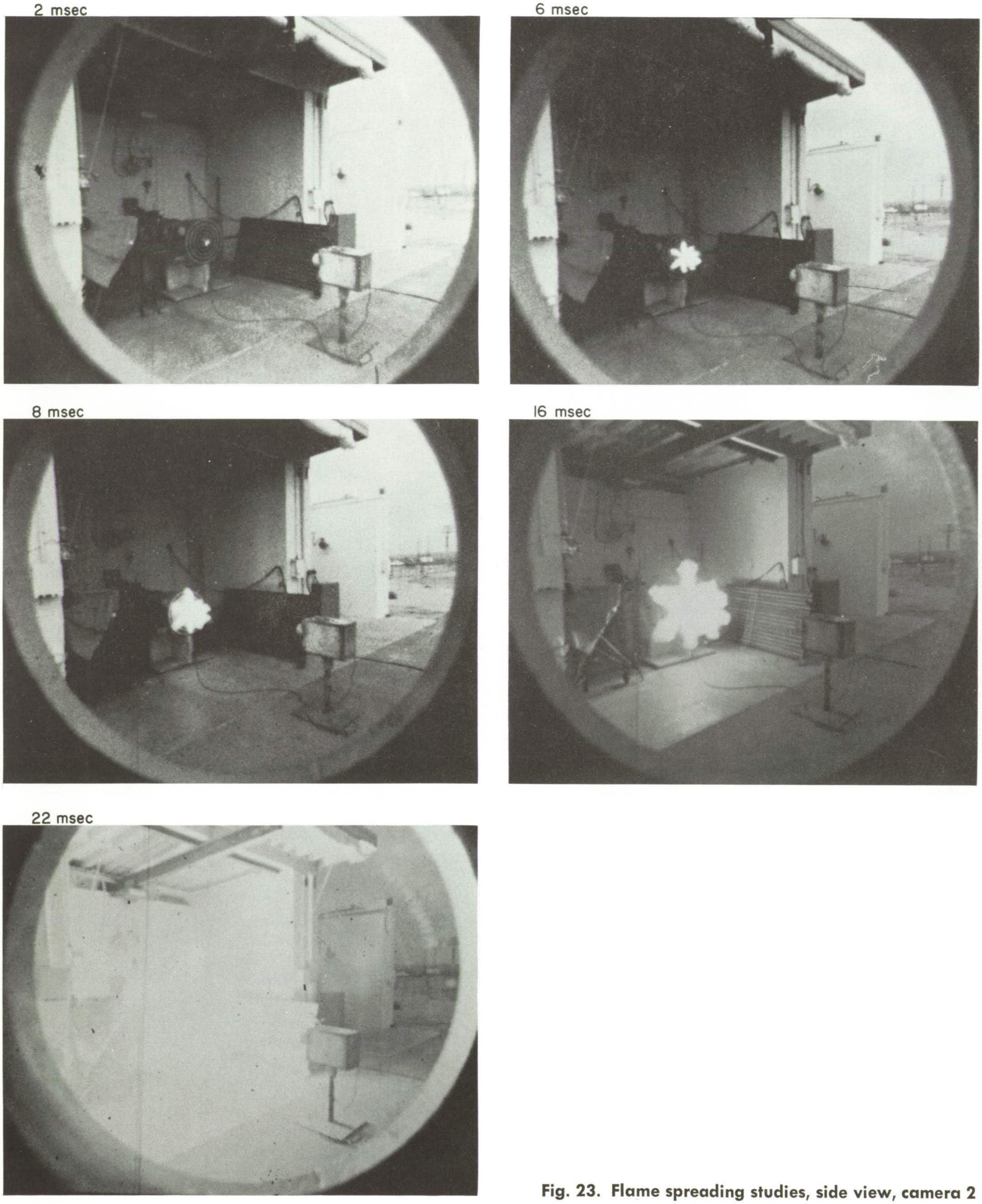



Fig. 23. Flame spreading studies, side view, camera 2

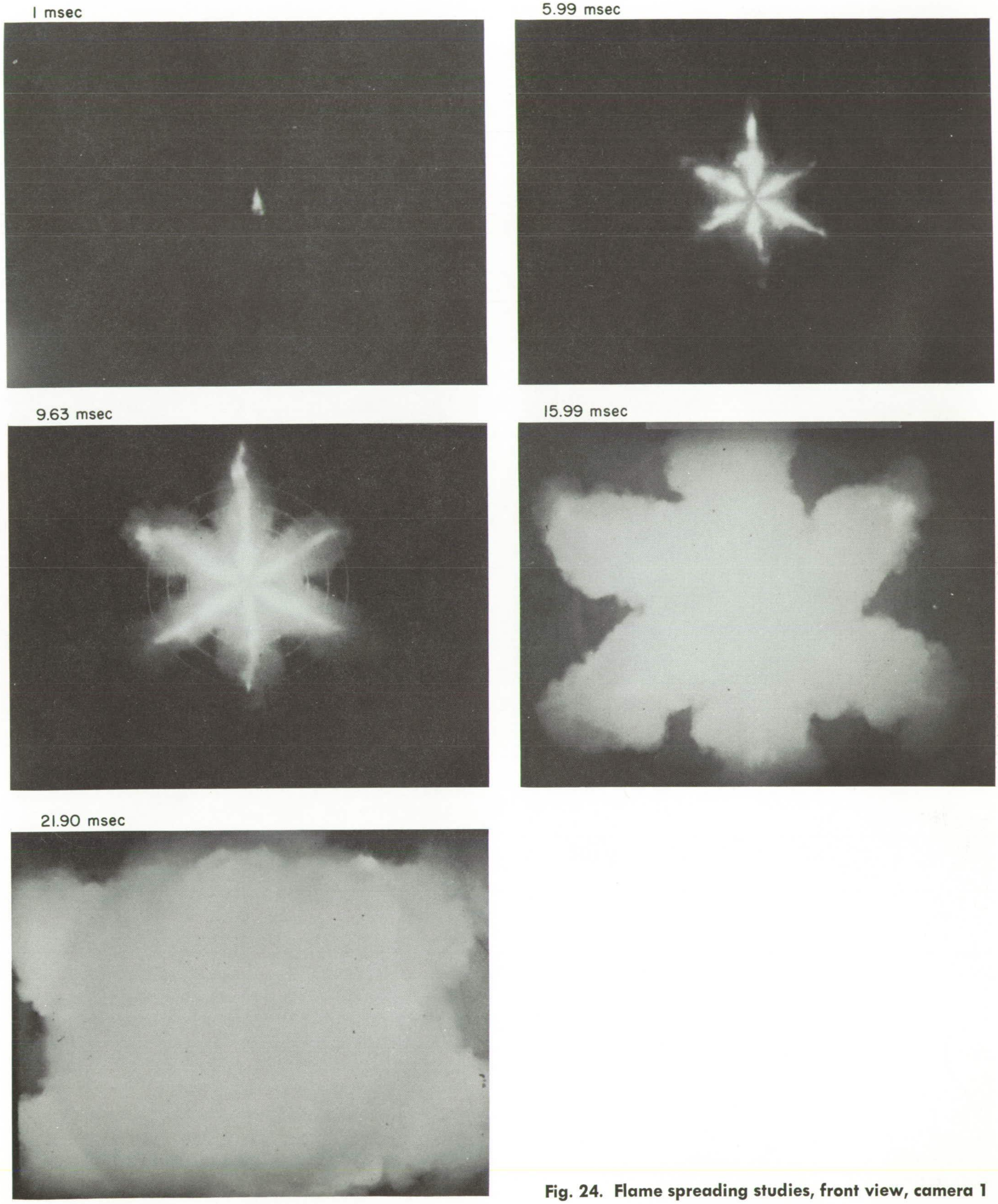



Fig. 24. Flame spreading studies, front view, camera 1

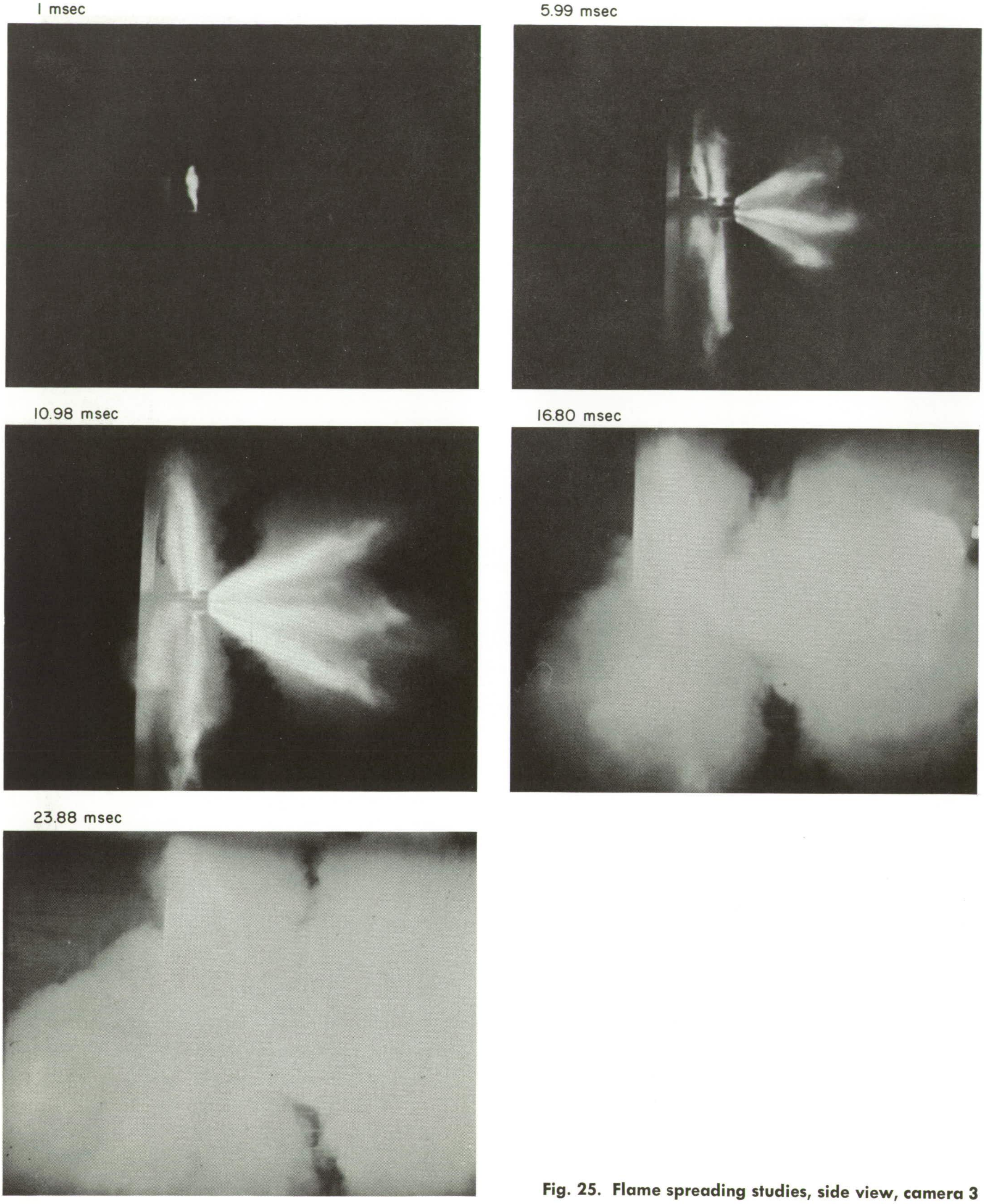



Fig. 25. Flame spreading studies, side view, camera 3

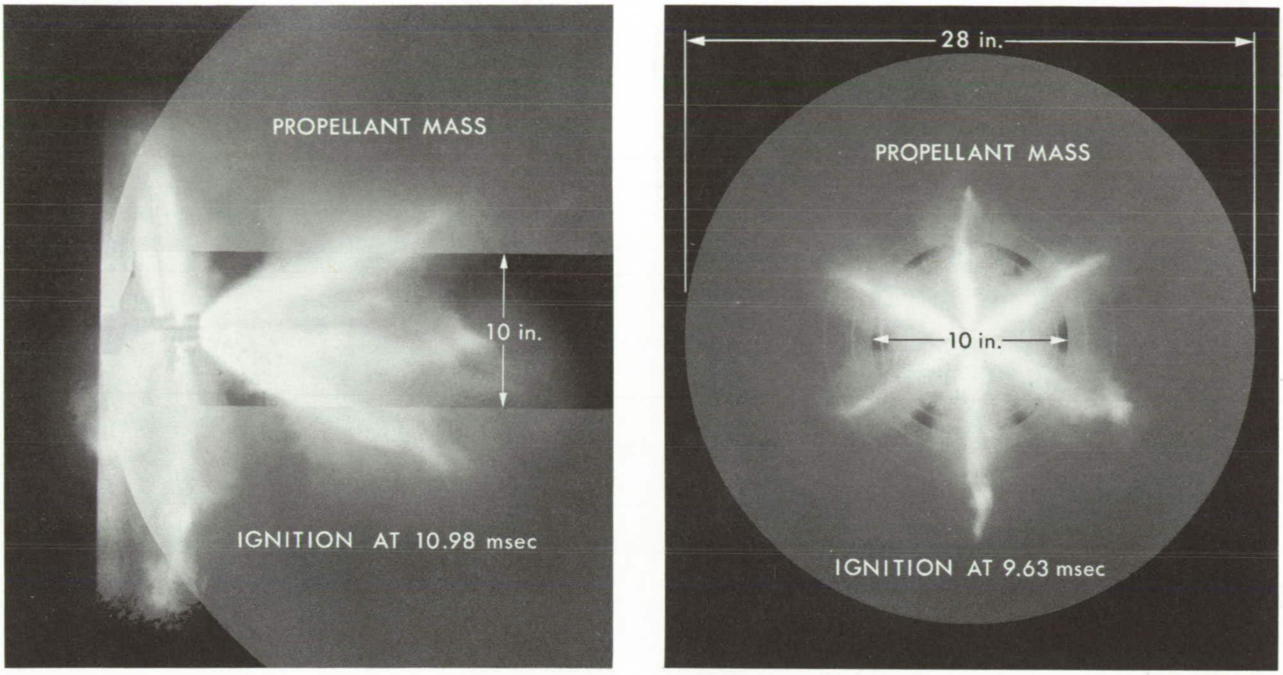



**Fig. 26. Flame propagation**

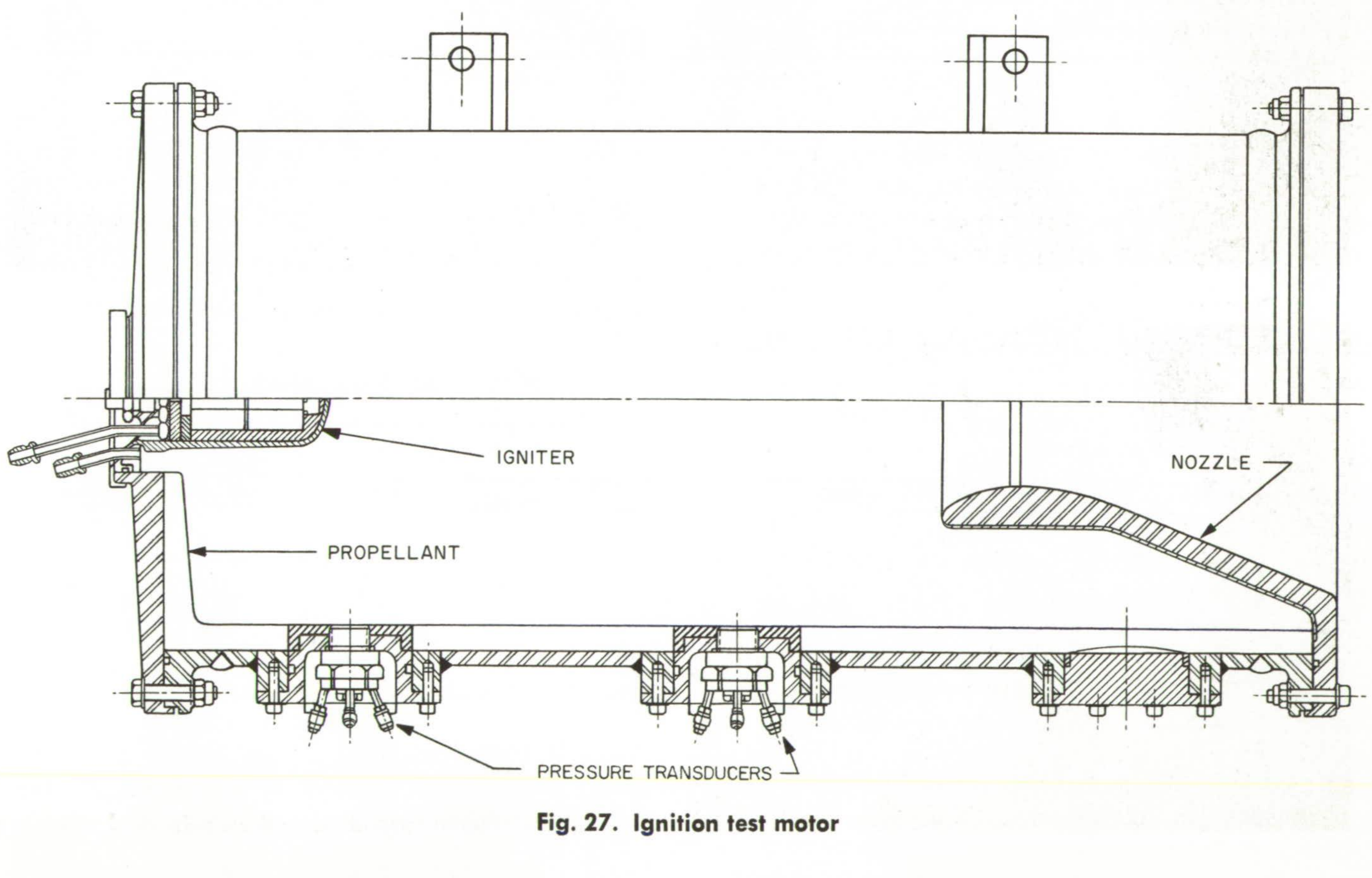



**Fig. 27. Ignition test motor**

**Table 3. ITM ignition data**

| Igniter | Test designation[a] | Igniter description | Pressure-time results[b] |
|---|---|---|---|
| SYA-206 | ITM-2 | Controlled pressure igniter as delivered from vendor (with a single 19-g primary grain). Main chamber orifice area = 1.51 in.$^2$ | Fire switch to first igniter pressure 0.008 sec<br>Maximum ignition pressure 2040 psia at 0.050 sec<br>Peak ignition pressure 178 psia at 0.102 sec<br>Ignition saddle minimum pressure 102 psia at 0.201 sec<br>Equilibrium motor chamber pressure 119 psia at 0.245 sec |
| SYA-207 | ITM-3 | Controlled pressure igniter with a primary charge of 16.15 g of ALCLO 0-052 pellets and an aluminum primary burst diaphragm 0.002-in. thick. Main chamber orifice area = 1.08 in.$^2$ | Fire switch to first igniter pressure 0.030 sec<br>Maximum ignition pressure 1238 psia at 0.065 sec<br>Peak ignition pressure 203 psia at 0.106 sec<br>Ignition saddle minimum pressure 99 psia at 0.191 sec<br>Equilibrium motor chamber pressure 122 psia at 0.242 sec |
| SYA-220 | ITM-5 | Controlled pressure igniter with a primary charge of 16.20 g of ALCLO 0-052 pellets and an aluminum primary burst diaphragm 0.004-in. thick. Main chamber orifice area = 0.96 in.$^2$ | Fire switch to first igniter pressure 0.009 sec<br>Maximum igniter pressure 3200 psia at 0.038 sec<br>Peak ignition pressure 225 psia at 0.053 sec<br>Ignition saddle minimum pressure 103 psia at 0.119 sec<br>Equilibrium motor chamber pressure 119 psia at 0.178 sec |

[a]All ITMs were ignited with the grain surface in the as-cast condition.

[b]The descriptions of pressure-time events are consistent with Table 2 and Fig. 17.

ignite than the machined surface of the full-scale motor. Ten ITM tests were run, including one test using only one main grain in the igniter. All tests, including the one-grain test, showed close pressure–time relationships. All motors ignited satisfactorily. The one-grain test proved, to some degree, the margin of safety contained in the igniter system. Table 3 gives a typical schedule of ITM development phase testing carried out to optimize the inert hardware of the igniter system.

### F. Igniter Closure Hydro Testing

A series of hydro tests were run on the igniter closure to test the expected ignition loads due to ALCLO burning and to determine the buckling and ultimate failure pressure of the closure.

Using a special test fixture, three tests were run on separate closures. The procedure used was to pressurize the test assembly in 100-psi increments to 800 psi. At each pressure increment the pressure was held for 3 min and a recording of pressure vs volume was made. After reaching 800 psi, increments of 50 psi were used until the end closure buckled. Two of the three closures used for the first test were retested to failure. The pressure–volume curves for the test to initial buckling (first test) are linear. The test results and conclusions are as follows:

*1. Test results.* The results of the first set of tests to determine the initial buckling pressures are given in Table 4.

**Table 4. ATS hydroburst test results**

| Closure No. | Theoretical minimum thickness, in. | Actual thickness, in. | Buckling pressure, psi | Normalized pressure, psi |
|---|---|---|---|---|
| 2 | 0.025 | 0.0257 | 1975 | 1920 |
| 3 | 0.025 | 0.0278 | 2175 | 1950 |
| 4 | 0.025 | 0.0260 | 2075 | 1990 |

The wall thicknesses of the closure used for normalization are the values in the area of the buckle, not the closure wall thickness inside the igniter basket.

The sequences of failures during the second set of tests to failure are given in Table 5.

**Table 5. Closure failure sequence**

| Closure No. 2 | | Closure No. 3 | |
|---|---|---|---|
| Event | Pressure, psi | Event | Pressure, psi |
| Outer ring completely buckled | 900+ | Outer ring completely buckled | 1100+ |
| Inner ring completely buckled | 1900+ | Inner ring completely buckled | 2000+ |
| Fracture of igniter closure (Fig. 28) | 3500+ | Igniter nut split (Fig. 29) | 3700+ |

The above values are not normalized to minimum wall thicknesses.

2. ***Test conclusion.*** The hydrostatic test to evaluate the igniter closure is conservative because:

1. The internal pressure due to ignition is a shock-type loading, but in this test the pressure is applied as a steady "long time" load.
2. The internal pressure due to ignition acts only internally to the igniter basket (pressure over the other portion of the closure is about 100 psi at maximum ignition pressure), but in this test the pressure is applied over the entire closure area.

The margins of safety based on initial buckling test (assume 800 psi as the design pressure) are:

Closure No. 2 = 1920/800 = 1 = 1.40

Closure No. 3 = 1950/800 = 1 = 1.44

Closure No. 4 = 1990/800 = 1 = 1.49

## IV. Igniter Pyrotechnics

There are two main grain charges used in the ATS igniter as shown in Figs. 6 and 30. The grains average out at about 87 g each. The ignition material of the grains is referred to as ALCLO, a trade name given by the Aerojet General Corporation, producer and developer of the material. ALCLO is a pyrotechnic-type of propellant composed of aluminum fuel, potassium perchlorate oxidizer, and suitable additives for binding,

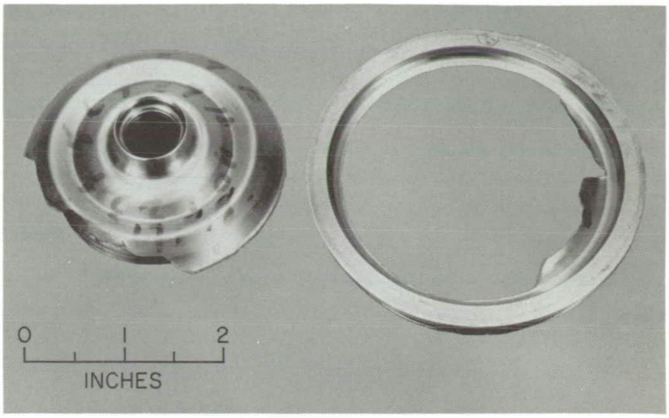



Fig. 28. Fracture of igniter closure

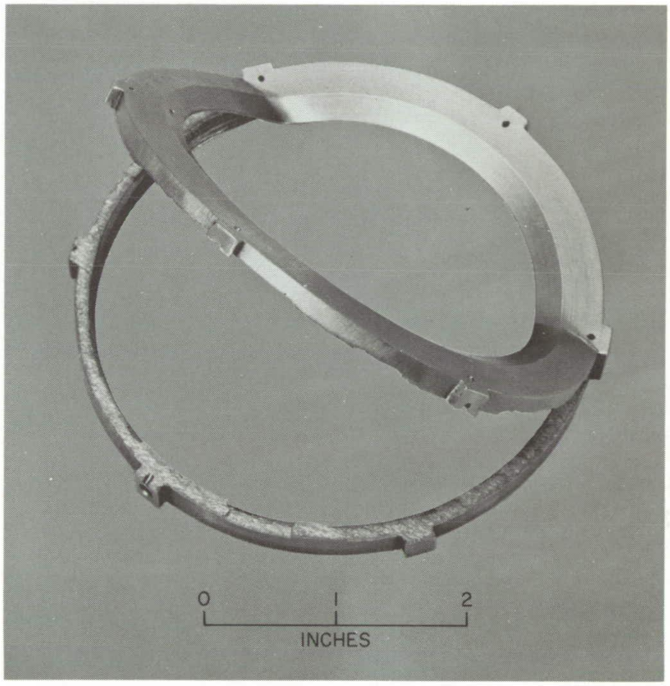



Fig. 29. Igniter nut split

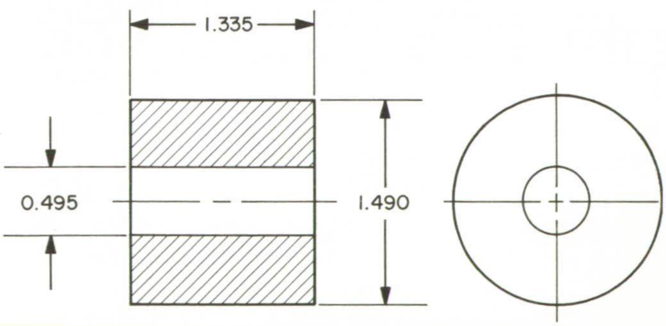



Fig. 30. Igniter grain

stabilization, and burning-rate control. The ingredients are compacted into a solid form. With the application of heat (as from an electric squib), ALCLO ignites and burns with an intensely hot flame, typical of metal/oxidant reactions, producing a great amount of energy per unit weight or volume. The products of combustion are solids even at relatively high temperatures. The ATS igniter used an ALCLO formulation type AGC-005. Physical properties and ballistic properties are listed in Table 6 and Fig. 31.

**Table 6. Physical properties of compacted ALCLO**

| Property | Type | | | |
|---|---|---|---|---|
| | AGC-004 | AGC-001 | AGC-005 | AGC-041 |
| Specific gravity | 2.45 | 2.80 | 2.61 | 2.68 |
| Density, lbm/in.$^3$ | 0.089 | 0.101 | 0.094 | 0.097 |
| Compressive strength, lb/in.$^2$ | 4650 | 5530 | 10,750 | — |
| Tensile strength, lb/in.$^2$ | — | — | 175 | — |
| Ignition temperature, °F | 1050 | 850 | 865 | 800 |
| Flame temperature (at 1000 psi),[a] °F | 8180 | 8400 | 8300 | 8350 |
| Heat of explosion, kcal/gm | 2.36 | 2.11 | 2.24 | 2.14 |
| Energy density, kcal/cm$^3$ | 5.78 | 5.91 | 5.85 | 5.74 |
| Specific heat (at 300°K),[a] cal/gm-°C | 0.1974 | 0.1772 | 0.1916 | 0.1842 |
| Specific heat (at 400°K),[a] cal/gm-°C | 0.2260 | 0.2021 | 0.2187 | 0.2108 |
| Specific heat (at 500°K),[a] cal/gm-°C | 0.2542 | 0.2268 | 0.2453 | 0.2372 |
| Specific heat (at 573°K),[a] cal/gm-°C | 0.2749 | 0.2449 | 0.2649 | 0.2565 |
| Thermal diffusivity cm$^2$/sec | 0.0307 | 0.0329 | 0.0310 | 0.0321 |
| Thermal conductivity (at 300°K), cal/cm-sec-°C | 0.0148 | 0.0163 | 0.0128 | 0.0158 |

[a]Theoretical

A primary charge of 19 ALCLO pellets of AGC-052 composition is used to ignite the two main grains. These pellets differ only in their formulation from the grains. The pellets are ignited by an electric squib (Fig. 6), thus insuring more reliable ignition from the limited energy of a squib. The pellets have a slower burning rate than the grains and therefore provide longer exposure to ignition temperatures and insure ignition of the larger grains.

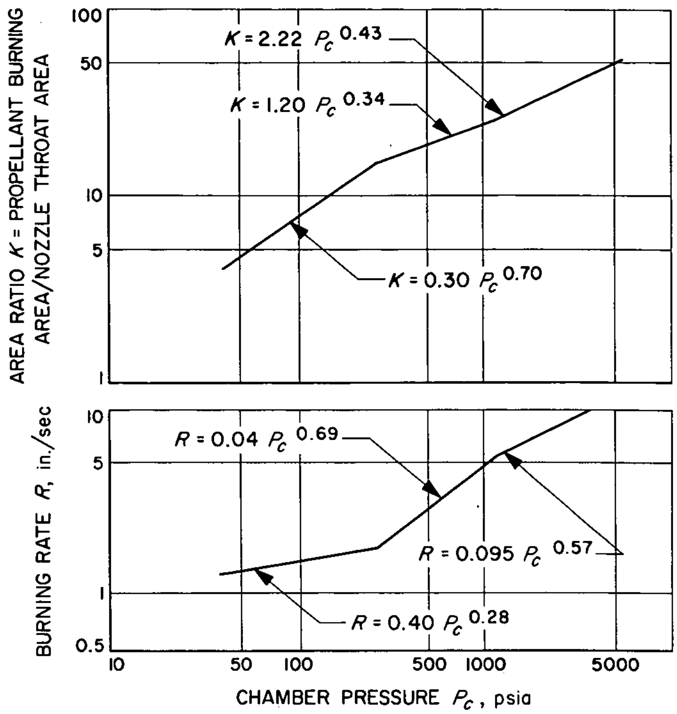



**Fig. 31. Ballistic properties of ALCLO formulation**

A specially designed shipping container was fabricated to facilitate packaging and shipment of the pyrotechnics (Appendix D).

## V. Motor Testing

The ATS motor development program (Table 7) included twenty-eight motor firings. Except for the three storage motors, the igniter performed satisfactorily in all tests. Table 2 gives a complete rundown of ignition events as well as data on isolated igniter tests to study high-speed movies of the flame spreading characteristics. Figure 17 is an ignition events index and shows, in exaggerated form, a typical igniter events curve. Figure 32 is a copy of ignition events for development test C-1. All traces have one channel for igniter pressure ($P_b$) and two for motor chamber pressure ($P_{c1}$, $P_{c2}$).

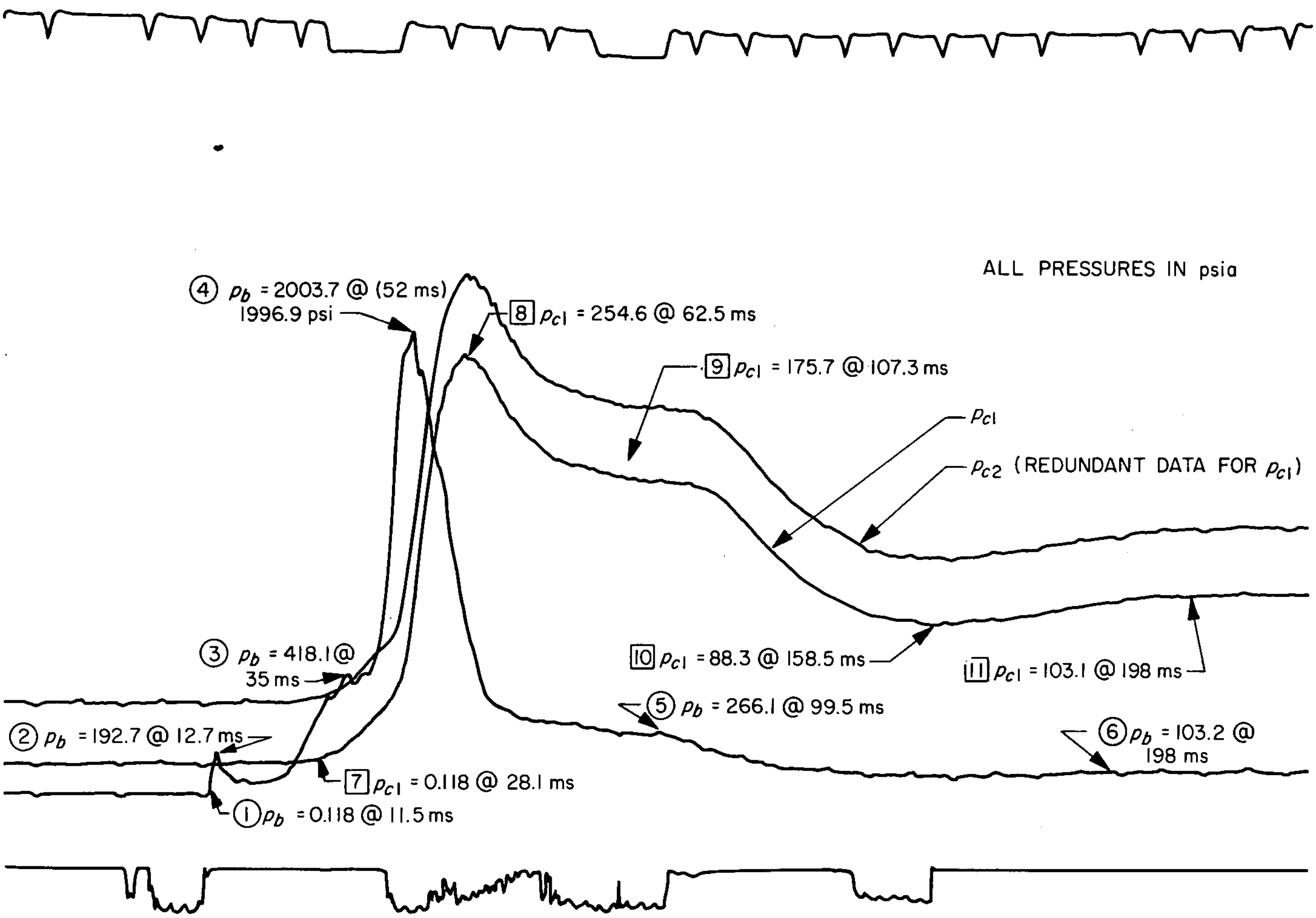



**Fig. 32. Ignition events, test C-1**

## Table 7. ATS apogee motor, development phase

| Motor test | Development code | Test conditions | | | | | Test environment | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature, °F | | | Location | Test stand type | Temperature cycle | Shipping temperature | Booster accelerator | Booster vibration | Vacuum start |
| | | 10 | 60 | 110 | | | | | | | |
| A. Heavy weight | A-1[a] | | | | ETS | Single component | | | | | √ |
| | A-2 | | √ | | | | | | | | √ |
| | A-3 | | √ | | | | | | | | √ |
| | A-4 | | √ | | | | | | | | √ |
| | A-5 | | √ | | | | | | | | |
| B. Hydrotest: 410 steel | B-1 | Ambient | | | JPL | None required | Hydrotest to destruction | | | | |
| 410 steel | B-2 | | | | | | | | | | |
| 410 steel | B-3F[b] | | | | | | | | | | |
| Titanium | B-4T[b] | | | | | | | | | | |
| Titanium | B-5T[b] | | | | | | | | | | |
| Titanium | B-6TF[b] | | | | | | | | | | |
| C. Basic | C-1 | | √ | | ETS | Single component | | | | | √ |
| | C-2 | | √ | | | | | | | | √ |
| | C-3 | | √ | | | Diffuser | | | | | √ |
| | C-3A[b] | | √ | | | | | | | | √ |
| | C-4 | √ | | | | Single component | | | | | √ |
| | C-5 | | | √ | | | | | | | √ |
| | C-6 | | √ | | | | | | | | |
| | C-7 | | | √ | | | | | | | |
| D. Dynamic model: JPL | D-1 | Ambient | | | ETS/JPL/Vendor | | | | √ | √ | |
| JPL | D-2T[b] | | | | | | | | | √ | |
| HAC | D-3 | | | | HAC | None required | | | | | |
| HAC | D-4 | | | | | | | | | | |
| HAC | D-5T[b] | | | | | | | | | | |
| Thermal model: HAC | D-6F[b] | | | | | | | | | | |
| HAC | D-7F[b] | | | | | | | | | | |
| HAC | D-8TF[b] | | | | | | | | | | |

## Table 7 (contd)

| Motor test | Development code | Test conditions | | | | | Test environment | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temperature, °F | | | Location | Test stand type | Temperature cycle | Shipping temperature | Booster accelerator | Booster vibration | Vacuum start |
| | | 10 | 60 | 110 | | | | | | | |
| E. Altitude | E-1 | | √ | | AEDC | Single component | | | | | √ |
| | E-2 | | √ | | | | | | | | √ |
| | E-3T[b] | | √ | | | Soft, HAC payload | | | | | √ |
| | E-4T[b] | | √ | | | | | | | | √ |
| F. Storage | F-1 | √ | | | ETS | 150-rpm spin rate | √ | | √ | √ | √ |
| | F-2 | √ | | | | | √ | | √ | √ | √ |
| | F-3 | √ | | | | | √ | | √ | √ | √ |
| G. Environment | G-1 | | | √ | ETS | Single component | √ | √ | | | |
| | G-2 | √ | | | | | √ | √ | | | |
| | G-3 | | √ | | AEDC | 100-rpm spin rate | | | | | √ |
| | G-4 | | √ | | | | | | | √ | √ |
| | G-5 | | √ | | ETS | 150-rpm spin rate | | | | | |
| | G-6 | | | √ | | | √ | | √ | √ | |
| | G-7 | √ | | | | | √ | | √ | √ | |
| | G-8T[b] | | | √ | | Single component | | | | | |
| | G-9T[b] | √ | | | | 150-rpm spin rate | √ | | √ | √ | |
| H. Minimum propellant load | H-1 | √ | | | ETS | Single component | | | | | |
| I. Safe and arm | I-1 | | √ | | ETS | Single component | | | | | |

[a]Dummy loading to check motor casting fixtures, casting procedures, and charge preparation.

[b]F = fired chamber; T = titanium chamber; A = repeat test.

The trace for C-1 (Fig. 32) includes a numbering sequence which will help to explain the events, which are as follows:

Igniter:

1. First sign of pressure, squib ignition.
2. Peak squib ignition. On some tests this is not distinguishable.
3. Indicates burst diaphragm rupture, at which time pellets burn through and begin to ignite the main grains.
4. Peak igniter pressure. Owing to the 12 gas ports, this pressure does not last long and a rapid decay to the outgassing phase is experienced.
5. This is an outgassing phase. The pellets and grains are nearly consumed at this time.
6. At this point the pressure tap in the igniter basket is measuring the motor chamber pressure. The igniter is no longer producing a pressure.

Motor:

7–10. These points, although measured through the motor chamber, are a function of the igniter pressure. As the igniter generates its pressures, it fills the motor chamber. Notice how each peak and valley of the motor chamber pressure lags the same point of the igniter trace.

11. At this point, the propellant grain has ignited and the motor chamber pressure is beginning to increase to a stabilizing pressure. The motor is considered ignited at this time. Figure 33 shows a typical closure after motor firing. The insulation was found to be adequate and no problems were encountered. Note that the igniter basket has been consumed, and only a trace of the basket thread has remained on the threads of the closure.

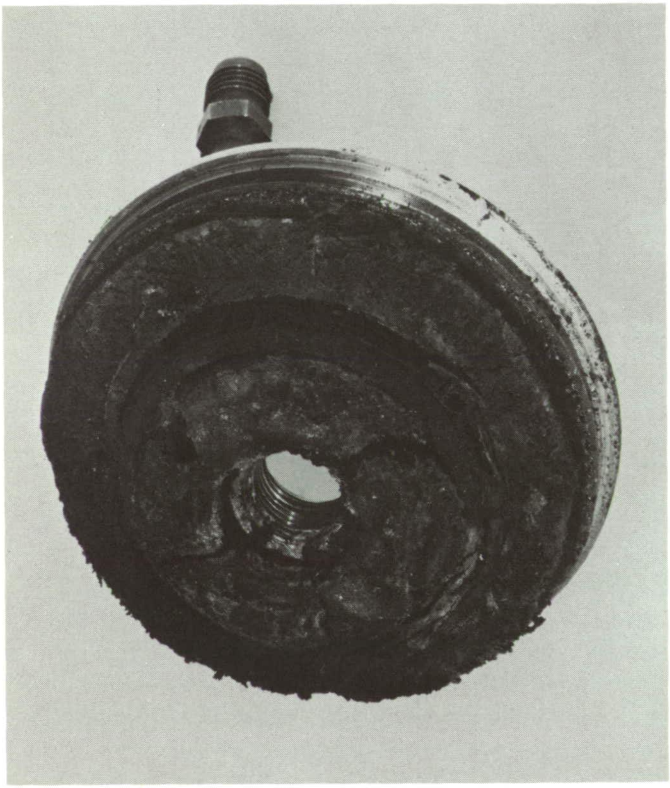


Fig. 33. ATS igniter closure, post-fire

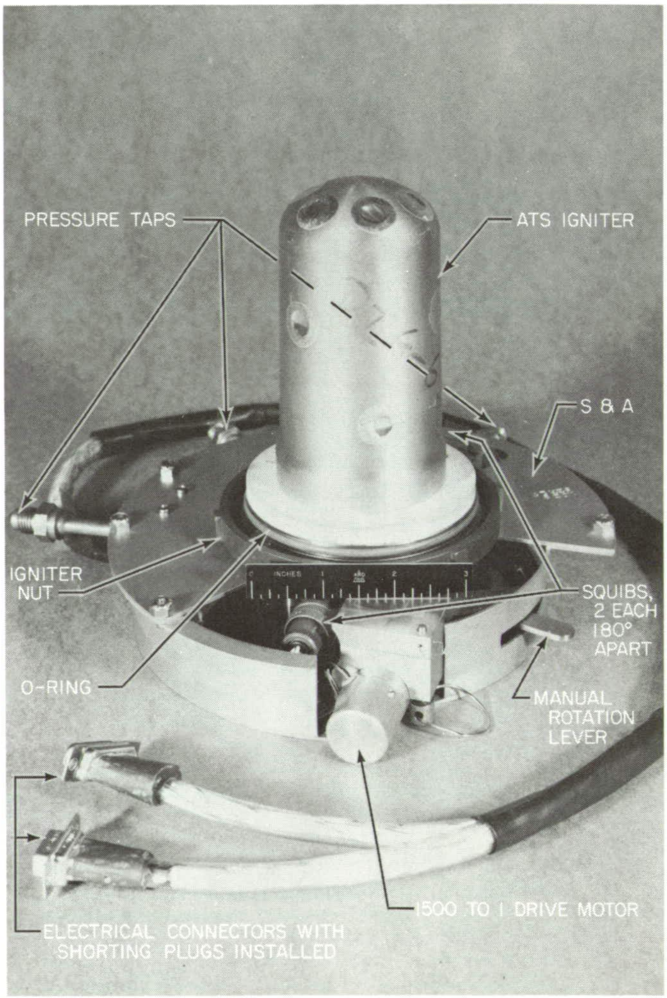



Fig. 34. ATS igniter/S&A

## VI. Qualification

In mid-1966 (June, July, August), eight ATS motors were fired at the Arnold Engineering Development Center for formal qualification. In all tests the igniter performed satisfactorily. During this series of tests, the igniter was interfaced with an S&A device (Fig. 34) instead of the standard closure used during development.

Four motors were fired at 110°F and four at 40°F as follows:

| 40°F | 110°F |
|---|---|
| Motor | |
| Q-1T | Q-2T |
| Q-3T | Q-4T |
| Q-5T | Q-6T |
| Q-7T | Q-8T |

As can be seen from the instrumentation traces (Fig. 35), a great degree of uniformity was achieved. Table 8 lists the ignition events.

From the 28 development firings and eight qualification firings, it was concluded that the ATS igniter, as designed and as described herein, will perform satisfactorily within its intended limits and will, in fact, ignite the ATS motor propellant grain in such a manner as to insure uniform ignition.

**Table 8. Igniter summary, qualification phase[a]**

| Qualification test | Test date | Temperature, °F | Vacuum start | $t_{D_i}$ msec | $P_{I_i}$ psia | $t_{I_i}$ msec | $P_{I_m}$ psia | $t_{I_m}$ msec | $t_{\Delta}$ msec | $t_{M_i}$ msec |
|---|---|---|---|---|---|---|---|---|---|---|
| QIG–1 | 8-19-66 | 40 | Yes | 3 | 1362 | 43.6 | 212.7 | 54.4 | 10.8 | 51.4 |
| QIG–2 | 8-5-66 | 100 | Yes | 3 | 1874 | 34.0 | 257.4 | 43.4 | 9.4 | 40.4 |
| QIG–3 | 8-23-66 | 40 | Yes | 2.5 | 1578 | 40.1 | 230.5 | 50.1 | 10.0 | 47.6 |
| QIG–4 | 8-9-66 | 100 | Yes | 2 | 1879 | 41.2 | 271.7 | 45.9 | 4.7 | 43.9 |
| QIG–5 | 8-15-66 | 40 | Yes | 1.5 | 1215 | 43.5 | 233.9 | 52.5 | 9.0 | 51.0 |
| QIG–6 | 8-3-66 | 100 | Yes | 2 | 1874 | 34.0 | 257.4 | 43.4 | 9.4 | 41.4 |
| QIG–7 | 8-18-66 | 40 | Yes | 2 | 1821 | 36.4 | 220.7 | 48.4 | 12.0 | 46.4 |
| QIG–8 | 7-29-66 | 100 | Yes | 2 | 1693 | 36.2 | 249.8 | 46.9 | 10.7 | 44.9 |

[a]See Fig. 17 for ignition events index.

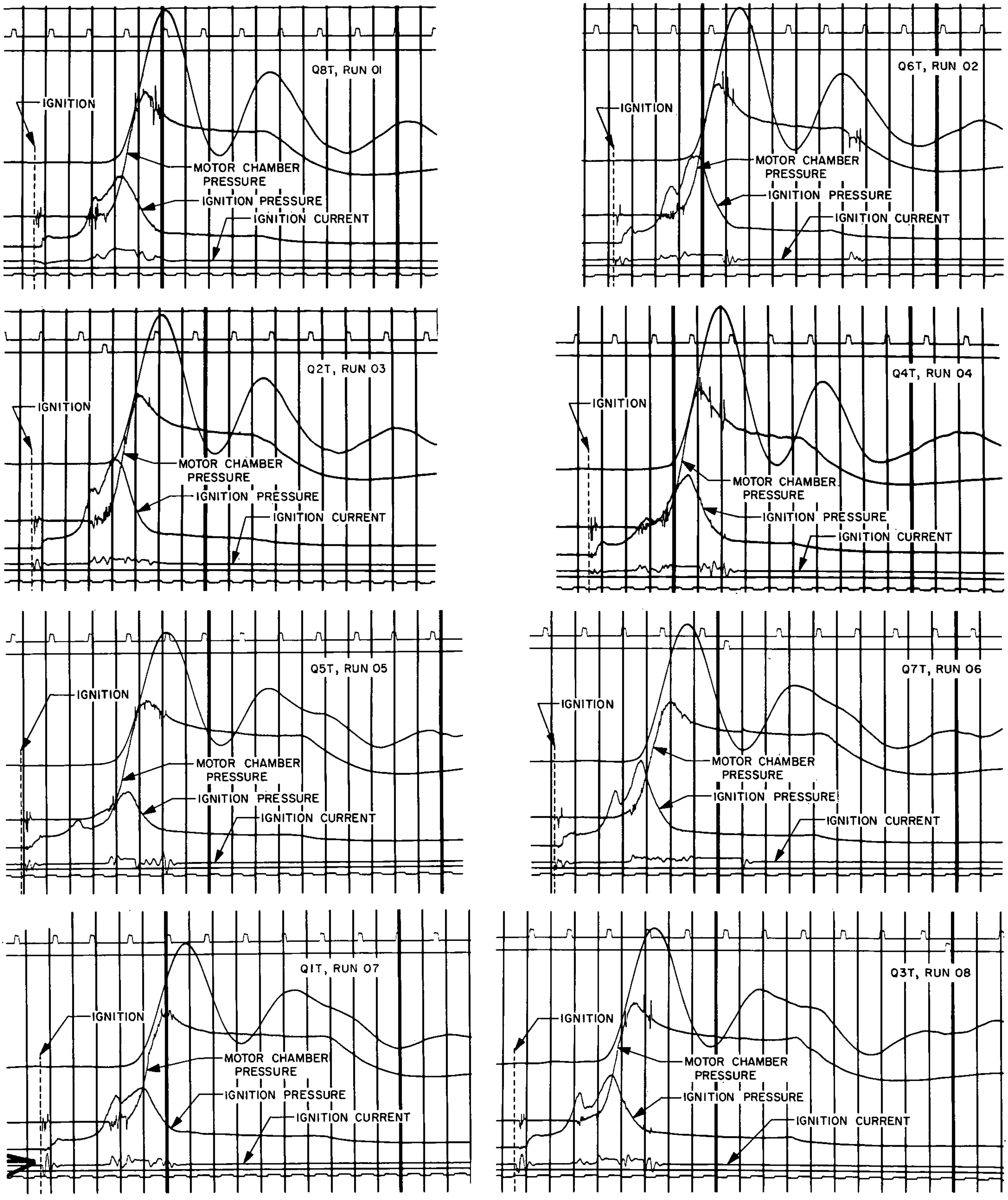



**Fig. 35. Instrumentation traces**

# Appendix A

## Safe-And-Arm Device

In order to meet Air Force Range Safety requirements at Cape Kennedy, a safe-and-arm (S&A) device was designed by the Harry Diamond Laboratories under contract to Goddard Space Flight Center to insure safe handling of the igniter and rocket motor.

Figures A-1 through A-3 show various views of the igniter/S&A system. The unit (igniter/S&A) with pressure taps weighs 6 lb, which includes the squibs, igniter nut, pressure taps, and cabling. Figure A-2 shows the S&A with three pressure taps. However, no pressure taps will be used on flight units (Fig. A-1).

One of the design limits imposed on the S&A device was the distance between the igniter boss on the motor and the spacecraft hardware. This constraint resulted in the flat, pancake shape of the device. Redundancy of ignition is achieved by the use of two PC-37 single bridgewire squibs[10] as opposed to a single dual-bridgewire squib used during development testing. In the safe position (Fig. A-4, upper right), an accidental firing of the squibs will result only in the squibs firing

[10]The PC-37 squib has been approved for use in the Surveyor Project. It is manufactured by Hi-Shear Corp., Torrance, Calif.

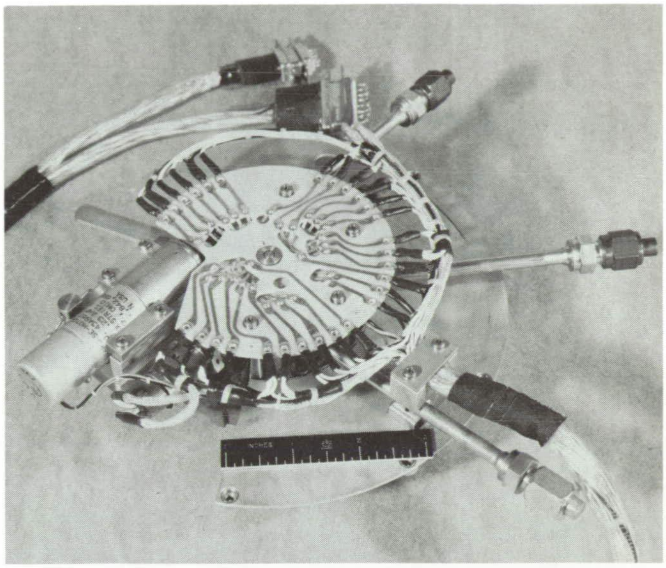


Fig. A-2. S&A device, cover removed

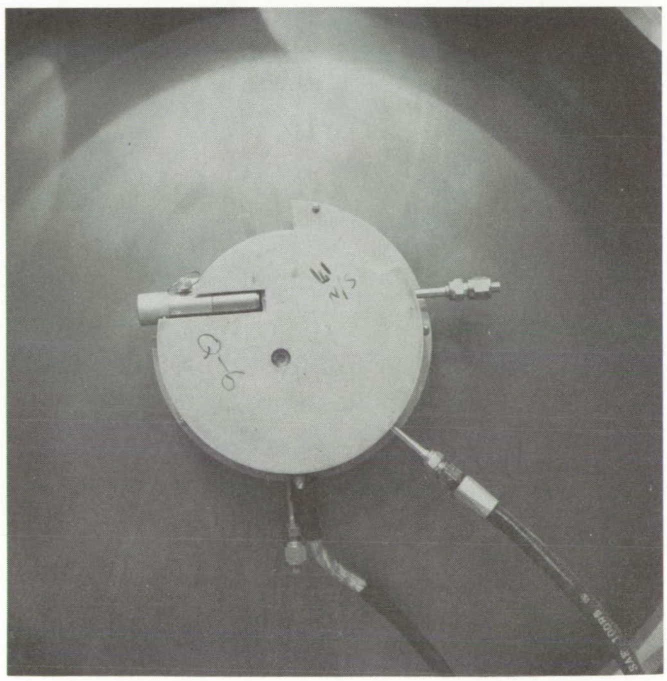


Fig. A-3. S&A device installed in ATS rocket motor

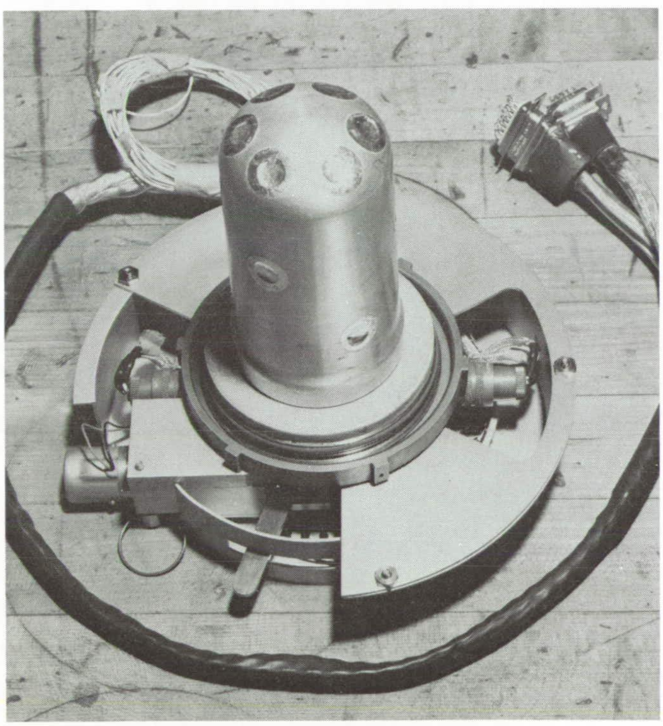


Fig. A-1. Igniter/S&A device

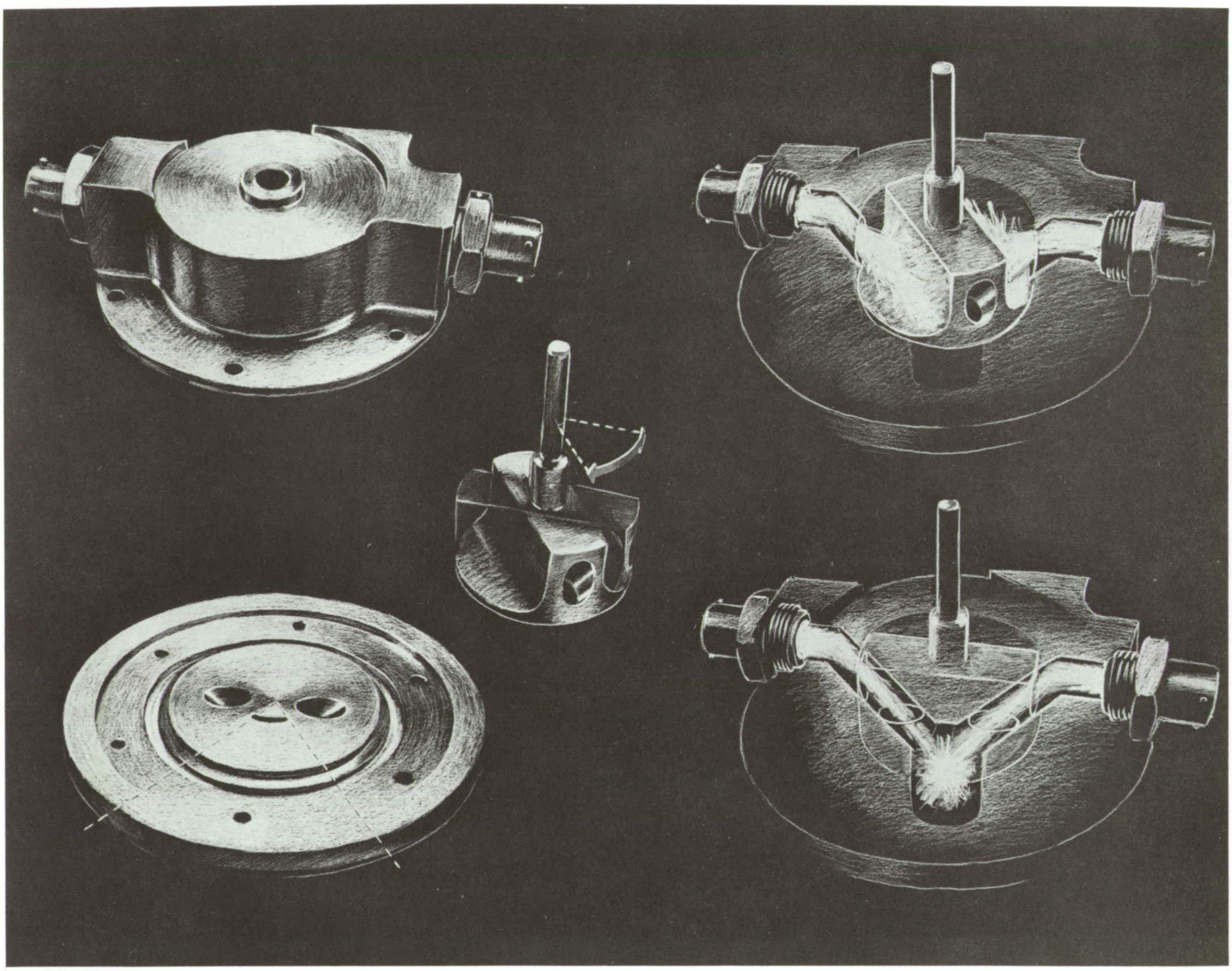


Fig. A-4. S&A device, rotary shaft

into a closed chamber. The flame is physically blocked by the rotary shaft (Fig. A-4, center). The rotary shaft is remotely rotated by a 1500:1, 28-v-dc drive motor. There is also a mechanical lever for rotation when necessary. Figure A-5 shows the S&A post-fire condition. The residue, which is normal, is from the insulation material.

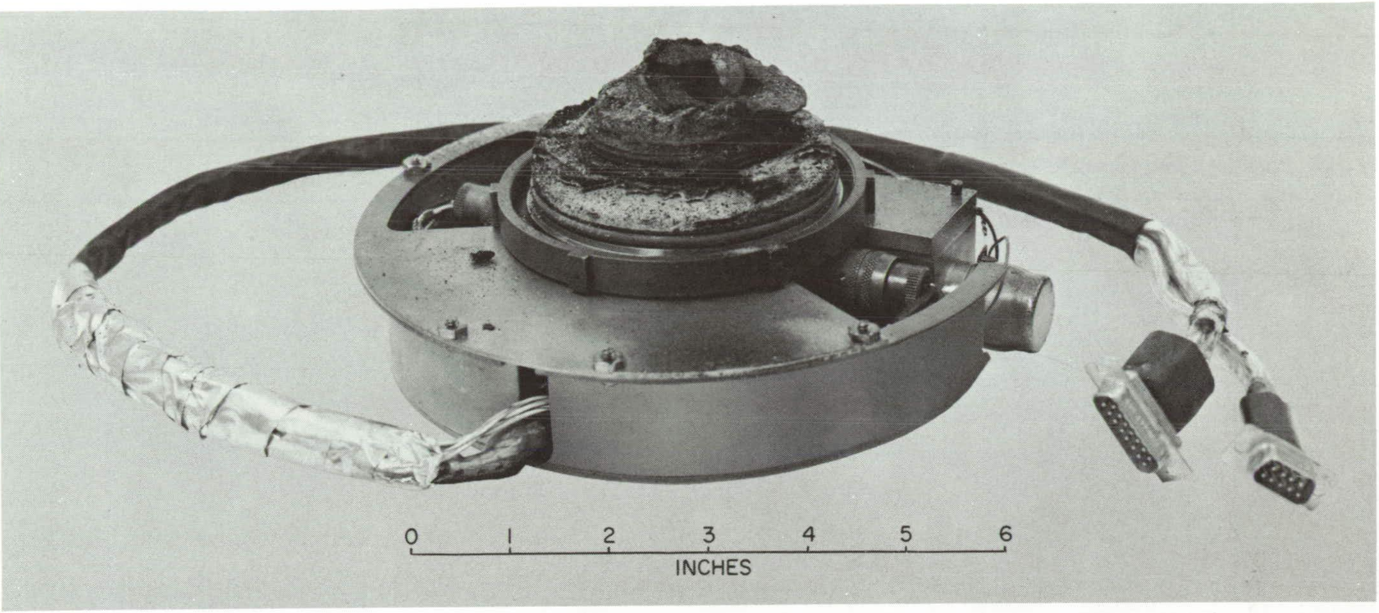



**Fig. A-5. S&A device, post-fire condition**

# Appendix B

## Standard Operating Procedures

Twelve standard operating procedures (SOP's) covering the various operations involving the ATS igniter have been published by JPL's Solid Propellant Engineering Section (Section 381). The procedures are listed below.

| SOP No. | Revision No. | Author | Date | Title |
|---|---|---|---|---|
| 200 | 2 | Lee | 8-24-65 | ATS Squib Inspection |
| 234 | 1 | Lee | 9-11-65 | Igniter Assembly Procedure (with Pressure Taps) |
| 237 | — | Lee | 10-20-65 | ATS Squib Storage |
| 238 | — | Lee | 12-29-65 | ATS Igniter Storage |
| 239 | — | Lee | 12-16-65 | ATS Igniter Packaging for Storage or Shipment |
| 244 | — | Lee | 8-24-65 | ATS Squib Inspection Removal from Storage |
| 245 | — | Lee | 10-15-65 | ATS Igniter Inspection—Post-Environmental Testing |
| 253 | — | Lee | 4-12-66 | ATS Flight Igniter Packaging, Shipment, Storage, and Receiving Inspection Procedure |
| 255 | 1 | Lee | 10-15-65 | Igniter Assembly Procedure (Flight) |
| 256 | — | Anderson, Lee | 4-18-66 | Installation of the ATS Igniter to the S&A Device |
| 257 | — | Anderson, Lee | 4-18-66 | Installation of the ATS S&A Igniter Assembly into the Apogee Motor |
| 258 | — | Lee | 8-18-66 | Installation of Squibs into the ATS S&A Device |

# Appendix C

## ATS/S&A Assembly Safety Test

To insure safety during the assembly of an ATS igniter to the S&A device, a ¼-in. plexiglass safety shield was designed and fabricated. A prototype shield was subjected to a live firing of an igniter to test the ability of the plexiglass to deflect the heat and fire generated by the igniter in the event of a premature ignition and to measure the heat generated. Figure C-1 shows the test pit setup. Figure C-2 shows various views during ignition; Fig. C-3 shows post-fire conditions. In the event of a premature ignition, it is felt that, although the operator would suffer hand burns and possible shock reactions, his face and body would be adequately protected. Because of the high reaction time of the ignition material (20–30 msec), the operator should be shielded from the igniter during hazardous operations.

**Fig. C-1. Safety shield setup**

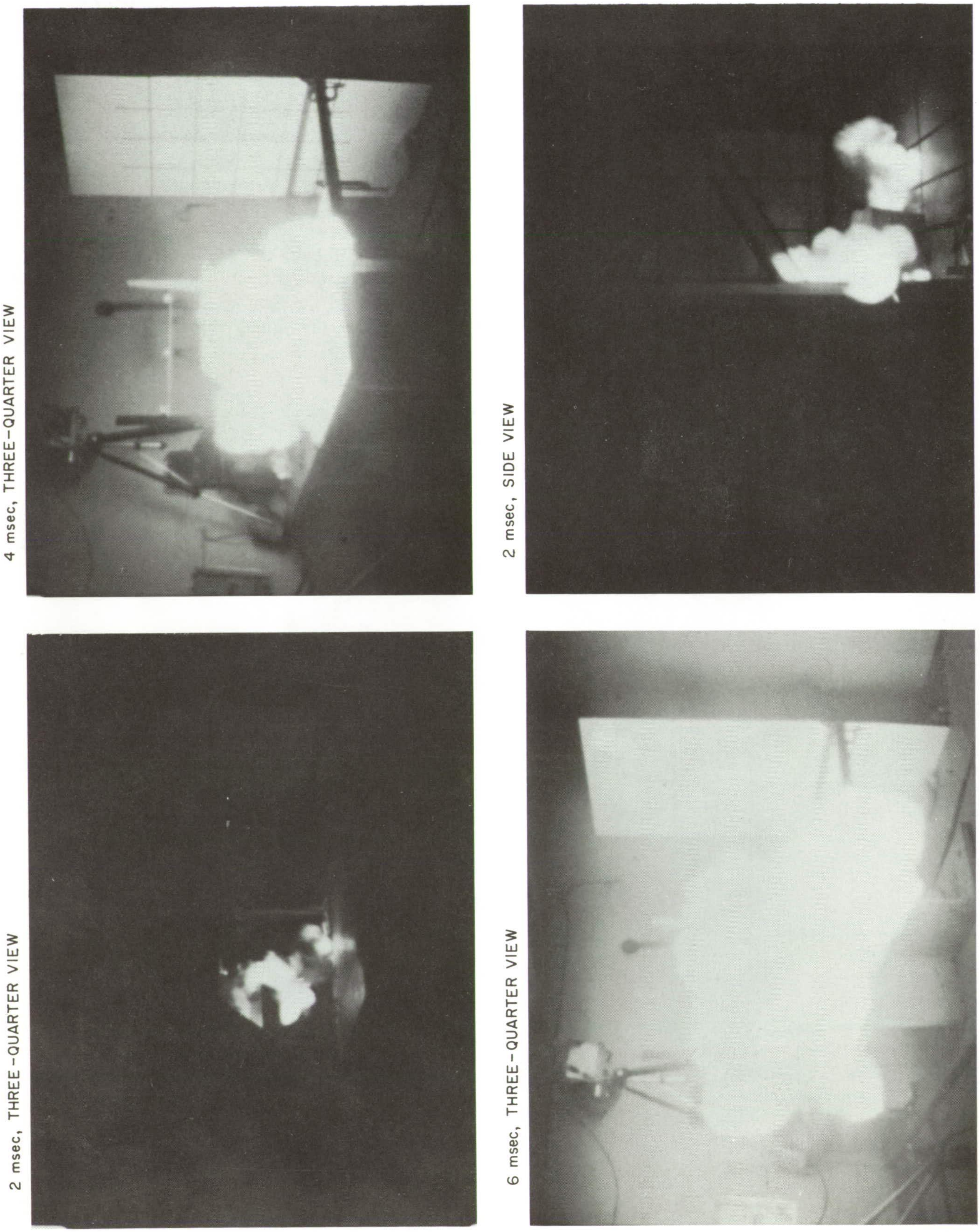
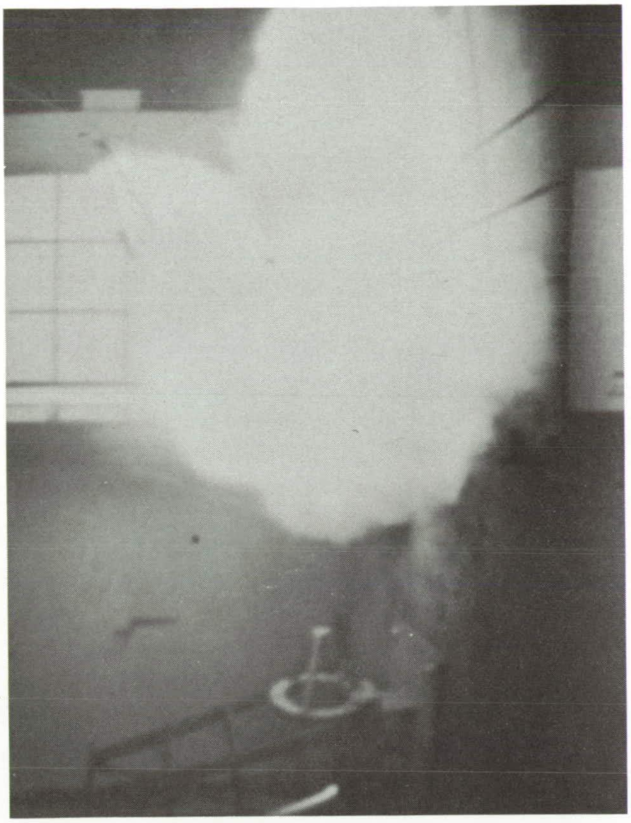
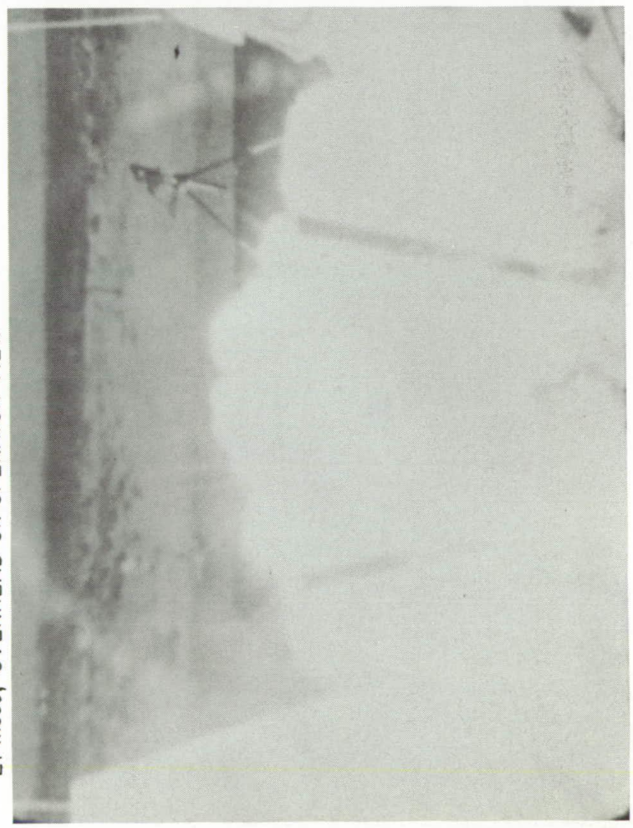



Fig. C-2. Test conditions during ignition

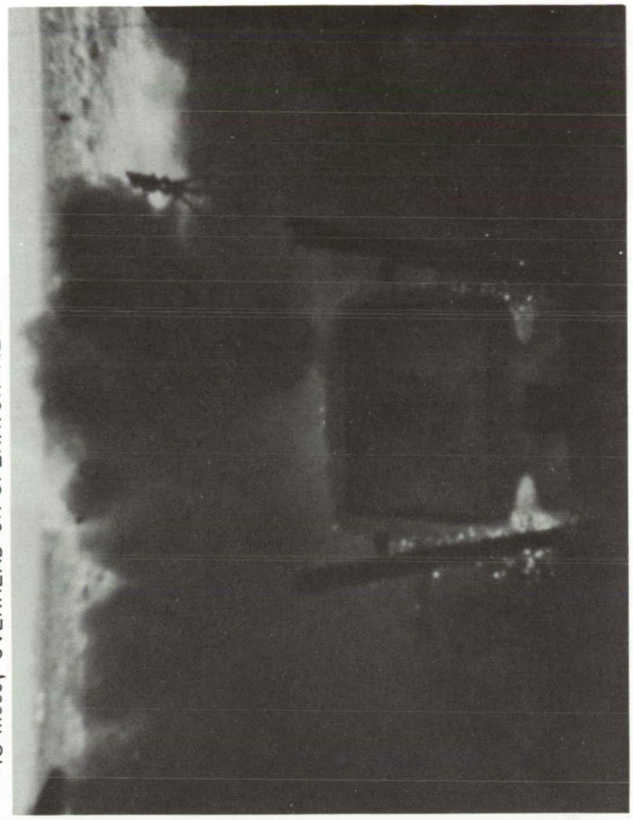
3 msec, SIDE VIEW



6 msec, SIDE VIEW



21 msec, OVERHEAD OR OPERATOR VIEW



48 msec, OVERHEAD OR OPERATOR VIEW

**Fig. C-2 (contd)**

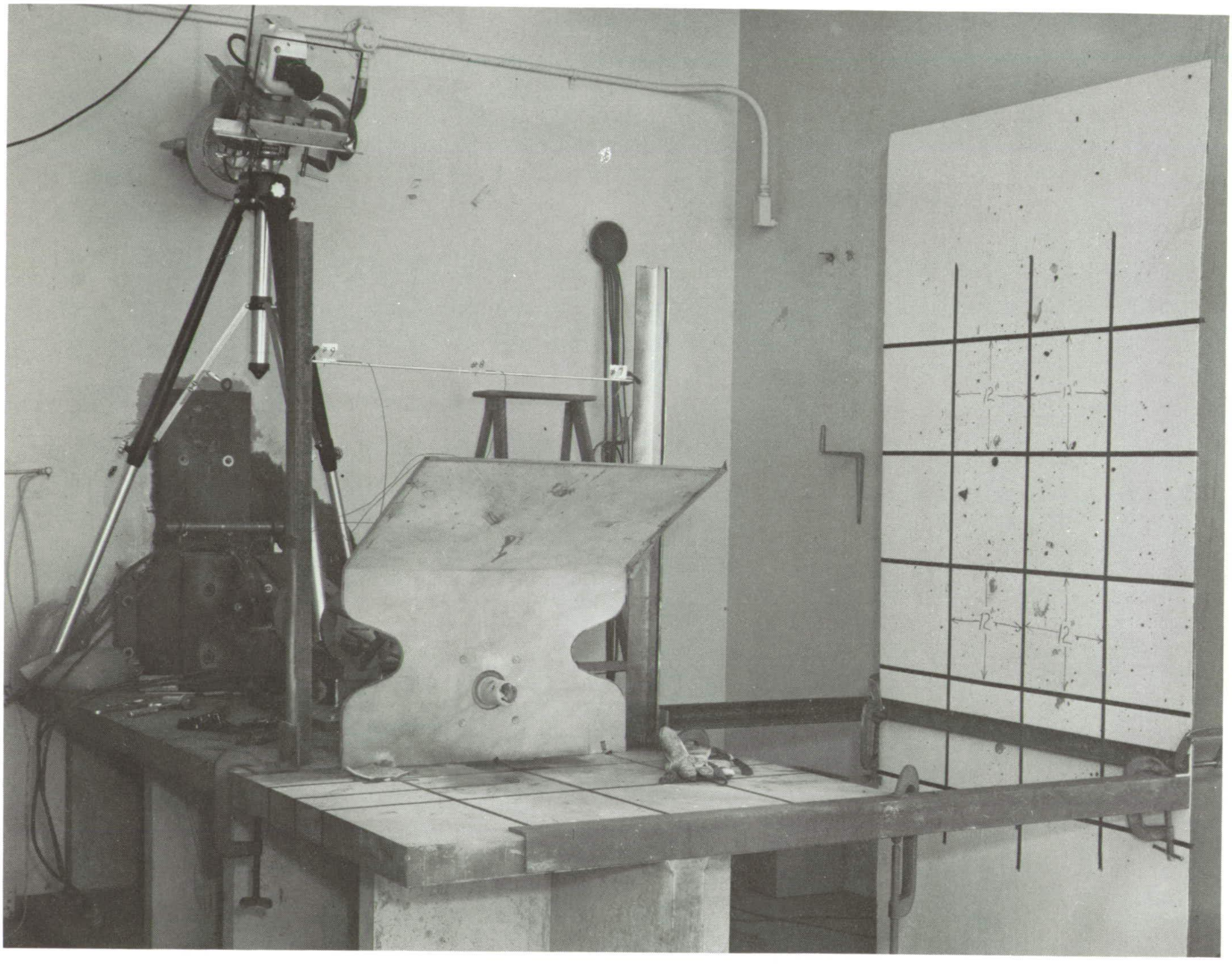



Fig. C-3. Safety shield setup, post-fire

# Appendix D

## Packaging and Shipment

To insure safe and proper handling of the flight igniters, a special packaging procedure was written. This procedure is outlined in SOP 253 (see Appendix B). Figures D-1, 2, 3 show the material used and the sequence of packaging. The ICC permit number authorizing shipment of ATS igniters as shown is BA 402.

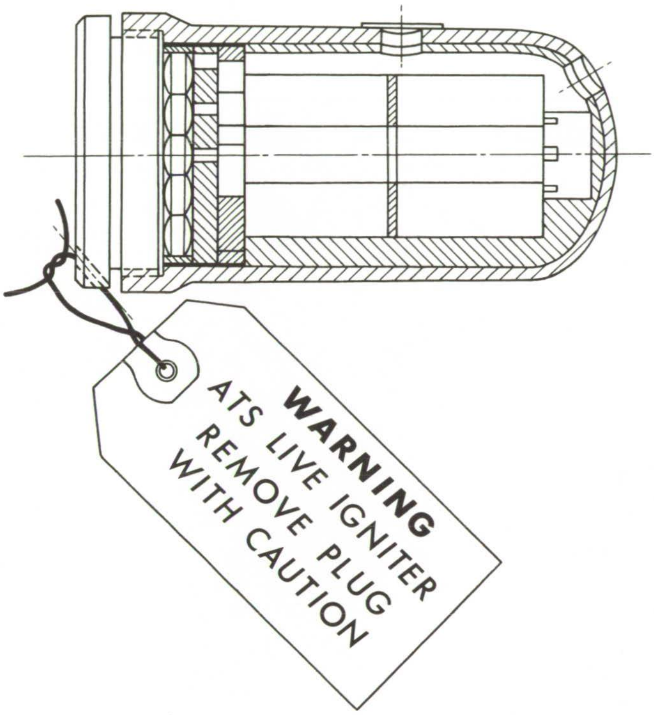



Fig. D-1. ATS igniter, shipping configuration

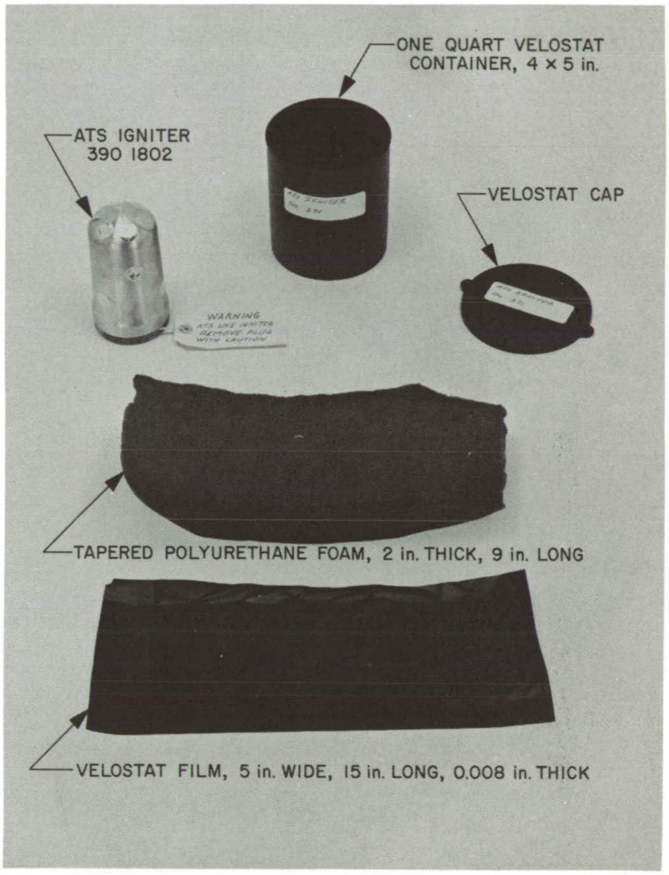



Fig. D-2. ATS igniter, packaging material

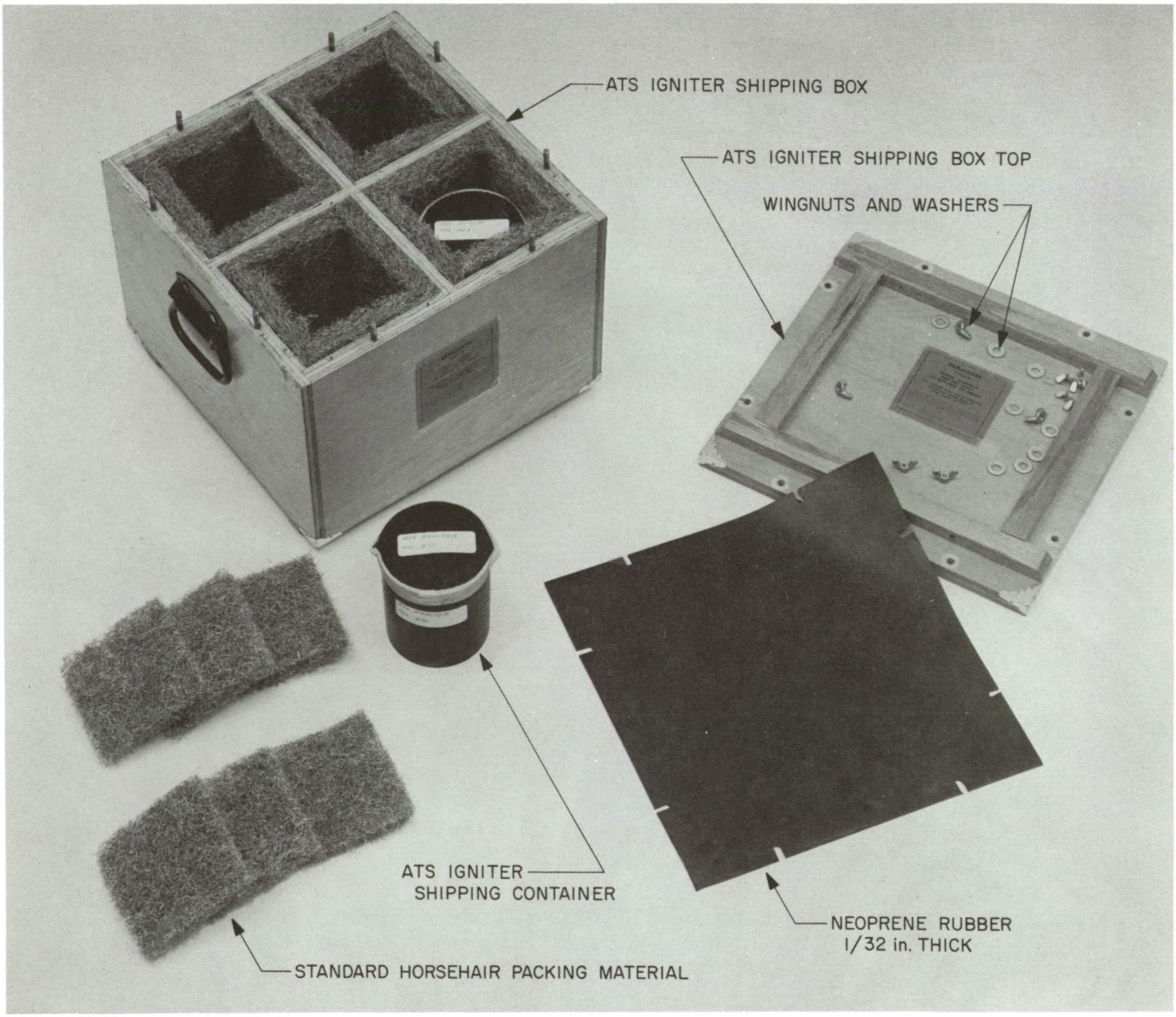



**Fig. D-3. ATS igniter, shipping box and hardware**

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